AN2648

Selecting and Testing 32 KHz Crystal Oscillators for AVR® Microcontrollers

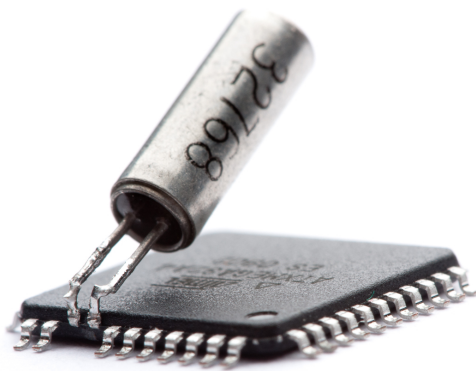## Introduction

Author: Torbjørn Kjørlaug, Microchip Technology Inc.

This application note summarizes the crystal basics, PCB layout considerations, and how to test a crystal in your application. A crystal selection guide shows recommended crystals tested by experts and found suitable for various oscillator modules in different Microchip AVR® families. Test firmware and test reports from various crystal vendors are included.

Features

- Crystal Oscillator Basics
- PCB Design Considerations
- Testing Crystal Robustness
- Test Firmware Included
- Crystal Recommendation Guide

Table of Contents

1.   Crystal Oscillator Basics

Many readers are familiar with the basic crystal oscillator theory and are only interested in how to test their applications. These readers may skip the topics in Chapter 1, *Crystal Oscillator Basics* and Chapter 2, *PCB Layout and Design Considerations*, and start reading Chapter 3, *Testing Crystal Oscillation Robustness*.

1.1   Introduction

A crystal oscillator uses the mechanical resonance of a vibrating piezoelectric material to generate a very stable clock signal. The frequency is usually used to provide a stable clock signal or to keep track of time; hence, crystal oscillators are widely used in RF and digital circuits.

Crystals are available from various vendors in a variety of shapes and sizes and can vary widely in performance and specifications. Understanding the parameters and the oscillator circuit is essential for a robust application stable over variations in temperature, humidity, power supply, and process.

All physical objects have a natural frequency of vibration, where the vibrating frequency is determined by its shape, size, elasticity, and speed of sound in the material. Piezoelectric material distorts when an electric field is applied and generates an electric field when it returns to its original shape. The most common piezoelectric material used in electronic circuits is a quartz crystal, but ceramic resonators are also used – usually in low-cost or less timing critical applications. 32 KHz (32768 Hz) crystals are usually cut in the shape of a tuning fork and very precise frequencies can be established.

Figure 1-1. Shape of a 32 KHz Tuning Fork Crystal
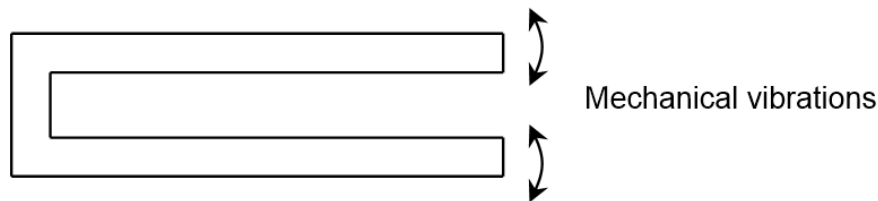
1.2   The Oscillator

The Barkhausen stability criteria are two conditions used to determine when an electronic circuit will oscillate. They state that if A is the gain of the amplifying element in the circuit and *β(jω)* is the transfer function of the feedback path, the circuit will sustain steady-state oscillations only at frequencies for which:

The loop gain is equal to unity in absolute magnitude, $|\beta A| = 1$

The phase shift around the loop is zero or an integer multiple of 2π, i.e. $\angle \beta A = 2\pi m$ for $n \in 0, 1, 2, 3...$

The first criterion will ensure a constant amplitude signal. A number less than 1 will attenuate the signal to zero and a number greater than 1 will amplify the signal to infinity. The second criterion will ensure a stable frequency. For other phase shift values, the sine wave output will be canceled due to the feedback loop.

Figure 1-2. Feedback Loop
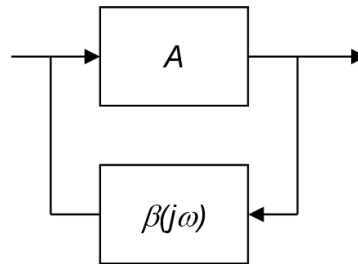
The 32 KHz oscillator in Microchip AVR microcontrollers is shown in Figure 1-3 and consists of an inverting amplifier (internal) and a crystal (external). Most AVR microcontrollers have an internal capacitive load (C_{L1} and $C_{L2}$), so external capacitors are usually not needed. In some cases, however, the external load must be added to meet the crystal specifications. Some AVR microcontrollers can select whether the internal capacitors should be connected or disconnected with the CKOPT fuse. More details can be found in the data sheet of your AVR device.

The inverting amplifier will give a π radian (180 degrees) phase shift, and the remaining π radian phase shift will be provided by the crystal and the capacitive load at 32768 Hz, causing a total phase shift of 2π radian. During start-up, the amplifier output will increase until steady state oscillation is established with a loop gain of 1, causing the Barkhausen criteria to be fulfilled. This is auto-controlled by the AVR microcontroller's oscillator circuitry.

Figure 1-3. Pierce Crystal Oscillator Circuit in AVR Devices (simplified)
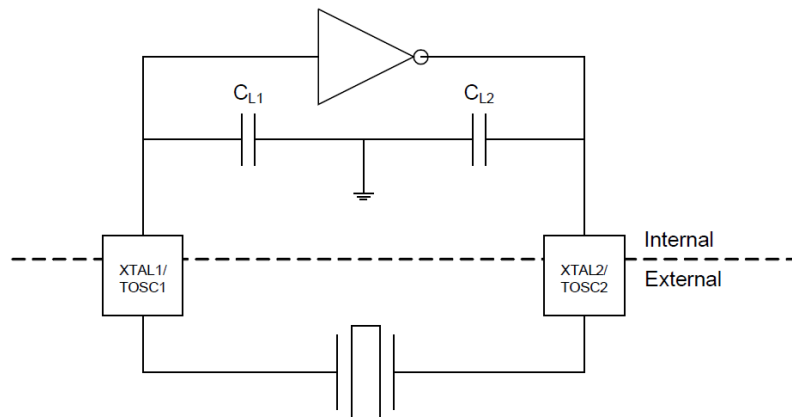
1.3 Electrical Model

The equivalent electric circuit of a crystal is shown in Figure 1-4. The series RLC network is called the motional arm and gives an electrical description of the mechanical behavior of the crystal, where C_1 represents the elasticity of the quartz, L_1 represents the vibrating mass, and R_1 represents losses due to damping. C_0 is called the shunt or static capacitance and is the sum of the electrical parasitic capacitance due to the crystal housing and electrodes. If a capacitance meter is used to measure the crystal capacitance, only C_0 will be measured (C_1 will have no effect).

Figure 1-4. Crystal Oscillator Equivalent Circuit
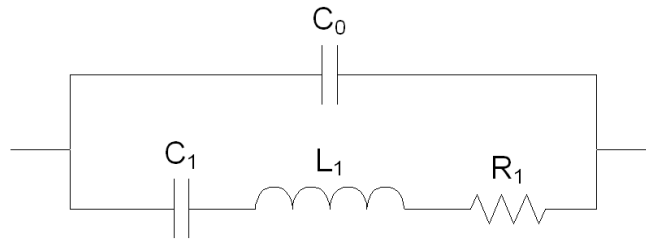
By using the Laplace transform, two resonant frequencies can be found in this network. The series resonant frequency, f_s, depends only on C_1 and L_1, and the parallel or anti-resonant frequency, f_p, also includes C_0. The reactance vs. frequency characteristics can be found in Figure 1-5.

Equation 1-1. Series Resonant Frequency

$$f_s = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

Equation 1-2. Parallel Resonant Frequency

$$f_s = \frac{1}{2\pi\sqrt{L_1 C_1}}\sqrt{1 + \frac{C_1}{C_0}}$$

Figure 1-5. Crystal Reactance Characteristics
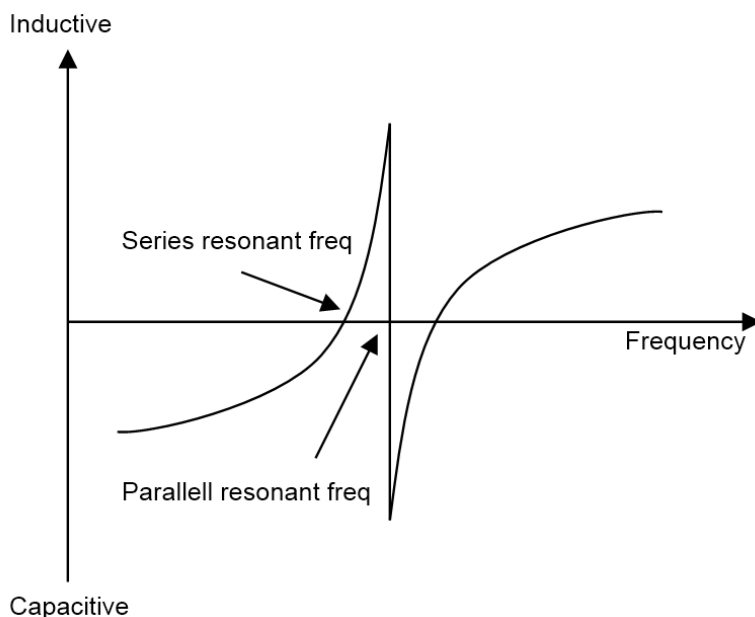
Crystals below 30 MHz can be operated at any frequency between the series and parallel resonant frequencies, which means that they are inductive in operation. High-frequency crystals above 30 MHz are usually operated at the series resonant frequency or overtone frequencies, which occur at multiples of the fundamental frequency. Adding a capacitive load, CL, to the crystal will cause a shift in frequency given by Equation 1-3. The crystal frequency can be tuned by varying the load capacitance, and this is called frequency pulling.

Equation 1-3. Shifted Parallel Resonant Frequency

$$\Delta f = f_s\left(\frac{C_1}{2(C_0 + C_L)}\right)$$

1.4 Equivalent Series Resistance (ESR)

The equivalent series resistance (ESR) is an electrical representation of the mechanical losses and at the series resonant frequency, f_s, it is equal to R_1 in the electrical model. The ESR is a very important parameter and can be found in the crystal data sheet. The ESR will usually be dependent on the crystal's physical size and small crystals (especially small SMD crystals) typically have higher losses and ESR values than larger crystals.

Higher ESR values will load the inverting amplifier more and too high ESR may cause unstable oscillator operation. Unity gain will not be achieved and the Barkhausen criterion will not be fulfilled.

1.5 Q-Factor and Stability

The frequency stability of a crystal is given by the Q-factor. The Q-factor is the ratio between the energy stored in the crystal and the sum of all energy losses. Typically, quartz crystals have Q in the range of 10,000 to 100,000, compared to perhaps 100 for an LC oscillator. Ceramic resonators have lower Q than quartz crystals and are more sensitive to capacitive load (pull ability is higher).

Equation 1-4. Q-Factor

$$Q = \frac{E_{STORED}}{\Sigma E_{LOSS}}$$

Several factors can affect the frequency stability: Mechanical stress induced by mounting, shock or vibration stress, variations in power supply, load impedance, temperature, magnetic and electric fields, and crystal aging may all have an effect. Crystal vendors usually list such parameters in their data sheets.

1.6 Start-Up Time

During start-up, noise will be amplified in the inverting amplifier. The crystal will act as a bandpass filter and feed back only the crystal resonance frequency component, which will be amplified. Before steady state oscillation is achieved, the loop gain of the crystal/inverting amplifier loop is greater than 1 and the signal amplitude will increase. At steady state, the loop gain will fulfill the Barkhausen criteria with a loop gain of 1 and constant amplitude.

Factors affecting the start-up time:

- High-ESR crystals will start more slowly than low-ESR crystals

   High Q-factor crystals will start more slowly than low Q-factor crystals

   High load capacitance will increase start-up time

   Oscillator amplifier drive capabilities (see more details on oscillator allowance in Section 3.2, *Negative Resistance Test and Safety Factor*).

In addition, crystal frequency will affect the start-up time (faster crystals will start faster), but this parameter is fixed for 32 KHz crystals.

Figure 1-6. Start-Up Signal of a Crystal Oscillator
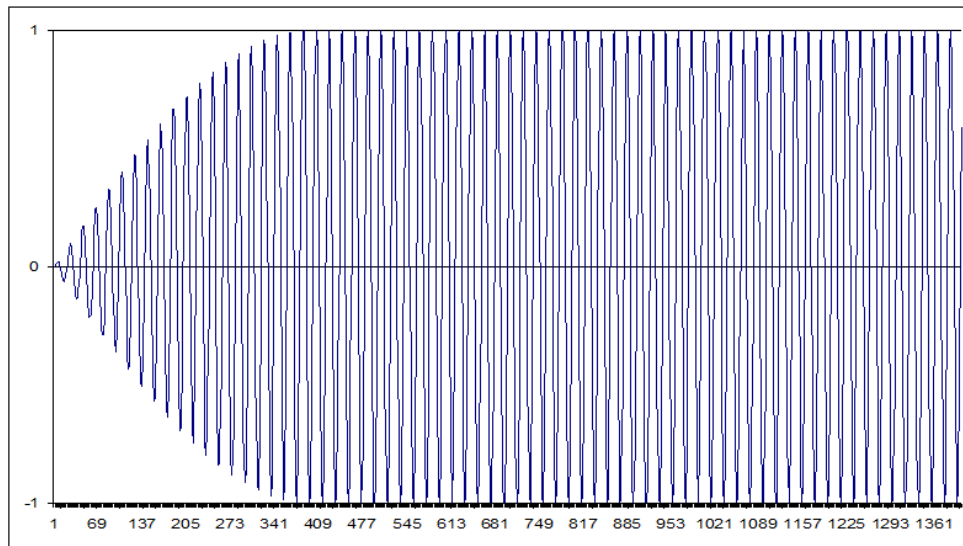
1.7   Temperature Tolerance

Typical tuning fork crystals are usually cut to center the nominal frequency at 25°C. Above and below 25°C, the frequency will decrease with a parabolic characteristic, as shown in Figure 1-7. The frequency shift is given by Equation 1-5, where f_0 is the target frequency at T_0 (typically 32768 Hz at 25°C) and the PPM is the temperature tolerance coefficient given by the crystal data sheet.

Equation 1-5. Effect of Temperature Variation

$$f = f_0(1 - PPM(T - T_0))^2$$

Figure 1-7. Typical Temperature vs. Frequency Characteristics of a Crystal
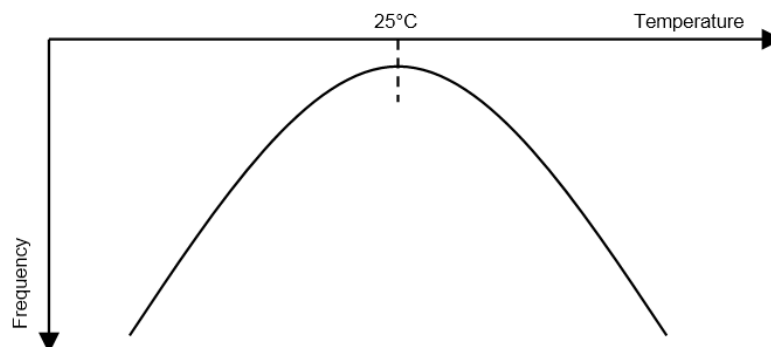
2. PCB Layout and Design Considerations

Even the best performing oscillator circuits and high-quality crystals will not perform well if the layout and materials used during assembly are not carefully considered. Ultra low-power 32 KHz oscillators typically dissipate significantly below 1 µW, and the current flowing in the circuit is, therefore, extremely small. In addition, the crystal frequency is highly dependent on the capacitive load.

To increase the robustness of the oscillator, we recommend these guidelines during PCB layout:

- Signal lines from XTAL1/TOSC1 and XTAL2/TOSC2 to the crystal should be as short as possible to reduce parasitic capacitance and increase noise and crosstalk immunity. Any kind of sockets should be avoided.
- Shield the crystal and signal lines by surrounding it with a ground plane and guard ring.
- Avoid routing digital lines, especially clock lines, close to the crystal lines. For multilayer PCB boards, avoid routing signals below the crystal lines.
- Use high-quality PCB and soldering materials.
- Dust and humidity will increase parasitic capacitance and reduce signal isolation, so, protective coating is recommended.

# 3. Testing Crystal Oscillation Robustness

3.1 Introduction

The 32 KHz crystal oscillator driver of AVR microcontrollers is optimized for very low power consumption, and thus the crystal driver strength is limited. Overloading the crystal driver may cause the oscillator to not start, or it may be affected (stopped temporarily) e.g., due to a noise spike or increased capacitive load caused by the contamination or proximity of a hand.

This means that care must be taken when selecting and testing the crystal to ensure proper robustness in your application. The two important crystal parameters are Equivalent Series Resistance (ESR) and Load Capacitance (CL).

When doing measurements on crystals, the crystal should be placed as close as possible to the 32 KHz oscillator pins to reduce parasitic capacitance. In general, we always recommend doing the measurement in your final application. For initial testing of the crystal, however, using a starter kit (e.g., STK600) will work fine.

We do not recommend connecting the crystal to the XTAL/TOSC output headers at the end of the STK600, as shown in Figure 3-1, because the signal path will be very sensitive to noise and thereby add extra capacitive load. Soldering the crystal directly to the leads, however, will give good results. To avoid extra capacitive load from the socket and routing on the STK600, we recommend bending the XTAL/TOSC leads upwards, as shown in Figure 3-2 and Figure 3-3, so they do not touch the socket. Crystals with leads (hole mounted) are easier to handle, but it is also possible to solder SMD directly to the XTAL/TOSC leads by using pin extensions, as shown in Figure 3-4. Soldering crystals to packages with narrow pin pitch is also possible, as shown in Figure 3-5, but is a bit trickier and requires a steady hand.

Figure 3-1. Do Not Connect the Crystal to the XTAL/TOSC Headers at the End of the STK600. This Will Give a Very Long Signal Path that Will Add Parasitic Capacitance and be Sensitive to Noise and Crosstalk
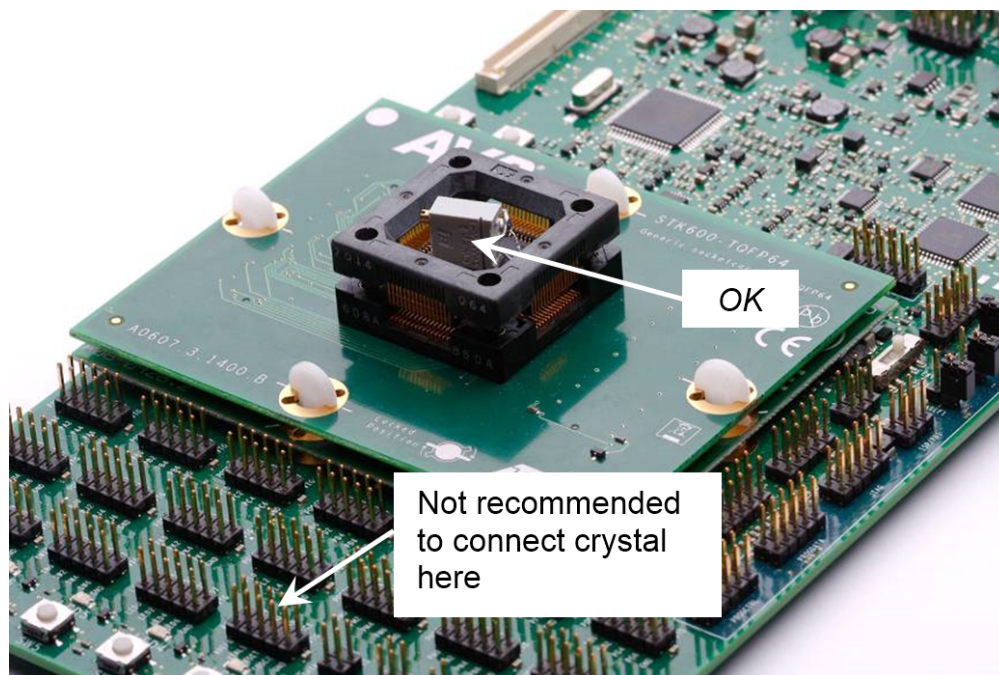
Since capacitive load will have a great effect on the oscillator, you should not probe the crystal directly unless you have high-quality equipment intended for crystal measurements. Standard 10X oscilloscope probes impose a loading of 10-15 pF and will have a high impact on the measurements. Touching the pins of a crystal with a finger or a 10X probe can be sufficient to start or stop oscillations or give false results. Firmware for outputting the clock signal to a standard I/O pin is supplied with this application note. Unlike the XTAL/TOSC pins, I/O pins can be probed with standard 10X oscilloscope probes without affecting the measurements. More details can be found in Chapter 4, *Test Firmware.*

Figure 3-2. Crystal Soldered Directly to Bent XTAL/TOSC Leads
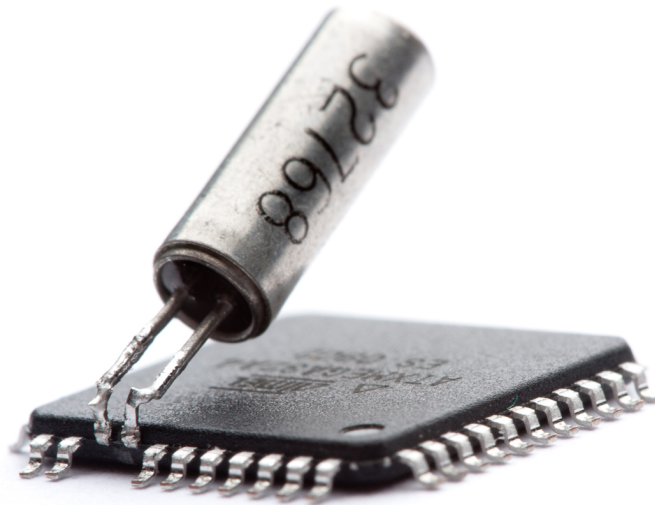
Figure 3-3. Ensure That XTAL/TOSC Leads Do Not Touch the Socket

Space between MCU/crystal pins and socket
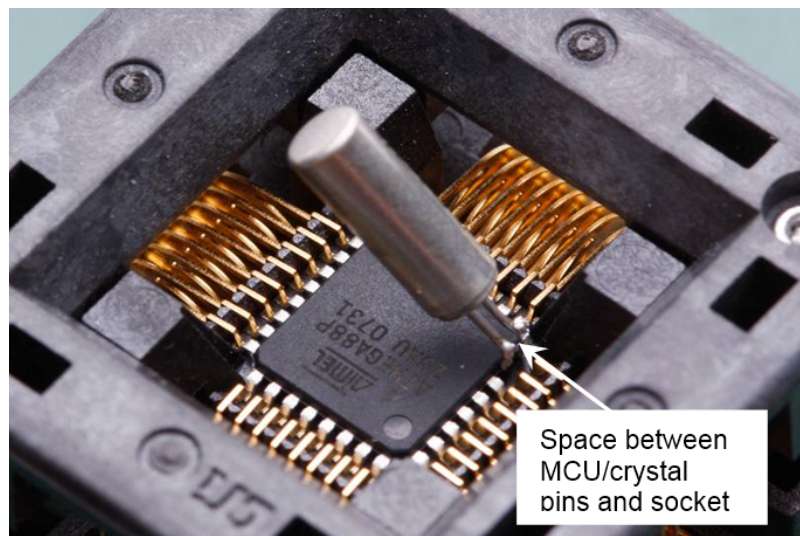
Figure 3-4. SMD Crystal Soldered Directly to MCU by using Pin Extensions
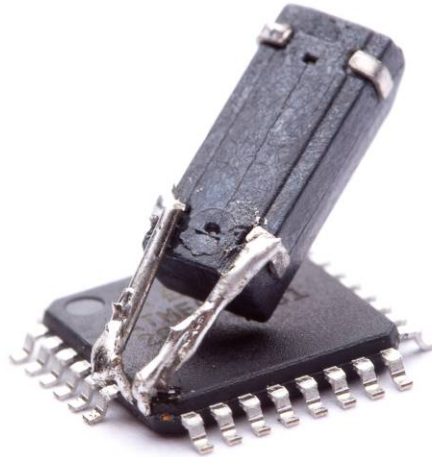
Figure 3-5. 100-Pin TQFP Package (e.g. ATmega6490, ATmega2560, ATxmega128A1) with Narrow Pin Pitch is Also Possible to use but Requires a Steady Hand when Soldering
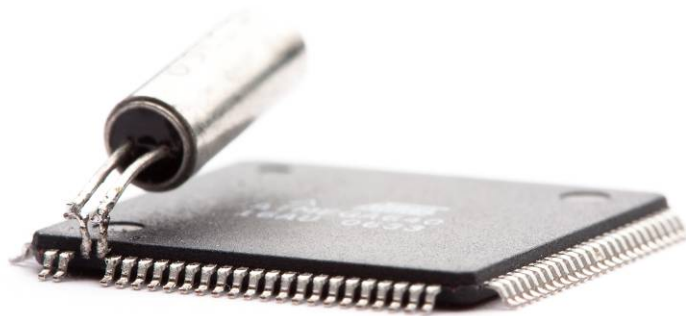
3.2   Negative Resistance Test and Safety Factor

The negative resistance test finds the margin between the crystal amplifier load used in your application and the maximum load. At the maximum load, the amplifier will choke and the oscillations will stop. This point is called the oscillator allowance (OA). The oscillator allowance can be found by temporarily adding a variable series resistor between the amplifier output (XTAL2/TOSC2) lead and the crystal, as shown in Figure 3-6. The series resistor should be increased until the crystal stops oscillating. The oscillator

allowance will then be the sum of this series resistance, R_{MAX}, and the ESR. We recommend using a potentiometer with a range of at least *ESR < R_{POT} < 5 ESR*.

Finding a correct R_{MAX} value can be a bit tricky because no exact oscillator allowance point exists. Before the oscillator stops, you may observe a gradual frequency reduction, and there may also be a start-stop hysteresis. After the oscillator stops, you will need to reduce the R_{MAX} value by 10-50 kΩ before oscillations resume. We recommend performing a power cycling each time after the variable resistor is increased. R_{MAX} will then be the resistor value where the oscillator does not start after a power cycling. Note that the start-up times will be quite long at the oscillator allowance point, so be patient.

Equation 3-1. Oscillator Allowance

$$OA = R_{MAX} + ESR$$

Figure 3-6. Measuring Oscillator Allowance/RMAX

We recommend using a high-quality potentiometer with low parasitic capacitance (an SMD potentiometer suitable for RF will usually give the best results). However, if you are able to achieve good oscillator allowance/RMAX with a cheap potentiometer, you will be safe.
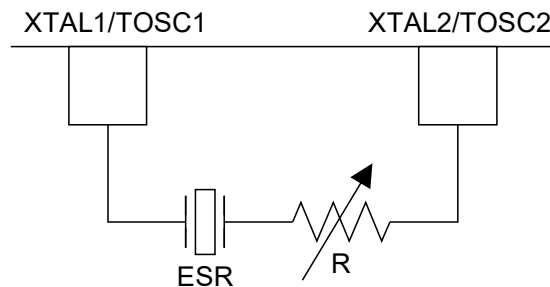
When the maximum series resistance is found, you can find the safety factor from Equation 3-2. Various MCU and crystal vendors operate with different safety factor recommendations. The safety factor is intended to add a margin for negative effects of different variables such as oscillator amplifier gain, change due to the power supply and temperature variations, process variations, and load capacitance. The 32 KHz oscillator amplifier on AVR microcontrollers is temperature and power compensated, and so by having these variables more or less constant, we can reduce the requirements for the safety factor compared to other MCU/IC manufacturers. The safety factor recommendations can be found in Table 3-1.

Equation 3-2. Safety Factor

$$SF = \frac{OA}{ESR} = \frac{R_{MAX} + ESR}{ESR}$$

Figure 3-7. Series Potentiometer Between the XTAL2/TOSC2 Pin and Crystal
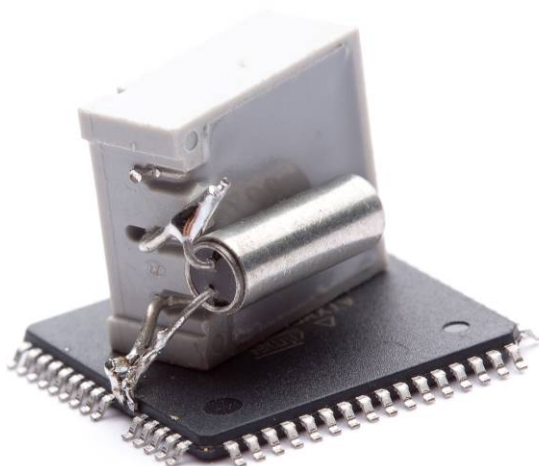
Figure 3-8. Allowance Test in Socket

Table 3-1. Safety Factor Recommendations

Safety Factor	Recommendation
5<	Excellent
4	Very good
3	Good
<3	Not recommended

3.3   Measuring Effective Load Capacitance

The crystal frequency is dependent on the capacitive load applied, as shown by Equation 1-2. Applying the capacitive load specified in the crystal data sheet will provide a frequency very close to the nominal frequency of 32768 Hz. If other capacitive loads are applied, the frequency will change. The frequency

will increase if the capacitive load is decreased, and will decrease if the load is increased, as shown in Figure 3-9.

The frequency pull-ability or bandwidth—how far from the nominal frequency the resonant frequency can be forced by applying load—depends on the Q-factor of the resonator. The bandwidth is given by the nominal frequency divided by the Q-factor, and for high-Q quartz crystals, the usable bandwidth will be very limited. If the measured frequency deviates from the nominal frequency, the oscillator will be less robust. This is due to higher attenuation in the feedback loop β(jω) that will cause a higher loading of the amplifier A to achieve unity gain (see Figure 1-2).

Equation 3-3. Bandwidth

$$BW = \frac{f_{resonant}}{Q}$$

A good way of measuring the effective load capacitance (the sum of load capacitance and parasitic capacitance) is to measure the oscillator frequency and compare it to the nominal frequency of 32768 Hz. If the measured frequency is close to 32768 Hz, the effective load capacitance will be close to the specification. This can be done using the firmware supplied with this application note and a standard 10X scope probe on the clock output on an I/O pin, or, if available, measuring the crystal directly with a high-impedance probe intended for crystal measurements. More details can be found in Chapter 4, *Test Firmware*.

Figure 3-9. Frequency vs. Load Capacitance
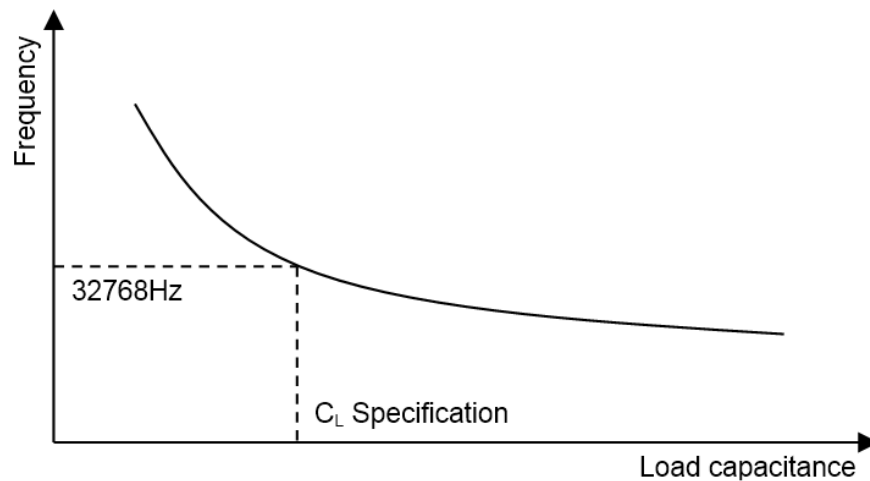
Without external capacitors, the total load capacitance will be given by Equation 3-4. In some cases, external capacitors (CEL1 and CEL2) must be added to match the capacitive load specified in the crystal's data sheet. If external capacitors are used, the total capacitive load will be given by Equation 3-5.

Equation 3-4. Total Capacitive Load without External Capacitors

$$\Sigma C_L = \frac{(C_{L1} + C_{P1})(C_{L2} + C_{P2})}{C_{L1} + C_{L2} + C_{P1} + C_{P2}}$$

Equation 3-5. Total Capacitive Load with External Capacitors

$$\Sigma C_L = \frac{(C_{L1} + C_{P1} + C_{EL1})(C_{L2} + C_{P2} + C_{EL2})}{C_{L1} + C_{L2} + C_{P1} + C_{P2} + C_{EL1} + C_{EL2}}$$

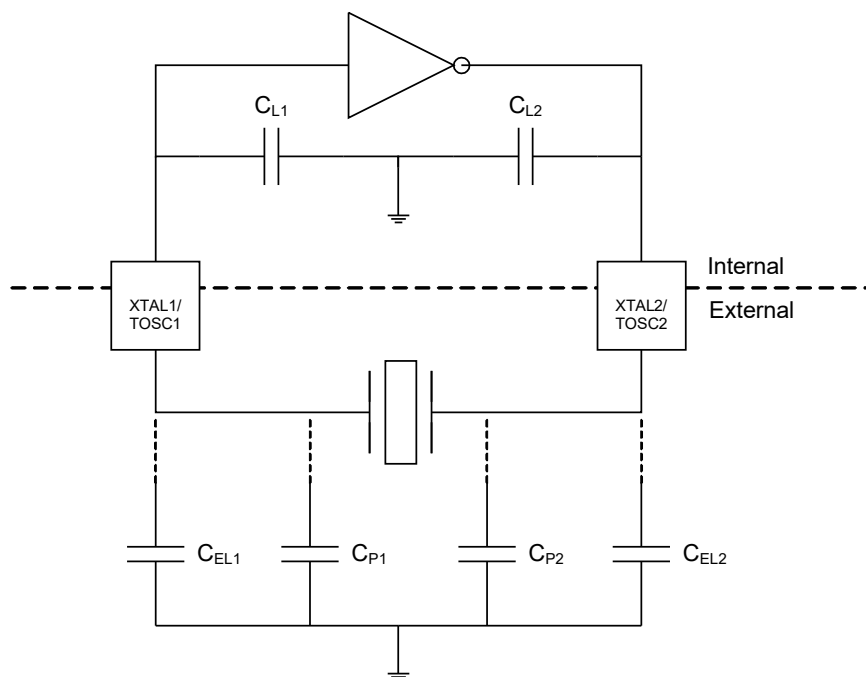**Figure 3-10. Crystal Circuit with Internal, Parasitic, and External Capacitors**

4.   Test Firmware

Test firmware for outputting the clock signal to an I/O port that may be loaded with a standard 10X probe, is included in the .zip file distributed with this application note. The crystal electrodes should not be measured directly if you do not have very high impedance probes intended for such measurements.

Compile the source code and program the .hex file into the device.

Apply V_{CC} within the operating range listed in the data sheet, connect the crystal between XTAL1/TOSC1 and XTAL2/TOSC2, and measure the clock signal on the output pin.

The output compare pin will differ from device to device, so you need to look into the code to find which I/O pin will output the clock signal.

4.1   tinyAVR®

The clock signal is output to PORTB by using an endless while loop that toggles the port, and hence the clock signal will be divided by 10 (nominal frequency of 3276.8 Hz). All Microchip tinyAVR® devices are supported. To use a 32768 Hz crystal as the clock source for the device, the low-frequency crystal oscillator must be selected by setting CKSEL fuses. Look in the data sheet for details.

4.2   megaAVR®

An asynchronous timer overflow is used to toggle an I/O pin, and hence the clock signal will be divided by 2 (nominal frequency of 16384 Hz). All megaAVR® devices are supported, but a device family define needs to be set (see the list of defines in the .c file).

4.3   XMEGA®

The Microchip AVR XMEGA® families have support for outputting the peripheral clock directly to an I/O port. No clock division will be done. The firmware will set up the external low-frequency crystal as the system clock and enable low-power mode. The clock signal will be output on port PC7.

4.4   UC3

UC3 support will be included in a future release of this application note.

5. Crystal Recommendations

Table 5-2 is a selection of crystals that have been tested and found suitable for various AVR microcontrollers. Using crystal-MCU combinations from the table below will ensure good compatibility, and is highly recommended for users with little or limited crystal expertise. Even though the crystal-MCU combinations are tested by highly experienced crystal oscillator experts at the various crystal vendors, we still recommend testing your design as described in Chapter 3, *Testing Crystal Oscillation Robustness* to ensure that no issues have been introduced during layout, soldering, etc.

Refer to the .zip file attached to this application note for test reports and crystal data sheets.

Table 5-1 shows a list of the different oscillator modules and a list of devices where these modules are included can be found in Chapter 6, *Oscillator Module Overview*.

Table 5-1. Overview of Oscillators in AVR Devices

#	Oscillator Module	Description
1	X32K_2v7[1]	2.7-5.5V oscillator used in megaAVR devices
2	X32K_1v8[1]	1.8-5.5V oscillator used in megaAVR/tinyAVR devices
3	X32K_1v8_ULP	1.8-3.6V ultra low-power oscillator used in megaAVR/tinyAVR picoPower® devices
4	X32K_XMEGA	1.6-3.6V ultra low-power oscillator used in XMEGA devices – oscillator setup in normal mode
5	X32K_XMEGA	1.6-3.6V ultra low-power oscillator used in XMEGA devices – oscillator setup in low-power mode
6	X32K_XRTC32	1.6-3.6V ultra low-power RTC oscillator used in XMEGA devices with battery backup
7	X32K_1v8_5v5_ULP	1.8-5.5V ultra low-power oscillator used in tinyAVR 1-series and megaAVR 0-series devices

Note:
1. Not used with the megaAVR and tinyAVR 1- and 0-series

Table 5-2. Recommended 32 KHz Crystals

Vendor	Type	Mount	Oscillator Modules Tested and Approved (See Table 5-1)	Frequency Tolerance [±ppm]	Load Capacitance [pF]	Equivalent Series Resistance (ESR) [kΩ]
Microcrystal	CC7V-T1A	SMD	1, 2, 3, 4, 5	20/100[1]	7.0/9.0/12.5	50/70
Abracon	ABS06	SMD	2	20	12.5	90
Cardinal	CPFB	SMD	2, 3, 4, 5	20	12.5	50
Cardinal	CTF6	HOLE	2, 3, 4, 5	20	12.5	50
Cardinal	CTF8	HOLE	2, 3, 4, 5	20	12.5	50

..........continued

Vendor	Type	Mount	Oscillator Modules Tested and Approved (See Table 5-1)	Frequency Tolerance [±ppm]	Load Capacitance [pF]	Equivalent Series Resistance (ESR) [kΩ]
Endrich Citizen	CFS206	HOLE	1, 2, 3, 4	20	12.5	35
Endrich Citizen	CM315	SMD	1, 2, 3, 4	20	12.5	70
Epson Tyocom	MC-306	SMD	1, 2, 3	20/50	12.5[2]	50
Fox	FSXLF	SMD	2, 3, 4, 5	20	12.5	65
Fox	FX135	SMD	2, 3, 4, 5	20	12.5	70
Fox	FX122	SMD	2, 3, 5	20	12.5	90
Fox	FSRLF	SMD	1, 2, 3, 4, 5	20	12.5	50
NDK	NX3215SA	SMD	1, 2 ,3	20	12.5	80
Seiko	SSP-T7-FL	SMD	3	20	6	65
Seiko	SSP-T7-F	SMD	1, 2	20	12.5	65
Seiko	SSP-T7-F	SMD	4	20	7	65
Seiko	SSP-T7-FL	SMD	5	20	4.4	65

Note:
1. Tighter and wider frequency tolerances on request
2. 12.5 pF standard, but 6 pF to ∞ available on request

6. Oscillator Module Overview

Table 6-1 shows a list of which 32 KHz oscillators are included in various Microchip megaAVR, Microchip tinyAVR, and Microchip XMEGA devices. The list will be extended with UC3 devices in future releases.

Table 6-1. Oscillator Module Overview

Device Family	Device	Oscillator Module
megaAVR	ATmega128	X32K_2v7
megaAVR	ATmega1280	X32K_1v8
megaAVR	ATmega1281	X32K_1v8
megaAVR	ATmega1284P	X32K_1v8_ULP
megaAVR	ATmega128A	X32K_2v7
megaAVR	ATmega16	X32K_2v7
megaAVR	ATmega162	X32K_1v8
megaAVR	ATmega164A	X32K_1v8_ULP
megaAVR	ATmega164P	X32K_1v8_ULP
megaAVR	ATmega164PA	X32K_1v8_ULP
megaAVR	ATmega165A	X32K_1v8_ULP
megaAVR	ATmega165P	X32K_1v8_ULP
megaAVR	ATmega165PA	X32K_1v8_ULP
megaAVR	ATmega168	X32K_1v8
megaAVR	ATmega168A	X32K_1v8_ULP
megaAVR	ATmega168P	X32K_1v8_ULP
megaAVR	ATmega168PA	X32K_1v8_ULP
megaAVR	ATmega168PB	X32K_1v8_ULP
megaAVR	ATmega169	X32K_1v8
megaAVR	ATmega169A	X32K_1v8_ULP
megaAVR	ATmega169P	X32K_1v8_ULP
megaAVR	ATmega169PA	X32K_1v8_ULP
megaAVR	ATmega16A	X32K_2v7
megaAVR	ATmega2560	X32K_1v8
megaAVR	ATmega2561	X32K_1v8
megaAVR	ATmega32	X32K_2v7
megaAVR	ATmega324A	X32K_1v8_ULP
megaAVR	ATmega324P	X32K_1v8_ULP

..........continued		
Device Family	**Device**	**Oscillator Module**
megaAVR	ATmega324PA	X32K_1v8_ULP
megaAVR	ATmega3250A	X32K_1v8_ULP
megaAVR	ATmega3250P	X32K_1v8_ULP
megaAVR	ATmega3250PA	X32K_1v8_ULP
megaAVR	ATmega325A	X32K_1v8_ULP
megaAVR	ATmega32A	X32K_2v7
megaAVR	ATmega48	X32K_1v8
megaAVR	ATmega48A	X32K_1v8_ULP
megaAVR	ATmega324PA	X32K_1v8_ULP
megaAVR	ATmega324PB	X32K_1v8_ULP
megaAVR	ATmega325P	X32K_1v8_ULP
megaAVR	ATmega325PA	X32K_1v8_ULP
megaAVR	ATmega328	X32K_1v8
megaAVR	ATmega328P	X32K_1v8_ULP
megaAVR	ATmega328PA	X32K_1v8_ULP
megaAVR	ATmega328PB	X32K_1v8_ULP
megaAVR	ATmega329	X32K_1v8
megaAVR	ATmega3290A	X32K_1v8_ULP
megaAVR	ATmega3290P	X32K_1v8_ULP
megaAVR	ATmega3290PA	X32K_1v8_ULP
megaAVR	ATmega329A	X32K_1v8_ULP
megaAVR	ATmega329P	X32K_1v8_ULP
megaAVR	ATmega329PA	X32K_1v8_ULP
megaAVR	ATmega32A	X32K_2v7
megaAVR	ATmega48	X32K_1v8
megaAVR	ATmega48A	X32K_1v8_ULP
megaAVR	ATmega48P	X32K_1v8_ULP
megaAVR	ATmega48PA	X32K_1v8_ULP
megaAVR	ATmega48PB	X32K_1v8_ULP
megaAVR	ATmega64	X32K_2v7
megaAVR	ATmega640	X32K_1v8

	Device Family	Device	Oscillator Module
..........continued			
	megaAVR	ATmega644A	X32K_1v8_ULP
	megaAVR	ATmega644P	X32K_1v8_ULP
	megaAVR	ATmega644PA	X32K_1v8_ULP
	megaAVR	ATmega6450A	X32K_1v8_ULP
	megaAVR	ATmega6450P	X32K_1v8_ULP
	megaAVR	ATmega645A	X32K_1v8_ULP
	megaAVR	ATmega645P	X32K_1v8_ULP
	megaAVR	ATmega649	X32K_1v8
	megaAVR	ATmega6490	X32K_1v8_ULP
	megaAVR	ATmega6490A	X32K_1v8_ULP
	megaAVR	ATmega6490P	X32K_1v8_ULP
	megaAVR	ATmega649A	X32K_1v8_ULP
	megaAVR	ATmega649P	X32K_1v8_ULP
	megaAVR	ATmega64	X32K_2v7
	megaAVR	ATmega640	X32K_1v8
	megaAVR	ATmega644A	X32K_1v8_ULP
	megaAVR	ATmega644P	X32K_1v8_ULP
	megaAVR	ATmega644PA	X32K_1v8_ULP
	megaAVR	ATmega6450A	X32K_1v8_ULP
	megaAVR	ATmega6450P	X32K_1v8_ULP
	megaAVR	ATmega645A	X32K_1v8_ULP
	megaAVR	ATmega645P	X32K_1v8_ULP
	megaAVR	ATmega649	X32K_1v8
	megaAVR	ATmega6490	X32K_1v8_ULP
	megaAVR	ATmega6490A	X32K_1v8_ULP
	megaAVR	ATmega6490P	X32K_1v8_ULP
	megaAVR	ATmega649A	X32K_1v8_ULP
	megaAVR	ATmega649P	X32K_1v8_ULP
	megaAVR	ATmega64A	X32K_2v7
	megaAVR	ATmega8	X32K_2v7
	megaAVR	ATmega88	X32K_1v8

..........continued		
Device Family	**Device**	**Oscillator Module**
megaAVR	ATmega88A	X32K_1v8_ULP
megaAVR	ATmega88P	X32K_1v8_ULP
megaAVR	ATmega88PA	X32K_1v8_ULP
megaAVR	ATmega88PB	X32K_1v8_ULP
megaAVR	ATmega8A	X32K_2v7
megaAVR 0-series	ATmega3208	X32K_1v8_5v5_ULP
megaAVR 0-series	ATmega3209	X32K_1v8_5v5_ULP
megaAVR 0-series	ATmega4808	X32K_1v8_5v5_ULP
megaAVR 0-series	ATmega4809	X32K_1v8_5v5_ULP
tinyAVR	ATtiny84A	X32K_1v8
tinyAVR	ATtiny85	X32K_1v8
tinyAVR	ATtiny861	X32K_1v8
tinyAVR	ATtiny2313A	X32K_1v8
tinyAVR	ATtiny24	X32K_1v8
tinyAVR	ATtiny24A	X32K_1v8
tinyAVR	ATtiny25	X32K_1v8
tinyAVR	ATtiny261	X32K_1v8
tinyAVR	ATtiny261A	X32K_1v8
tinyAVR	ATtiny4313	X32K_1v8
tinyAVR	ATtiny44	X32K_1v8
tinyAVR	ATtiny44A	X32K_1v8
tinyAVR	ATtiny45	X32K_1v8
tinyAVR	ATtiny461	X32K_1v8
tinyAVR	ATtiny461A	X32K_1v8
tinyAVR	ATtiny84	X32K_1v8
tinyAVR	ATtiny861A	X32K_1v8
tinyAVR 1-series	ATtiny212	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny214	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny412	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny414	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny416	X32K_1v8_5v5_ULP

..........continued

Device Family	Device	Oscillator Module
tinyAVR 1-series	ATtiny417	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny814	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny816	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny817	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny1614	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny1616	X32K_1v8_5v5_ULP
tinyAVR 1-series	ATtiny1617	X32K_1v8_5v5_ULP
XMEGA	ATxmega128A1	X32K_XMEGA
XMEGA	ATxmega128A3	X32K_XMEGA
XMEGA	ATxmega128A4	X32K_XMEGA
XMEGA	ATxmega128B1	X32K_XMEGA
XMEGA	ATxmega128B3	X32K_XMEGA
XMEGA	ATxmega128D3	X32K_XMEGA
XMEGA	ATxmega128D4	X32K_XMEGA
XMEGA	ATxmega16A4	X32K_XMEGA
XMEGA	ATxmega16D4	X32K_XMEGA
XMEGA	ATxmega192A1	X32K_XMEGA
XMEGA	ATxmega192A3	X32K_XMEGA
XMEGA	ATxmega192D3	X32K_XMEGA
XMEGA	ATxmega256A1	X32K_XMEGA
XMEGA	ATxmega256D3	X32K_XMEGA
XMEGA	ATxmega32A4	X32K_XMEGA
XMEGA	ATxmega32D4	X32K_XMEGA
XMEGA	ATxmega348A1	X32K_XMEGA
XMEGA	ATxmega64A1	X32K_XMEGA
XMEGA	ATxmega64A3	X32K_XMEGA
XMEGA	ATxmega64A4	X32K_XMEGA
XMEGA	ATxmega64B1	X32K_XMEGA
XMEGA	ATxmega64B3	X32K_XMEGA
XMEGA	ATxmega64D3	X32K_XMEGA
XMEGA	ATxmega64D4	X32K_XMEGA

..........continued		
Device Family	**Device**	**Oscillator Module**
XMEGA	ATxmega256A3B	X32K_XRTC32

7. Revision History

Doc. Rev.	Date	Comments
8333A	08/2010	Initial document revision.
8333B	11/2010	Several updates and corrections.
8333C	02/2011	Recommendation list updated.
8333D	072011	Recommendation list updated.
8333E	03/2015	1. Changed XMEGA clock output from PD7 to PC7. 2. XMEGA B added.
A	02/2018	1. Converted to Microchip format and replaced the Atmel document number 8333. 2. Added support for tinyAVR 0- and 1-series.
B	09/2018	1. Corrected Table 5-1 2. Corrected cross references

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

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	**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	**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
Atlanta Duluth, GA Tel: 678-957-9614 Fax: 678-957-1455	**China - Guangzhou** Tel: 86-20-8755-8029 **China - Hangzhou** Tel: 86-571-8792-8115	**Korea - Daegu** Tel: 82-53-744-4301 **Korea - Seoul** Tel: 82-2-554-7200	**Germany - Garching** Tel: 49-8931-9700 **Germany - Haan** Tel: 49-2129-3766400
Austin, TX Tel: 512-257-3370	**China - Hong Kong SAR** Tel: 852-2943-5100	**Malaysia - Kuala Lumpur** Tel: 60-3-7651-7906	**Germany - Heilbronn** Tel: 49-7131-67-3636
Boston Westborough, MA Tel: 774-760-0087 Fax: 774-760-0088	**China - Nanjing** Tel: 86-25-8473-2460 **China - Qingdao** Tel: 86-532-8502-7355	**Malaysia - Penang** Tel: 60-4-227-8870 **Philippines - Manila** Tel: 63-2-634-9065	**Germany - Karlsruhe** Tel: 49-721-625370 **Germany - Munich** Tel: 49-89-627-144-0 Fax: 49-89-627-144-44
Chicago Itasca, IL Tel: 630-285-0071 Fax: 630-285-0075	**China - Shanghai** Tel: 86-21-3326-8000 **China - Shenyang** Tel: 86-24-2334-2829	**Singapore** Tel: 65-6334-8870 **Taiwan - Hsin Chu** Tel: 886-3-577-8366	**Germany - Rosenheim** Tel: 49-8031-354-560 **Israel - Ra'anana** Tel: 972-9-744-7705
Dallas Addison, TX Tel: 972-818-7423 Fax: 972-818-2924	**China - Shenzhen** Tel: 86-755-8864-2200 **China - Suzhou** Tel: 86-186-6233-1526	**Taiwan - Kaohsiung** Tel: 886-7-213-7830 **Taiwan - Taipei** Tel: 886-2-2508-8600	**Italy - Milan** Tel: 39-0331-742611 Fax: 39-0331-466781 **Italy - Padova** Tel: 39-049-7625286
Detroit Novi, MI Tel: 248-848-4000	**China - Wuhan** Tel: 86-27-5980-5300 **China - Xian** Tel: 86-29-8833-7252	**Thailand - Bangkok** Tel: 66-2-694-1351 **Vietnam - Ho Chi Minh** Tel: 84-28-5448-2100	**Netherlands - Drunen** Tel: 31-416-690399 Fax: 31-416-690340
Houston, TX Tel: 281-894-5983	**China - Xiamen** Tel: 86-592-2388138		**Norway - Trondheim** Tel: 47-72884388
Indianapolis Noblesville, IN Tel: 317-773-8323 Fax: 317-773-5453 Tel: 317-536-2380	**China - Zhuhai** Tel: 86-756-3210040		**Poland - Warsaw** Tel: 48-22-3325737 **Romania - Bucharest** Tel: 40-21-407-87-50
Los Angeles Mission Viejo, CA Tel: 949-462-9523 Fax: 949-462-9608 Tel: 951-273-7800			**Spain - Madrid** Tel: 34-91-708-08-90 Fax: 34-91-708-08-91 **Sweden - Gothenberg** Tel: 46-31-704-60-40
Raleigh, NC Tel: 919-844-7510			**Sweden - Stockholm** Tel: 46-8-5090-4654
New York, NY Tel: 631-435-6000			**UK - Wokingham** Tel: 44-118-921-5800 Fax: 44-118-921-5820
San Jose, CA Tel: 408-735-9110 Tel: 408-436-4270			
Canada - Toronto Tel: 905-695-1980 Fax: 905-695-2078			