AN2648

Selecting and Testing 32.768 kHz Crystal Oscillators for AVR® Microcontrollers

Introduction

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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

1. Crystal Oscillator Basics

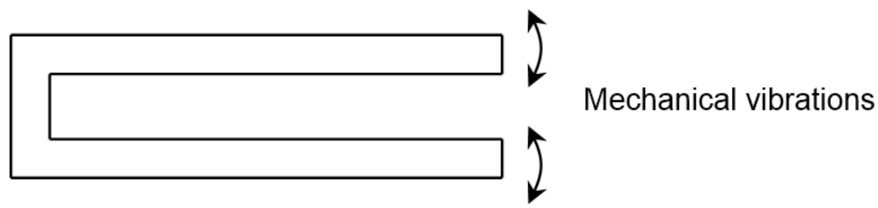
1.1 Introduction

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 keep track of time; hence, crystal oscillators are widely used in Radio Frequency (RF) applications and time-sensitive digital circuits.

Crystals are available from various vendors in different 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 – generally in low-cost or less timing-critical applications. 32.768 kHz crystals are usually cut in the shape of a tuning fork. With quartz crystals, very precise frequencies can be established.

Figure 1-1. Shape of a 32.768 kHz Tuning Fork Crystal



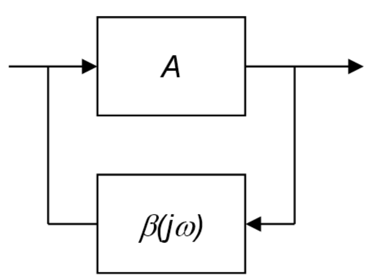
1.2 The Oscillator

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 electronic circuit and $\beta(j\omega)$ is the transfer function of the feedback path, steady-state oscillations will be sustained 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., $\angle\beta A = 2\pi n$ 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, 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.

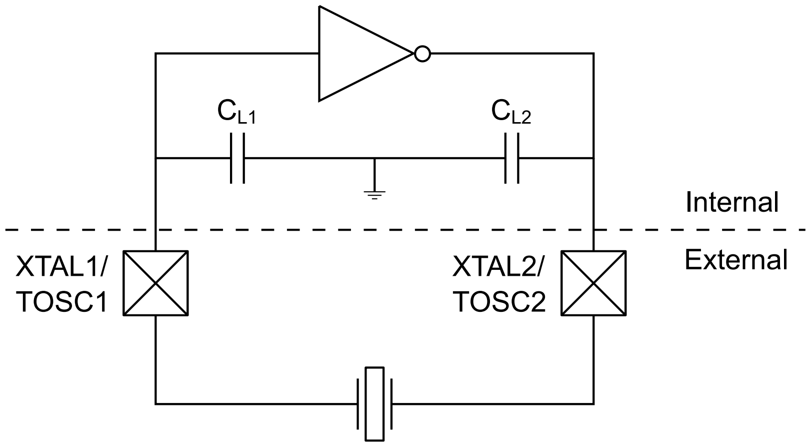
Figure 1-2. Feedback Loop



The 32.768 kHz oscillator in Microchip AVR microcontrollers is shown in Figure 1-3 and consists of an inverting amplifier (internal) and a crystal (external). Capacitors (C_{L1} and C_{L2}) represent internal parasitic capacitance. Some AVR devices also have selectable internal load capacitors, which may be used to reduce the need for external load capacitors, depending on the crystal used.

The inverting amplifier gives a π radian (180 degrees) phase shift. The remaining π radian phase shift is provided by the crystal and the capacitive load at 32.768 kHz, 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 controlled automatically by the AVR microcontroller's oscillator circuitry.

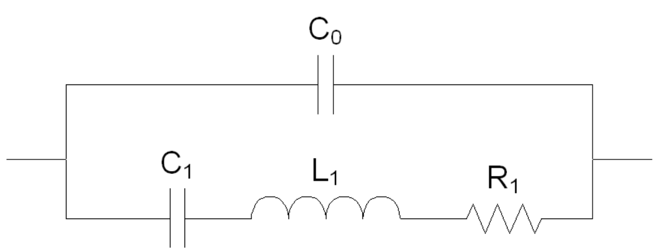
Figure 1-3. Pierce Crystal Oscillator Circuit in AVR® Devices (simplified)



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. The parallel or anti-resonant frequency, f_p, also includes C_0. See Figure 1-5 for the reactance vs. frequency characteristics.

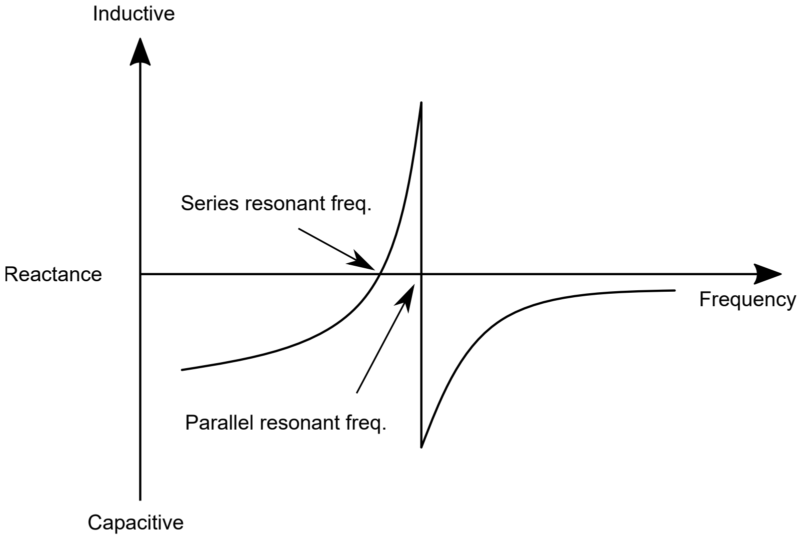
Equation 1-1. Series Resonant Frequency

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

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

Higher ESR values put a higher load on the inverting amplifier. Too high ESR may cause unstable oscillator operation. Unity gain can, in such cases, not be achieved, and the Barkhausen criterion may not be fulfilled.

1.5 Q-Factor and Stability

The crystal's frequency stability 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 changes in capacitive load.

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. Crystal vendors usually list such parameters in their data sheets.

1.6 Start-Up Time

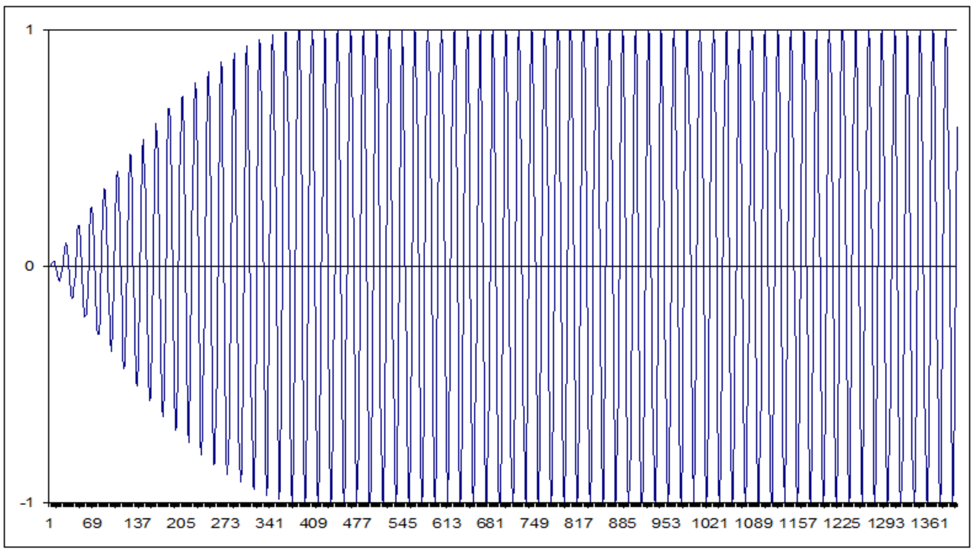
During start-up, the inverting amplifier amplifies noise. The crystal will act as a bandpass filter and feed back only the crystal resonance frequency component, which is then amplified. Before achieving steady-state oscillation, the loop gain of the crystal/inverting amplifier loop is greater than 1 and the signal amplitude will increase. At steady-state oscillation, 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 32.768 kHz crystals.

Figure 1-6. Start-Up of a Crystal Oscillator



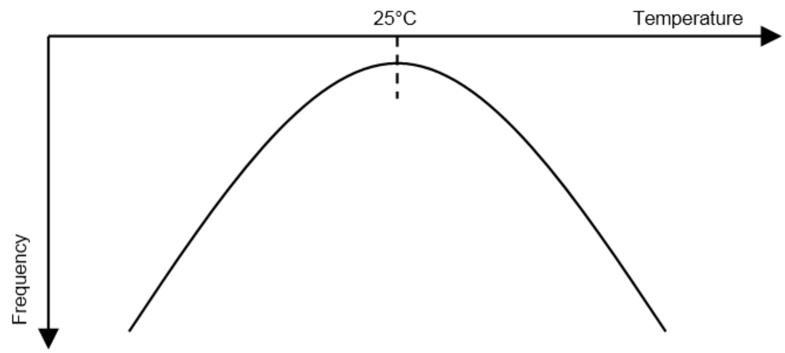
1.7 Temperature Tolerance

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 32.768 kHz at 25°C) and B is the temperature coefficient given by the crystal data sheet (typically a negative number).

Equation 1-5. Effect of Temperature Variation

$$f = f_0\left(1 + B(T - T_0)^2\right)$$

Figure 1-7. Typical Temperature vs. Frequency Characteristics of a Crystal



1.8 Drive Strength

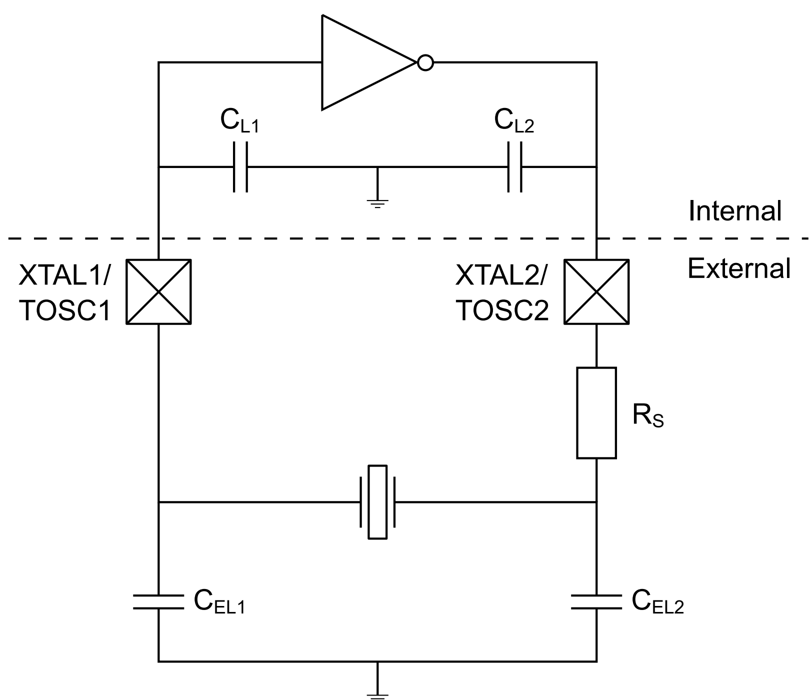
The strength of the crystal driver circuit determines the characteristics of the sine wave output of the crystal oscillator. The sine wave is the direct input into the digital clock input pin of the microcontroller. This sine wave must easily span the input minimum and maximum voltage levels of the crystal driver’s input pin while not being clipped, flattened or distorted at the peaks. A too low sine wave amplitude shows that the crystal circuit load is too heavy for the driver, leading to potential oscillation failure or misread frequency input. Too high amplitude means that the loop gain is too high and may lead to the crystal jumping to a higher harmonic level or permanent damage to the crystal.

Determine the crystal's output characteristics by analyzing the XTAL1/TOSC1 pin voltage. Be aware that a probe connected to the XTAL1/TOSC1 leads to added parasitic capacitance, which must be accounted for.

The loop gain is negatively affected by temperature and positively by voltage (V_{DD}). That means that the drive characteristics must be measured at the highest temperature and lowest V_{DD}, and the lowest temperature and highest V_{DD} at which the application is specified to operate.

Select a crystal with lower ESR or capacitive load if the loop gain is too low. If the loop gain is too high, a series resistor, R_S, may be added to the circuit to attenuate the output signal. The figure below shows an example of a simplified crystal driver circuit with an added series resistor (R_S) at the output of the XTAL2/TOSC2 pin.

Figure 1-8. Crystal Driver with Added Series Resistor



2. PCB Layout and Design Considerations

Even the best performing oscillator circuits and high-quality crystals will not perform well if not carefully considering the layout and materials used during assembly. Ultra-low power 32.768 kHz oscillators typically dissipate significantly below 1 µW, so the current flowing in the circuit is extremely small. In addition, the crystal frequency is highly dependent on the capacitive load.

To ensure the robustness of the oscillator, these guidelines are recommended during PCB layout:

- Signal lines from XTAL1/TOSC1 and XTAL2/TOSC2 to the crystal must be as short as possible to reduce parasitic capacitance and increase noise and crosstalk immunity. Do not use sockets.
- Shield the crystal and signal lines by surrounding it with a ground plane and guard ring
- Do not route digital lines, escpecially 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

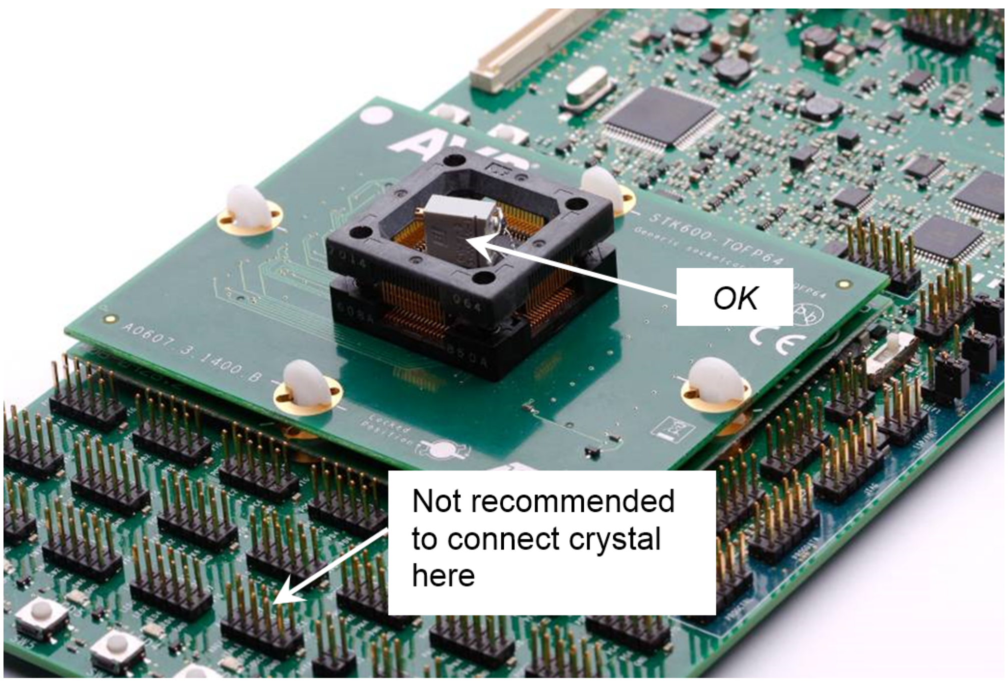
The AVR microcontroller's 32.768 kHz crystal oscillator driver is optimized for low power consumption, and thus the crystal driver strength is limited. Overloading the crystal driver may cause the oscillator not to start, or it may be affected (stopped temporarily, for example) due to a noise spike or increased capacitive load caused by the contamination or proximity of a hand.

Take care when selecting and testing the crystal to ensure proper robustness in your application. The crystal's two most important parameters are Equivalent Series Resistance (ESR) and Load Capacitance (C_L).

When measuring crystals, the crystal must be placed as close as possible to the 32.768 kHz oscillator pins to reduce parasitic capacitance. In general, we always recommend doing the measurement in your final application. A custom PCB prototype containing at least the microcontroller and crystal circuit may also provide accurate test results. For initial testing of the crystal, using a development or starter kit (e.g., STK600) may suffice.

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 thus 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 the 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. STK600 Test Setup



As a capacitive load will have a significant effect on the oscillator, you must 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 thus 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 together with this application note. Unlike the XTAL/TOSC input pins, I/O pins configured as buffered outputs can be probed with standard 10X oscilloscope probes without affecting the measurements. More details can be found in Section 4, *Test Firmware*.

Figure 3-2. Crystal Soldered Directly to Bent XTAL/TOSC Leads

Figure 3-3. Crystal Soldered in STK600 Socket

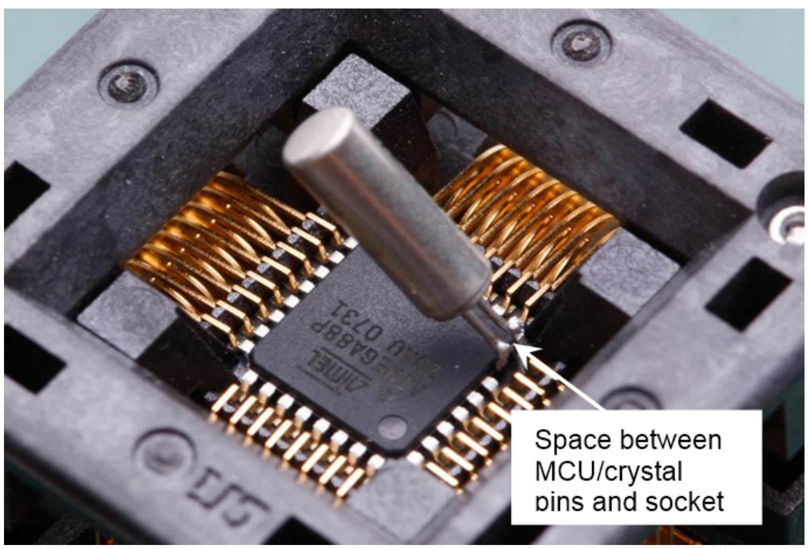


Figure 3-4. SMD Crystal Soldered Directly to MCU Using Pin Extensions

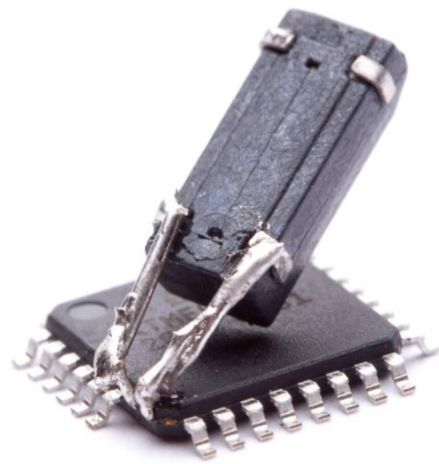
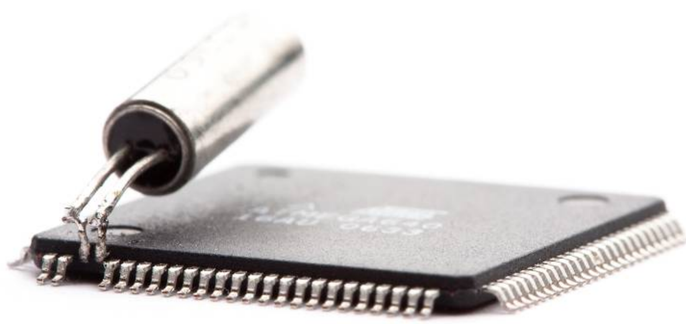


Figure 3-5. Crystal Soldered to 100-Pin TQFP Package with Narrow Pin Pitch



3.2 Negative Resistance Test and Safety Factor

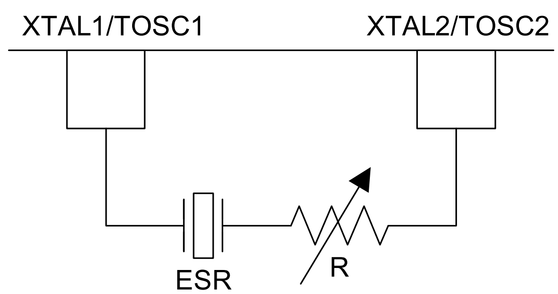
The negative resistance test finds the margin between the crystal amplifier load used in your application and the maximum load. At max load, the amplifier will choke, and the oscillations will stop. This point is called the oscillator allowance (OA). Find the oscillator allowance by temporarily adding a variable series resistor between the amplifier output (XTAL2/TOSC2) lead and the crystal, as shown in Figure 3-6. Increase the series resistor until the crystal stops oscillating. The oscillator allowance will then be the sum of this series resistance, R_{MAX}, and the ESR. Using a potentiometer with a range of at least $ESR < R_{POT} < 5\ ESR$ is recommended.

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. A power cycling must be performed 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



Using a high-quality potentiometer with low parasitic capacitance is recommended (e.g., an SMD potentiometer suitable for RF) to yield the most accurate results. However, if you can achieve good oscillator allowance/R_{MAX} with a cheap potentiometer, you will be safe.

When finding the maximum series resistance, you can find the safety factor from Equation 3-2. Various MCU and crystal vendors operate with different safety factor recommendations. The safety factor adds a margin for any negative effects of the different variables such as oscillator amplifier gain, change due to the power supply and temperature variations, process variations, and load capacitance. The 32.768 kHz oscillator amplifier on AVR microcontrollers is temperature and power compensated. 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 are listed 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

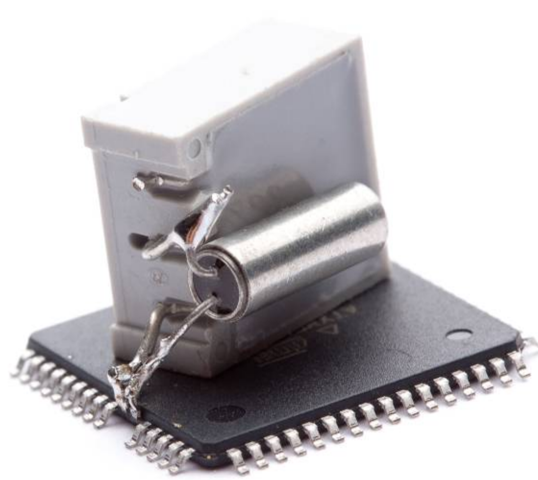


Figure 3-8. Allowance Test in Socket

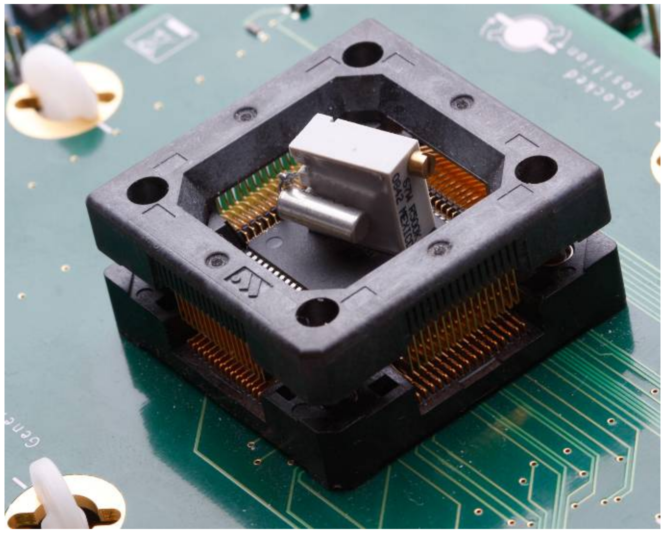


Table 3-1. Safety Factor Recommendations

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 32.768 kHz. 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.

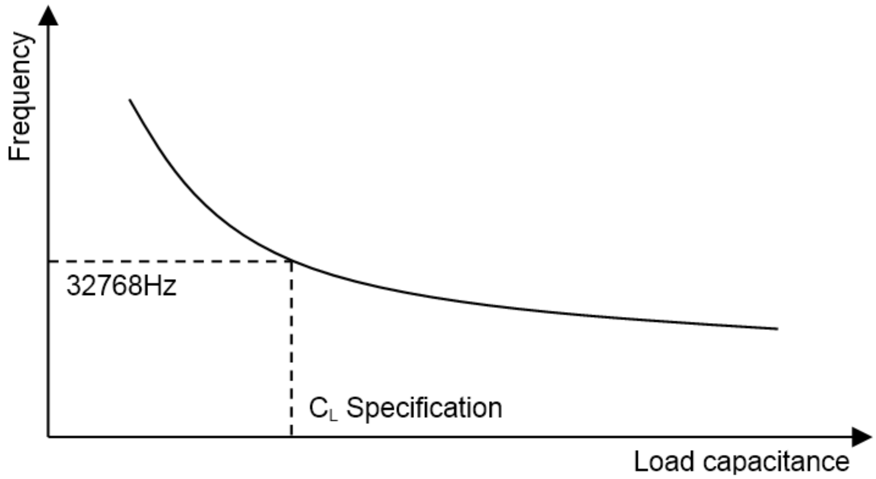
The frequency pull-ability or bandwidth, that is, how far from the nominal frequency the resonant frequency can be forced by applying load, depends on the Q-factor of the resonator. The bandwidth is given by the nominal frequency divided by the Q-factor, and for high-Q quartz crystals, the usable bandwidth is 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 32.768 kHz. If the measured frequency is close to 32.768 kHz, the effective load capacitance will be close to the specification. Do this by 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. See Section 4, *Test Firmware*, for more details.

Figure 3-9. Frequency vs. Load Capacitance



Equation 3-4 gives the total load capacitance without external capacitors. In most cases, external capacitors (C_{EL1} and C_{EL2}) must be added to match the capacitive load specified in the crystal's data sheet. If using external capacitors, Equation 3-5 gives the total capacitive load.

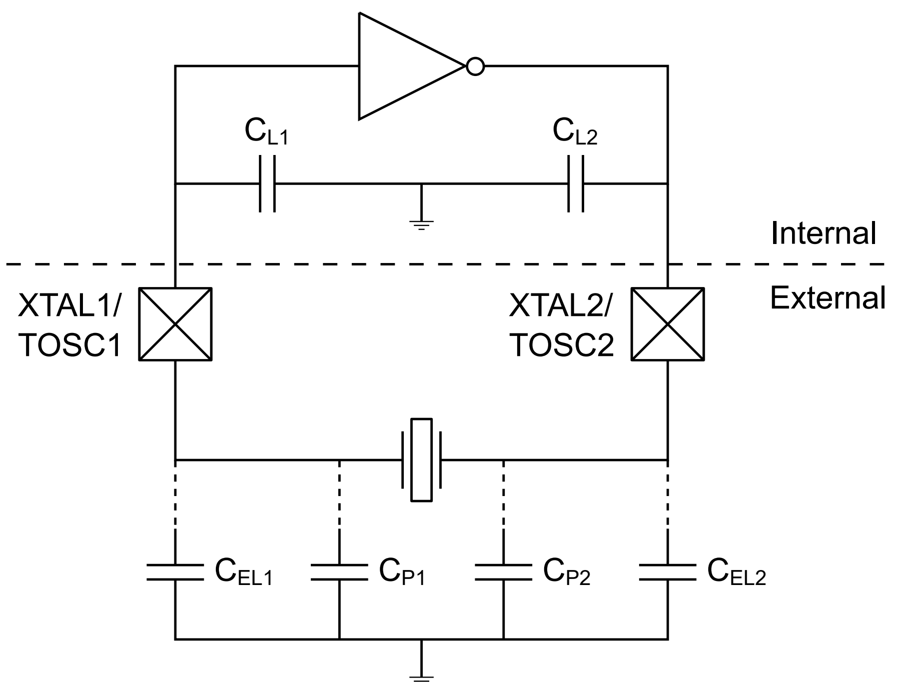
Equation 3-4. Total Capacitive Load without External Capacitors

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

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. Do not measure the crystal electrodes 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 pin differs on the different devices. The correct pins are listed below.

- ATmega128: The clock signal is output to PB4, and its frequency is divided by 2. The expected output frequency is 16.384 kHz.
- ATmega328P: The clock signal is output to PD6, and its frequency is divided by 2. The expected output frequency is 16.384 kHz.
- ATtiny817: The clock signal is output to PB5, and its frequency is not divided. The expected output frequency is 32.768 kHz.
- ATtiny85: The clock signal is output to PB1, and its frequency is divided by 2. The expected output frequency is 16.384 kHz.
- ATxmega128A1: The clock signal is output to PC7, and its frequency is not divided. The expected output frequency is 32.768 kHz.
- ATxmega256A3B: The clock signal is output to PC7, and its frequency is not divided. The expected output frequency is 32.768 kHz.
- PIC18F25Q10: The clock signal is output to RA6, and its frequency is divided by 4. The expected output frequency is 8.192 kHz.

Important: The PIC18F25Q10 was used as a representative of an AVR Dx series device when testing crystals. It uses the OSC_LP_v10 oscillator module, which is the same as used by the AVR Dx series.

5. Crystal Recommendations

Table 5-2 shows a selection of crystals that have been tested and found suitable for various AVR microcontrollers.

Important: Since many microcontrollers share oscillator modules, only a selection of representative microcontroller products have been tested by crystal vendors. See the files distributed with the application note to see the original crystal test reports. See section 6. Oscillator Module Overview for an overview of which microcontroller product uses which oscillator module.

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 Section 3, *Testing Crystal Oscillation Robustness*, to ensure that no issues have been introduced during layout, soldering, etc.

Table 5-1 shows a list of the different oscillator modules. Section 6, *Oscillator Module Overview*, has a list of devices where these modules are included.

Table 5-1. Overview of Oscillators in AVR® Devices

#	Oscillator Module	Description
1	X32K_2v7	2.7-5.5V oscillator used in megaAVR® devices[(1)]
2	X32K_1v8	1.8-5.5V oscillator used in megaAVR/tinyAVR® devices[(1)]
3	X32K_1v8_ULP	1.8-3.6V ultra-low power oscillator used in megaAVR/tinyAVR picoPower® devices
4	X32K_XMEGA (normal mode)	1.6-3.6V ultra-low power oscillator used in XMEGA® devices. Oscillator configured to normal mode.
5	X32K_XMEGA (low-power mode)	1.6-3.6V ultra-low power oscillator used in XMEGA devices. Oscillator configured to 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 0-, 1- and 2-series and megaAVR 0-series devices
8	OSC_LP_v10 (normal mode)	1.8-5.5V ultra-low power oscillator used in AVR Dx series devices. Oscillator configured to normal mode.
9	OSC_LP_v10 (low-power mode)	1.8-5.5V ultra-low power oscillator used in AVR Dx series devices. Oscillator configured to low-power mode.

Note:

1. Not used with the megaAVR® 0-series or tinyAVR® 0-, 1- and 2-series.

Table 5-2. Recommended 32.768 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	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

...........continued						
Vendor	**Type**	**Mount**	**Oscillator Modules Tested and Approved (See Table 5-1)**	**Frequency Tolerance [±ppm]**	**Load Capacitance [pF]**	**Equivalent Series Resistance (ESR) [kΩ]**
Cardinal	CTF6	TH	2, 3, 4, 5	20	12.5	50
Cardinal	CTF8	TH	2, 3, 4, 5	20	12.5	50
Endrich Citizen	CFS206	TH	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	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, 4	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
NDK	NX1610SE	SMD	1, 2, 4, 5, 6, 7, 8, 9	20	6	50
NDK	NX2012SE	SMD	1, 2, 4, 5, 6, 8, 9	20	6	50
Seiko Instruments	SSP-T7-FL	SMD	2, 3, 5	20	4.4/6/12.5	65
Seiko Instruments	SSP-T7-F	SMD	1, 2, 4, 6, 7, 8, 9	20	7/12.5	65
Seiko Instruments	SC-32S	SMD	1, 2, 4, 6, 7, 8, 9	20	7	70
Seiko Instruments	SC-32L	SMD	4	20	7	40
Seiko Instruments	SC-20S	SMD	1, 2, 4, 6, 7, 8, 9	20	7	70
Seiko Instruments	SC-12S	SMD	1, 2, 6, 7, 8, 9	20	7	90

Note:

1. Crystals may be available with multiple load capacitance and frequency tolerance options. Contact the crystal vendor for more information.

6. Oscillator Module Overview

This section shows a list of which 32.768 kHz oscillators are included in various Microchip megaAVR, tinyAVR, Dx, and XMEGA® devices.

6.1 megaAVR® Devices

Table 6-1. megaAVR® Devices

Device	Oscillator Module
ATmega1280	X32K_1v8
ATmega1281	X32K_1v8
ATmega1284P	X32K_1v8_ULP
ATmega128A	X32K_2v7
ATmega128	X32K_2v7
ATmega1608	X32K_1v8_5v5_ULP
ATmega1609	X32K_1v8_5v5_ULP
ATmega162	X32K_1v8
ATmega164A	X32K_1v8_ULP
ATmega164PA	X32K_1v8_ULP
ATmega164P	X32K_1v8_ULP
ATmega165A	X32K_1v8_ULP
ATmega165PA	X32K_1v8_ULP
ATmega165P	X32K_1v8_ULP
ATmega168A	X32K_1v8_ULP
ATmega168PA	X32K_1v8_ULP
ATmega168PB	X32K_1v8_ULP
ATmega168P	X32K_1v8_ULP
ATmega168	X32K_1v8
ATmega169A	X32K_1v8_ULP
ATmega169PA	X32K_1v8_ULP
ATmega169P	X32K_1v8_ULP
ATmega169	X32K_1v8
ATmega16A	X32K_2v7
ATmega16	X32K_2v7

...........continued

Device	Oscillator Module
ATmega2560	X32K_1v8
ATmega2561	X32K_1v8
ATmega3208	X32K_1v8_5v5_ULP
ATmega3209	X32K_1v8_5v5_ULP
ATmega324A	X32K_1v8_ULP
ATmega324PA	X32K_1v8_ULP
ATmega324PB	X32K_1v8_ULP
ATmega324P	X32K_1v8_ULP
ATmega3250A	X32K_1v8_ULP
ATmega3250PA	X32K_1v8_ULP
ATmega3250P	X32K_1v8_ULP
ATmega325A	X32K_1v8_ULP
ATmega325PA	X32K_1v8_ULP
ATmega325P	X32K_1v8_ULP
ATmega328PB	X32K_1v8_ULP
ATmega328P	X32K_1v8_ULP
ATmega328	X32K_1v8
ATmega3290A	X32K_1v8_ULP
ATmega3290PA	X32K_1v8_ULP
ATmega3290P	X32K_1v8_ULP
ATmega329A	X32K_1v8_ULP
ATmega329PA	X32K_1v8_ULP
ATmega329P	X32K_1v8_ULP
ATmega329	X32K_1v8
ATmega32A	X32K_2v7
ATmega32	X32K_2v7
ATmega406	X32K_1v8_5v5_ULP
ATmega4808	X32K_1v8_5v5_ULP
ATmega4809	X32K_1v8_5v5_ULP
ATmega48A	X32K_1v8_ULP
ATmega48PA	X32K_1v8_ULP

...........continued

Device	Oscillator Module
ATmega48PB	X32K_1v8_ULP
ATmega48P	X32K_1v8_ULP
ATmega48	X32K_1v8
ATmega640	X32K_1v8
ATmega644A	X32K_1v8_ULP
ATmega644PA	X32K_1v8_ULP
ATmega644P	X32K_1v8_ULP
ATmega6450A	X32K_1v8_ULP
ATmega6450P	X32K_1v8_ULP
ATmega645A	X32K_1v8_ULP
ATmega645P	X32K_1v8_ULP
ATmega6490A	X32K_1v8_ULP
ATmega6490P	X32K_1v8_ULP
ATmega6490	X32K_1v8_ULP
ATmega649A	X32K_1v8_ULP
ATmega649P	X32K_1v8_ULP
ATmega649	X32K_1v8
ATmega64A	X32K_2v7
ATmega64	X32K_2v7
ATmega808	X32K_1v8_5v5_ULP
ATmega809	X32K_1v8_5v5_ULP
ATmega88A	X32K_1v8_ULP
ATmega88PA	X32K_1v8_ULP
ATmega88PB	X32K_1v8_ULP
ATmega88P	X32K_1v8_ULP
ATmega88	X32K_1v8
ATmega8A	X32K_2v7
ATmega8	X32K_2v7

6.2 tinyAVR® Devices

Table 6-2. tinyAVR® Devices

Device	Oscillator Module
ATtiny1604	X32K_1v8_5v5_ULP
ATtiny1606	X32K_1v8_5v5_ULP
ATtiny1607	X32K_1v8_5v5_ULP
ATtiny1614	X32K_1v8_5v5_ULP
ATtiny1616	X32K_1v8_5v5_ULP
ATtiny1617	X32K_1v8_5v5_ULP
ATtiny1624	X32K_1v8_5v5_ULP
ATtiny1626	X32K_1v8_5v5_ULP
ATtiny1627	X32K_1v8_5v5_ULP
ATtiny202	X32K_1v8_5v5_ULP
ATtiny204	X32K_1v8_5v5_ULP
ATtiny212	X32K_1v8_5v5_ULP
ATtiny214	X32K_1v8_5v5_ULP
ATtiny2313A	X32K_1v8
ATtiny24A	X32K_1v8
ATtiny24	X32K_1v8
ATtiny25	X32K_1v8
ATtiny261A	X32K_1v8
ATtiny261	X32K_1v8
ATtiny3216	X32K_1v8_5v5_ULP
ATtiny3217	X32K_1v8_5v5_ULP
ATtiny3224	X32K_1v8_5v5_ULP
ATtiny3226	X32K_1v8_5v5_ULP
ATtiny3227	X32K_1v8_5v5_ULP
ATtiny402	X32K_1v8_5v5_ULP
ATtiny404	X32K_1v8_5v5_ULP
ATtiny406	X32K_1v8_5v5_ULP
ATtiny412	X32K_1v8_5v5_ULP
ATtiny414	X32K_1v8_5v5_ULP

...........continued

Device	Oscillator Module
ATtiny416	X32K_1v8_5v5_ULP
ATtiny417	X32K_1v8_5v5_ULP
ATtiny424	X32K_1v8_5v5_ULP
ATtiny426	X32K_1v8_5v5_ULP
ATtiny427	X32K_1v8_5v5_ULP
ATtiny4313	X32K_1v8
ATtiny44A	X32K_1v8
ATtiny44	X32K_1v8
ATtiny45	X32K_1v8
ATtiny461A	X32K_1v8
ATtiny461	X32K_1v8
ATtiny804	X32K_1v8_5v5_ULP
ATtiny806	X32K_1v8_5v5_ULP
ATtiny807	X32K_1v8_5v5_ULP
ATtiny814	X32K_1v8_5v5_ULP
ATtiny816	X32K_1v8_5v5_ULP
ATtiny817	X32K_1v8_5v5_ULP
ATtiny824	X32K_1v8_5v5_ULP
ATtiny826	X32K_1v8_5v5_ULP
ATtiny827	X32K_1v8_5v5_ULP
ATtiny84A	X32K_1v8
ATtiny84	X32K_1v8
ATtiny85	X32K_1v8
ATtiny861A	X32K_1v8
ATtiny861	X32K_1v8

6.3 AVR® Dx Devices

Table 6-3. AVR® Dx Devices

Device	Oscillator Module
AVR128DA28	OSC_LP_v10
AVR128DA32	OSC_LP_v10

...........continued

Device	Oscillator Module
AVR128DA48	OSC_LP_v10
AVR128DA64	OSC_LP_v10
AVR32DA28	OSC_LP_v10
AVR32DA32	OSC_LP_v10
AVR32DA48	OSC_LP_v10
AVR64DA28	OSC_LP_v10
AVR64DA32	OSC_LP_v10
AVR64DA48	OSC_LP_v10
AVR64DA64	OSC_LP_v10
AVR128DB28	OSC_LP_v10
AVR128DB32	OSC_LP_v10
AVR128DB48	OSC_LP_v10
AVR128DB64	OSC_LP_v10
AVR32DB28	OSC_LP_v10
AVR32DB32	OSC_LP_v10
AVR32DB48	OSC_LP_v10
AVR64DB28	OSC_LP_v10
AVR64DB32	OSC_LP_v10
AVR64DB48	OSC_LP_v10
AVR64DB64	OSC_LP_v10
AVR128DD28	OSC_LP_v10
AVR128DD32	OSC_LP_v10
AVR128DD48	OSC_LP_v10
AVR128DD64	OSC_LP_v10
AVR32DD28	OSC_LP_v10
AVR32DD32	OSC_LP_v10
AVR32DD48	OSC_LP_v10
AVR64DD28	OSC_LP_v10
AVR64DD32	OSC_LP_v10
AVR64DD48	OSC_LP_v10
AVR64DD64	OSC_LP_v10

6.4 AVR® XMEGA® Devices

Table 6-4. AVR® XMEGA® Devices

Device	Oscillator Module
ATxmega128A1	X32K_XMEGA
ATxmega128A3	X32K_XMEGA
ATxmega128A4	X32K_XMEGA
ATxmega128B1	X32K_XMEGA
ATxmega128B3	X32K_XMEGA
ATxmega128D3	X32K_XMEGA
ATxmega128D4	X32K_XMEGA
ATxmega16A4	X32K_XMEGA
ATxmega16D4	X32K_XMEGA
ATxmega192A1	X32K_XMEGA
ATxmega192A3	X32K_XMEGA
ATxmega192D3	X32K_XMEGA
ATxmega256A3B	X32K_XRTC32
ATxmega256A1	X32K_XMEGA
ATxmega256D3	X32K_XMEGA
ATxmega32A4	X32K_XMEGA
ATxmega32D4	X32K_XMEGA
ATxmega64A1	X32K_XMEGA
ATxmega64A3	X32K_XMEGA
ATxmega64A4	X32K_XMEGA
ATxmega64B1	X32K_XMEGA
ATxmega64B3	X32K_XMEGA
ATxmega64D3	X32K_XMEGA
ATxmega64D4	X32K_XMEGA

7. Revision History

Doc. Rev.	Date	Comments
D	05/2022	1. Added the section 1.8. Drive Strength. 2. Updated the section 5. Crystal Recommendations with new crystals.
C	09/2021	1. General review of the application note text. 2. Corrected Equation 1-5. 3. Updated section 5. Crystal Recommendations with new AVR devices and crystals.
B	09/2018	1. Corrected Table 5-1. 2. Corrected cross references.
A	02/2018	1. Converted to Microchip format and replaced the Atmel document number 8333. 2. Added support for tinyAVR 0- and 1-series.
8333E	03/2015	1. Changed XMEGA clock output from PD7 to PC7. 2. XMEGA B added.
8333D	072011	Recommendation list updated.
8333C	02/2011	Recommendation list updated.
8333B	11/2010	Several updates and corrections.
8333A	08/2010	Initial document revision.

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