AVR4100: Selecting and testing 32kHz crystal oscillators for Atmel AVR microcontrollers

Features

- **Crystal oscillator basics**
- **PCB design considerations**
- **Testing crystal robustness**
- **Test firmware included**
- **Crystal recommendation guide**

1 Introduction

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 Atmel® AVR® families. Test firmware and test reports from various crystal vendors are included.

8-bit Atmel Microcontrollers

Application Note

Rev. Atmel-8333E-AVR-03/2015

2 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 chapters 2 and 3, and start reading chapter 4.

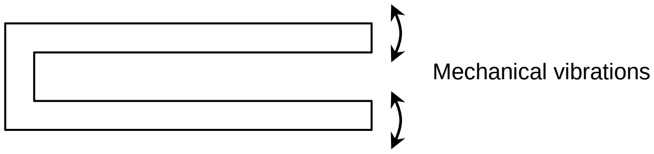
2.1 Introduction

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 are 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 quartz crystal, but ceramic resonators are also used – usually in low-cost or less timing critical applications. 32kHz (32768Hz) crystals are usually cut in the shape of a tuning fork, and very precise frequencies can be established.

Figure 2-1. Shape of a 32kHz tuning fork crystal.



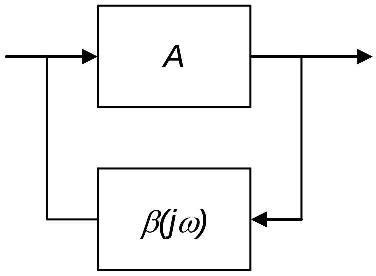
2.2 The oscillator

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 $\beta(j\omega)$ is the transfer function of the feedback path, the circuit will sustain steady-state oscillations only at frequencies for which:

1. The loop gain is equal to unity in absolute magnitude, $|\beta A| = 1$
2. 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 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 cancelled due to the feedback loop.

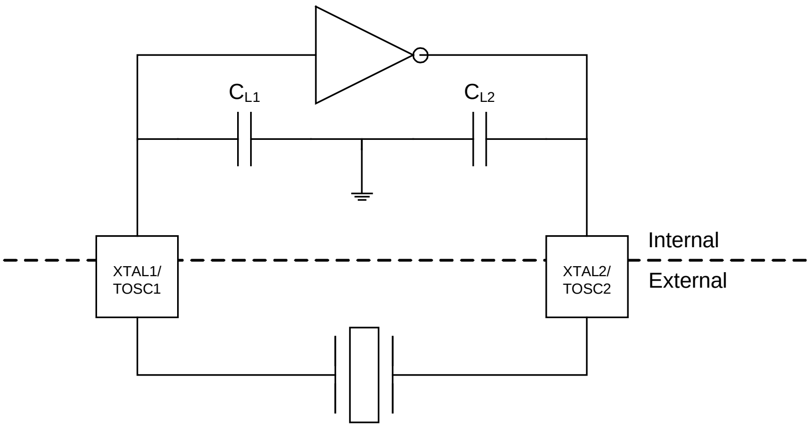
Figure 2-2. Feedback loop.



The 32kHz oscillator in Atmel® AVR® microcontrollers is shown in Figure 2-3, and consists of an inverting amplifier (internal) and a crystal (external). Most AVR microcontrollers have internal capacitive load (C_{L1} and C_{L2}), so external capacitors are usually not needed. In some cases, however, 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 datasheet of your AVR device.

The inverting amplifier will give a π radian (180 degree) phase shift, and the remaining π radian phase shift will be provided by the crystal and the capacitive load at 32768Hz, causing a total phase shift of 2π radian. During startup, 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.

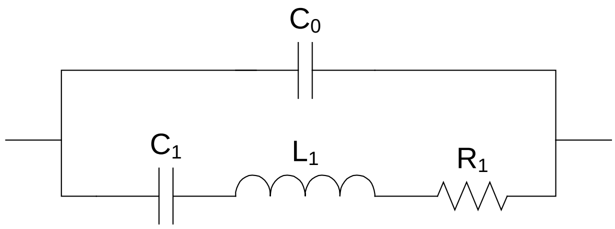
Figure 2-3. Pierce crystal oscillator circuit in AVR devices (simplified).



2.3 Electrical model

The equivalent electric circuit of a crystal is shown in Figure 2-4. 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 2-4. 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 2-5.

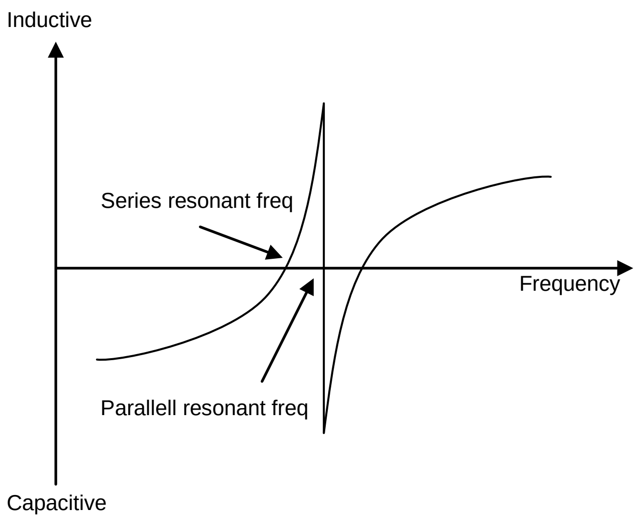
Equation 2-1. Series resonant frequency.

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

Equation 2-2. Parallel resonant frequency.

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

Figure 2-5. Crystal reactance characteristics.



Crystals below 30MHz 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 30MHz are usually operated at the series resonant frequency or overtone frequencies, which occur at multiples of the fundamental frequency. Adding a capacitive load, C_L, to the crystal will cause a shift in frequency given by Equation 2-3. The crystal frequency can be tuned by varying the load capacitance, and this is called frequency pulling.

Equation 2-3. Parallel resonant frequency.

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

2.4 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 datasheet. The ESR will usually be dependent of 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 an ESR may cause unstable oscillator operation. Unity gain will not be achieved, and the Barkhausen criterion will not be fulfilled.

2.5 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 a LC oscillator. Ceramic resonators have lower Q than quartz crystals, and are more sensitive to capacitive load (pull ability is higher).

Equation 2-4. Q-factor.

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

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 datasheets.

2.6 Start-up time

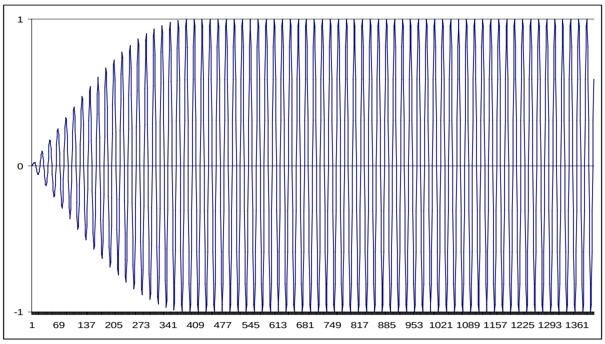
During startup, noise will be amplified in the inverting amplifier. The crystal will act as a band pass filter, and feed back only the crystal resonance frequency component, which will be amplified. Before steady state oscillation is achieved, the loop gain of the crystal/inverting amplifier loop is 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 startup time:

- High-ESR crystal 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 startup time
- Oscillator amplifier drive capabilities (see more details on oscillator allowance in Section 4.2)

In addition, crystal frequency will affect the startup time (faster crystals will start faster), but this parameter is fixed for 32kHz crystals

Figure 2-6. Startup signal of a crystal oscillator.



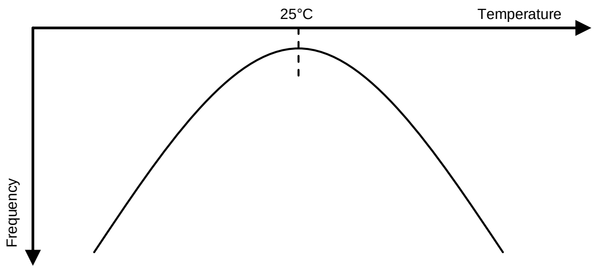
2.7 Temperature tolerance

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 2-7. The frequency shift is given by Equation 2-5, where f_0 is the target frequency at T_0 (typically 32768Hz at 25°C) and the PPM is the temperature tolerance coefficient given by the crystal datasheet.

Equation 2-5. Effect of temperature variation.

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

Figure 2-7. Typical temperature vs. frequency characteristics of a crystal.



3 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 32kHz oscillators typically dissipate significantly below 1µW, 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 multi-layer PCB boards, avoid routing signals below the crystal lines.
- PCB cleaning is recommended to reduce flux residues from soldering.
- Use high-quality PCB and soldering materials.
- Dust and humidity will increase parasitic capacitance and reduce signal isolation, so protective coating is recommended.

4 Testing crystal oscillation robustness

4.1 Introduction

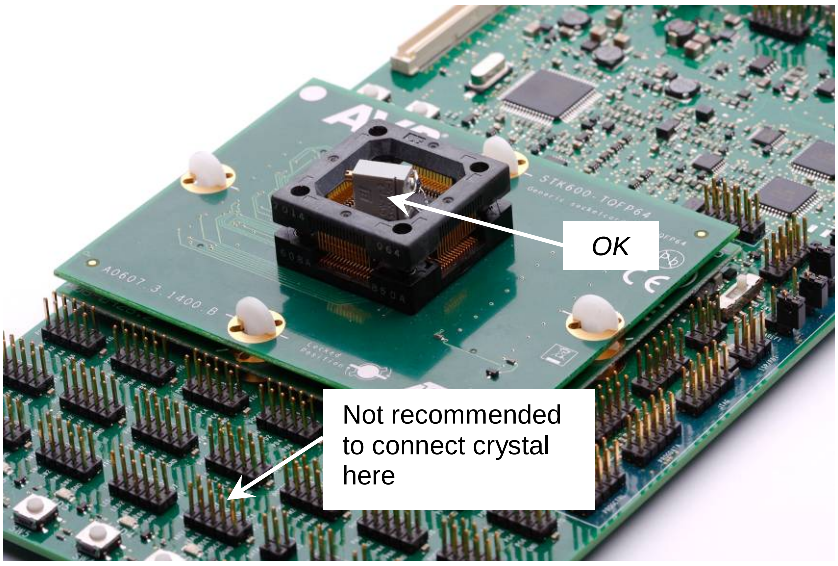
The 32kHz crystal oscillator driver of AVR microcontrollers is optimized for very low power consumption, and thus the crystal driver strength is limited. Overloading the crystal driver may cause the oscillator to not start, or it may be affected (stopped temporarily) e.g. due to a noise spike or increased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

This means that care should 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 (C_L).

When doing measurements on crystals, the crystal should be placed as close as possible to the 32kHz 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 4-1, because the signal path will be very sensitive to noise and 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 Figures 4-2 and 4-3, 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 4-4. Soldering crystals to packages with narrow pin pitch is also possible, as shown in Figure 4-5, but is a bit trickier and requires a steady hand.

Figure 4-1. 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 10-15pF, and will have 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 5.

Figure 4-2. Crystal soldered directly to bent XTAL/TOSC leads.

Figure 4-3. Ensure that XTAL/TOSC leads do not touch the socket.

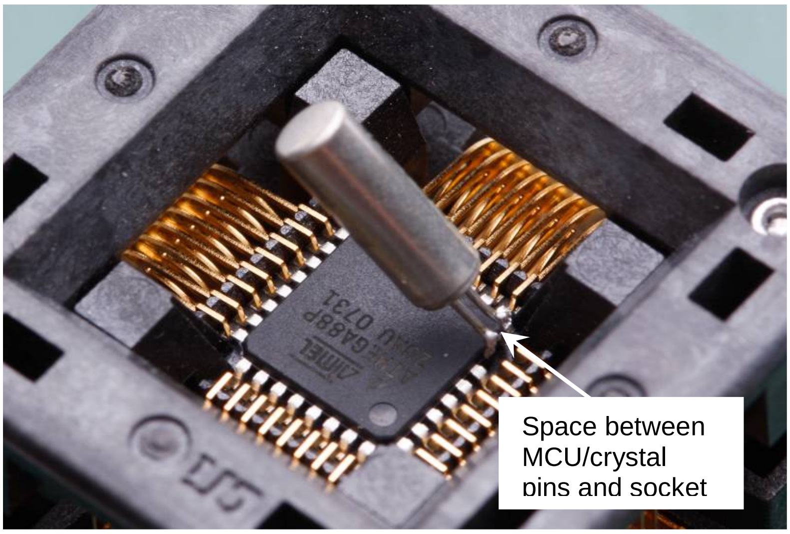


Figure 4-4. SMD crystal soldered directly to MCU by using pin extensions.

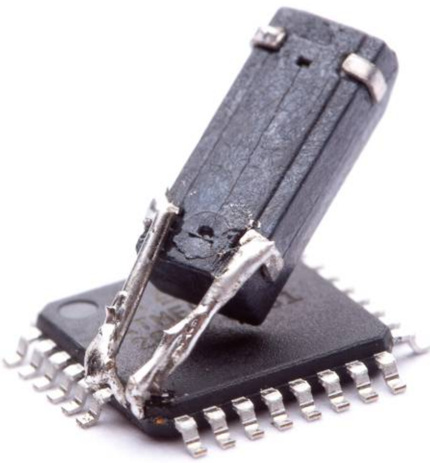
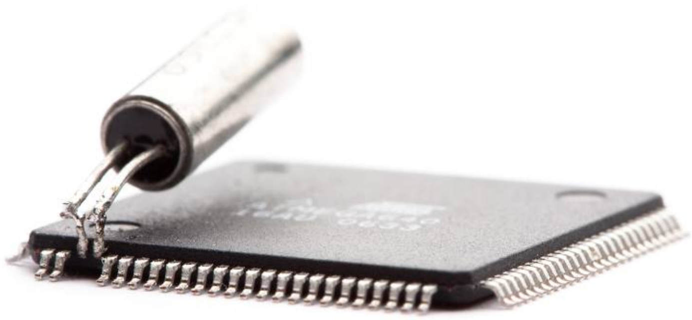


Figure 4-5. 100-pin TQFP package (e.g ATmega6490, ATmega2560, ATxmega128A1) with narrow pin pitch is also possible to use, but requires a steady hand when soldering.



4.2 Negative resistance test and safety factor

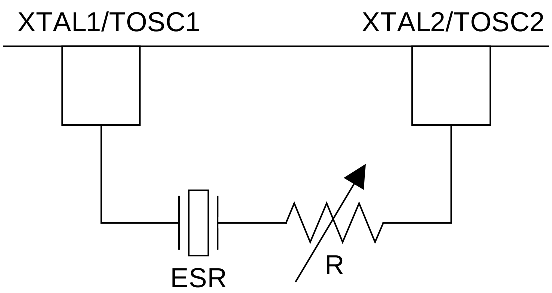
The negative resistance test finds the margin between the crystal amplifier load used in your application and the maximum load. At the maximum load, the amplifier will choke and the oscillations will stop. This point is called the oscillator allowance (OA). The oscillator allowance can be found by temporarily adding a variable series resistor between the amplifier output (XTAL2/TOSC2) lead and the crystal, as shown in Figure 4-6. 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 10-50kΩ 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 startup times will be quite long at the oscillator allowance point, so please be patient.

Equation 4-1. Oscillator allowance.

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

Figure 4-6. Measuring oscillator allowance/R_{MAX}



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/R_{MAX} with a cheap potentiometer, you will be safe.

When the maximum series resistance is found, you can find the safety factor from Equation 4-2. Various MCU and crystal vendors operate with different safety factor recommendations. The safety factor is intended to add margin for negative effects of different variables such as oscillator amplifier gain, change due to power supply and temperature variations, process variations, and load capacitance. The 32kHz 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 4-1.

Equation 4-2. Safety factor.

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

Figure 4-7. Series potentiometer between XTAL2/TOSC2 pin and crystal.

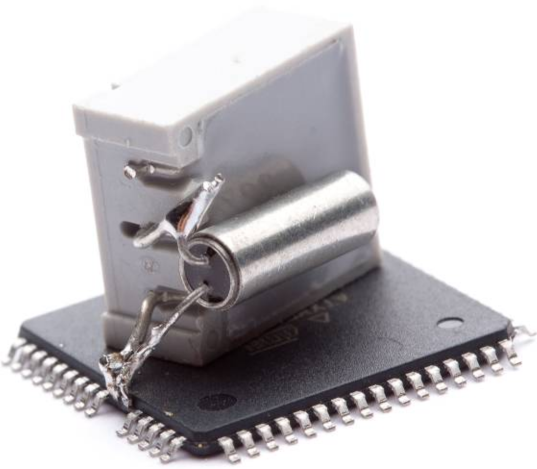


Figure 4-8. Allowance test in socket.

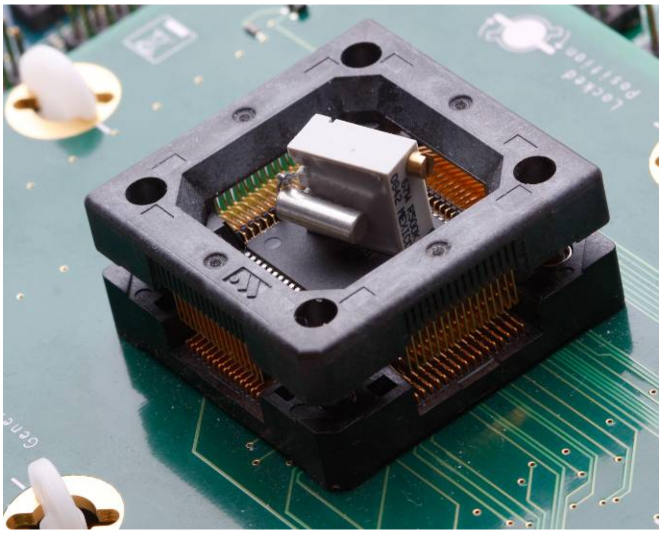


Table 4-1. Safety factor recommendations.

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

4.3 Measuring effective load capacitance

The crystal frequency is dependent on the capacitive load applied, as shown by Equation 2-3 in Section 2-3. Applying the capacitive load specified in the crystal datasheet will provide a frequency very close to the nominal frequency of 32768Hz. 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 4-9.

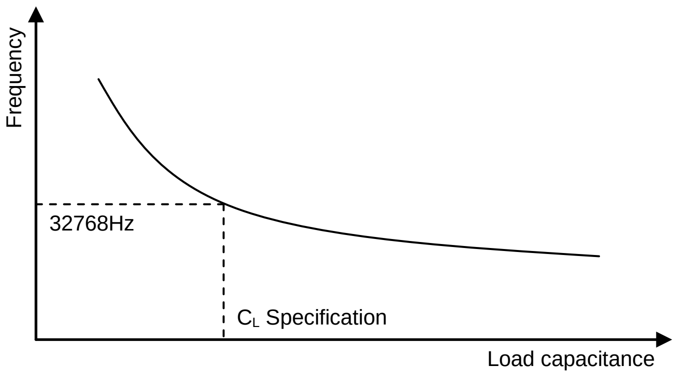
The frequency pullability or bandwidth—how far from the nominal frequency the resonant frequency can be forced by applying load—depends on the Q-factor of the resonator. The bandwidth is given by the nominal frequency divided by the Q-factor, and for high-Q quartz crystals, the usable bandwidth will 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 $\beta(j\omega)$ that will cause a higher loading of the amplifier *A* to achieve unity gain (see Figure 2-2).

Equation 4-3. Bandwidth.

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

A good way of measuring the effective load capacitance (sum of load capacitance and parasitic capacitance) is to measure the oscillator frequency and compare it to the nominal frequency of 32768Hz. If the measured frequency is close to 32768Hz, 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 5.

Figure 4-9. Frequency vs. load capacitance.



Without external capacitors, the total load capacitance will be given by Equation 4-4. In some cases, external capacitors (C_{EL1} and C_{EL2}) must be added to match the capacitive load specified in the crystal datasheet. If external capacitors are used, the total capacitive load will be given by Equation 4-5.

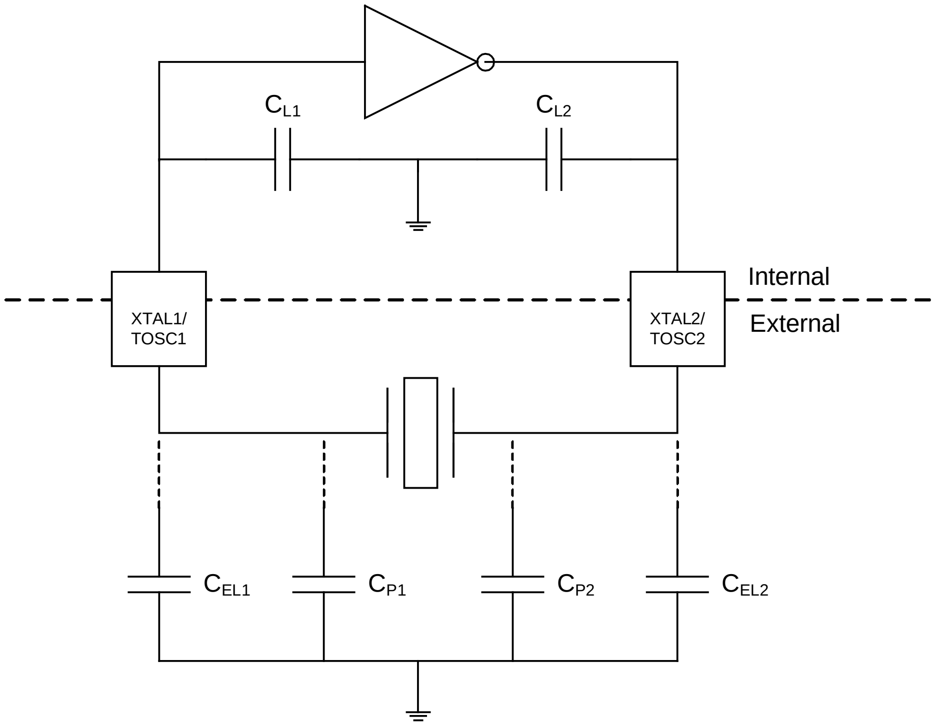
Equation 4-4. Total capacitive load without external capacitors.

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

Equation 4-5. Total capacitive load with external capacitors.

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

Figure 4-10. Crystal circuit with internal, parasitic and external capacitors.



5 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 (set the device define if required), and program the .hex file into the device.
- Apply Vcc within the operating range listed in the datasheet, 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 in the code to find which I/O pin will output the clock signal.

5.1 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 3276.8Hz). All Atmel® tinyAVR® devices are supported. To use a 32768Hz crystal as the clock source for the device, the low-frequency crystal oscillator must be selected by setting CKSEL fuses. Look in the datasheet for details.

5.2 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 16384Hz). All megaAVR® devices are supported, but a device family define needs to be set (see list of defines in the .c file).

5.3 XMEGA

The Atmel® 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.

5.4 UC3

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

6 Crystal recommendations

Table 6-2 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 4 to ensure that no issues have been introduced during layout, soldering, etc.

Please refer to the .zip file attached to this application note for test reports and crystal datasheets.

Table 6-1 shows a list of the different oscillator modules, and a list of devices where these modules are included can be found in Chapter 7.

Table 6-1. Overview of oscillators in AVR devices.

#	Oscillator module	Description
1	X32K_2v7	2.7-5.5V oscillator used in MegaAVR devices
2	X32K_1v8	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 pico power 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

Table 6-2. Recommended 32kHz crystals.

Vendor	Type	Mount	Oscillator modules tested and approved (see table 6-1)	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
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

Notes:

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

The table will be kept updated with more crystal vendors and recommendations for oscillator modules included in XMEGA and UC3 devices.

Are you representing a crystal vendor and not on the list? Please contact avr@atmel.com to participate in our crystal recommendation program.

7 Oscillator module overview

Table 7-1 shows a list of which 32kHz oscillators are included in various Atmel® MegaAVR®, Atmel® tinyAVR® and Atmel® XMEGA® devices. The list will be extended with UC3 devices in future releases.

Table 7-1. 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	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
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

Device Family	Device	Oscillator module
MegaAVR	ATmega32A	X32K_2v7
MegaAVR	ATmega48	X32K_1v8
MegaAVR	ATmega48A	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	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	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
TinyAVR	ATtiny84A	X32K_1v8
TinyAVR	ATtiny85	X32K_1v8
TinyAVR	ATtiny861	X32K_1v8
MegaAVR	ATmega48P	X32K_1v8_ULP

Device Family	Device	Oscillator module
MegaAVR	ATmega48PA	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
MegaAVR	ATmega88A	X32K_1v8_ULP
MegaAVR	ATmega88P	X32K_1v8_ULP
MegaAVR	ATmega88PA	X32K_1v8_ULP
MegaAVR	ATmega8A	X32K_2v7
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
XMEGA	ATxmega128A1	X32K_XMEGA
XMEGA	ATxmega128A3	X32K_XMEGA

Device Family	Device	Oscillator module
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
XMEGA	ATxmega256A3B	X32K_XRTC32

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