Reference Oscillator Crystal Requirements for MKW40 and MKW30 Device Series

1 Introduction

This document describes the reference oscillator crystal requirements for the Freescale 2.4 GHz Kinetis MKW40/30/20 MCU devices which integrate a Bluetooth® Low Energy and IEEE Std 802.15.4™ compliant modem. These devices contain an on-board reference oscillator that is designed for very low power consumption, and to meet tight frequency accuracy requirements. The Bluetooth Low Energy standard requires a maximum frequency drift of ±20 ppm. The IEEE Std 802.15.4 requires a frequency error of no greater than ±40 ppm. To ensure proper operation over temperature, limitations exist on the types of crystals that can be used.

MKW40/30/20 MCU devices requires an external 32 MHz crystal for the crystal oscillator operation. This document details the use of the reference oscillator and also provides specifications for the required crystal and the preferred crystal for the MKW40/30/20 MCUs.

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2   Reference oscillator crystal basics

The IEEE Std 802.15.4 requires that frequency tolerances for a wireless node must be kept within ±40 ppm accuracy. The Bluetooth Low Energy standard requires that the deviation of center frequency during packet should be less than 50 kHz (20.8 ppm). The following sections provide oscillator design and evaluation recommendations to obtain the required performance.

2.1   Basic oscillator

Figure 1 shows the 32 MHz reference oscillator for the MKW40 device families which is used here as a generic example for all the MKW40/30/20 MCUs. The oscillator is composed simply of the analog buffer amplifier, the crystal, and the capacitive loading. The buffer is an inverting amplifier, and when the circuit is in resonant oscillation, the crystal provides the additional 180° phase shift required for the oscillation (positive feedback).
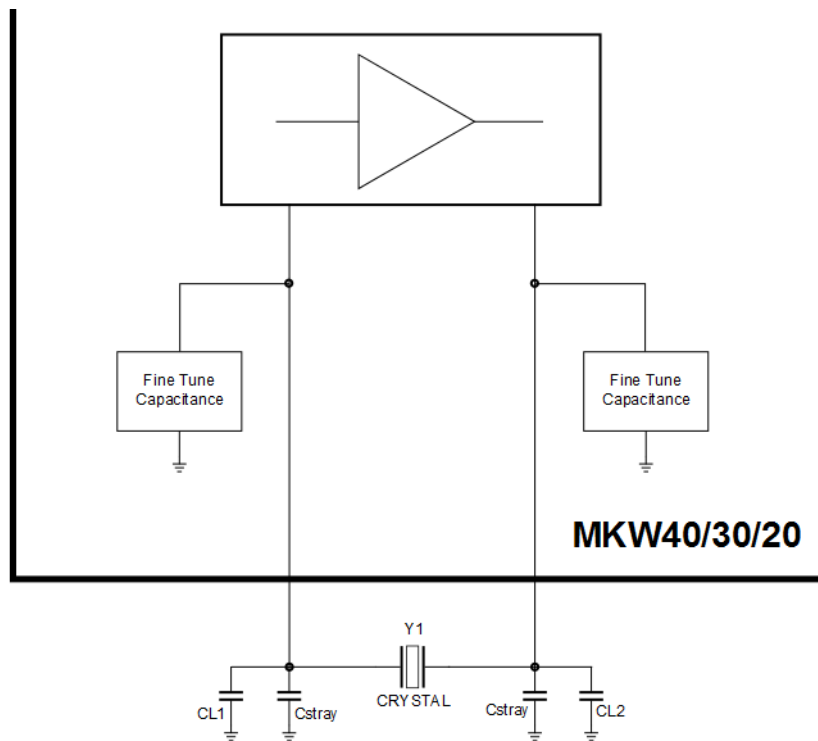

Figure 1. 32 MHz reference oscillator

The buffer output is fed back to the input through a resistor to DC bias the amplifier in the midrange of its analog swing. The resonant frequency of the crystal sets the frequency of operation. The resonant frequency of the crystal is set and specified at a particular capacitive loading.

The accuracy of the resonant frequency is dominated by:
*   Capacitive loading on the crystal
*   Temperature characteristics of the crystal

The sum or net capacitive load to the crystal can consist of three components:

- External discrete load capacitors—properly sized as determined by the crystal specification and other load components.
- Programmable onboard trim capacitors—to provide the user with the best possible accuracy, Freescale provides trimmable load capacitors on these devices.
- Stray capacitance—for these frequencies, the specified load capacitance is small, typically at 7-9 pF. With such a low desired load value, the stray capacitance due to the device pads and PCB traces impact the other load components.

2.2 Crystal considerations

The primary determining factor in meeting the IEEE Std 802.15.4 of ±40 ppm is the tolerance of the crystal oscillator reference frequency as set by the crystal. A number of factors can contribute to this tolerance, and a crystal specification quantifies each of them as follows:

1. The initial tolerance, also known as make or cut tolerance, of the crystal resonant frequency itself (at a specified load capacitance).
2. The variation of the crystal resonant frequency with temperature.
3. The variation of the crystal resonant frequency with time, also commonly known as aging.
4. The variation of the crystal resonant frequency with load capacitance, also commonly known as pulling. This is affected by:
   a) The external load capacitor (C_L) values—initial tolerance and variation with temperature.
   b) The internal trim capacitor (C_{trim}) values—initial tolerance and variation with temperature.
   c) Stray capacitance (C_{stray}) on the crystal pin nodes—including stray on-chip capacitance, stray package capacitance and stray board capacitance.

2.2.1 Crystal load capacitance

For any of the 2.4 GHz wireless devices, Freescale requires crystal load capacitance to be in the range of 5–9 pF. This low capacitance is required because these oscillators are designed for low-power and any larger capacitance can load the amplifiers more heavily.

The crystal manufacturer defines the load capacitance as that total external capacitance seen across the two terminals of the crystal. The oscillator amplifier configuration used here has two balanced load capacitances from each terminal of the crystal to ground. As such, the capacitance net loads for each pin are seen to be in series by the crystal, and the total load seen at each crystal terminal is the sum of the C_L, C_{trim}, and C_{stray}.

For the 32 MHz example, the external load capacitors are typically about 6.8 pF each, used in conjunction with a crystal that requires an 8–9 pF load capacitance. This value is used with the default internal nominal trim capacitor value (2.4 pF) and estimated stray capacitance value of 5–7 pF.

The value for the stray capacitance is determined empirically for a specific board layout. A different board layout may require different external load capacitor values. The on-chip trim capability may be used to determine the closest C_L standard value by adjusting the trim value and observing the frequency accuracy of the device.

Because of the trim capability, it is possible during manufacturing test, to trim out virtually all of the initial tolerance factors and put the frequency within less than 2–3 ppm on a board-by-board basis. Individual trimming of each board in a production environment may enable use of a lower cost crystal, but requires that each board go through a trimming procedure with added test cost. If the crystal is specified properly and the load capacitance is centered properly, production trimming is commonly not required.

A tolerance analysis budget may be created using all the previously stated factors. It is an engineering judgment whether the worst case tolerance assumes that all factors vary in the same direction, or if the various factors can be statistically rationalized using RSS (Root-Sum-Square) analysis. The aging factor is usually specified in ppm/year and the product designer can determine how many years are to be assumed for the product lifetime. The total budget must fit within the requirements of the Bluetooth Low Energy and the IEEE Std 802.15.4.

2.2.2 Crystal temperature variation

The make or cut frequency tolerance of a crystal is typically specified at 25°C (room temperature). The frequency of device (in the application) at room temperature should be set within the cut tolerance (typically ±10 ppm) or better. The oscillator frequency variation with temperature from this set point is dominated by the crystal characteristics. Frequency stability (temperature drift) is a specified parameter for the crystal over its temperature range. Figure 2 shows a curve of frequency tolerance versus temperature for a typical AT-cut crystal. In this example, the crystal could meet ±12 ppm maximum limit over a temperature range of -40°C to +85°C. A manufacturer can change the shape of this curve by varying the manufacturing of the crystal.
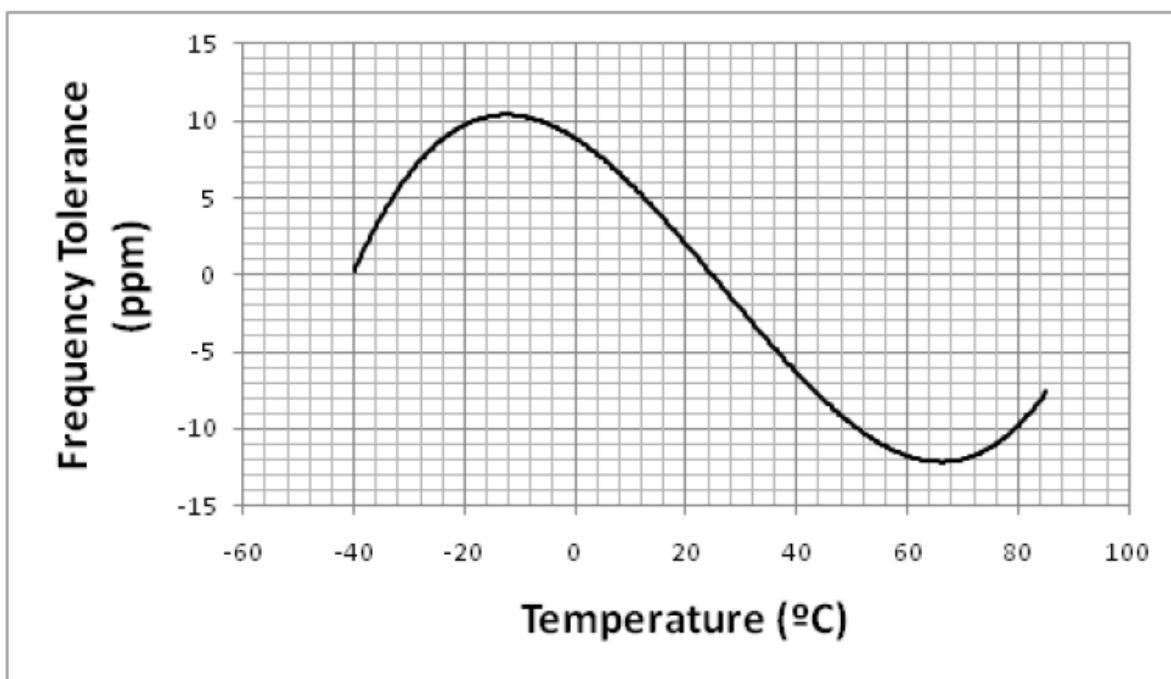

Figure 2. Typical AT-cut crystal frequency tolerance vs. temperature

2.2.3 Crystal equivalent series resistance (ESR)

Another crystal characteristic important to performance is its equivalent series resistance. ESR is the resistive component of the crystal impedance at resonance. ESR is expressed in ohms, and the lower this number is, the better the crystal. As ESR gets higher, the start and run load to the amplifier gets higher and can hinder oscillator start and run, especially at low temperatures.

2.2.4 Crystal specification

Table 1 provides the recommended crystal specifications. Freescale prefers to specify the crystal such that it is capable of maintaining a total frequency tolerance of ±30 ppm over the desired temperature range; this enables a margin of ±10 ppm for manufacturing variation, component tolerance, and aging.

In considering the table, critical parameters include:

- Desired frequency—specified to the Hz.
- Frequency tolerance at 25°C—this is maximum allowed for "cut" or manufacturing frequency variation.
  - This number may be larger than ±10 ppm for a more limited temperature range, if the frequency stability allows it.
  - This number may be larger if the user is willing to trim the center frequency at manufacturing final test.
- Frequency stability over the desired temperature range—this is the frequency drift of the crystal with temperature.
- Equivalent series resistance (ESR)—this a maximum series impedance for the crystal at resonance. Freescale recommends that this range from 40–60 Ù depending on the device.
- Load capacitance (C_L)—the number typically ranges from 5–9 pF.

Table 1. Recommended 16 MHz crystal specifications

Parameter	Value	Unit	Condition
Frequency	32	MHz	—
Frequency tolerance	±10	ppm	at 25°C
Frequency stability	±10	ppm	over desired temperature range
Aging	±5	ppm	maximum
Equivalent series resistance (ESR)	60	Ohm	maximum
Load capacitance	9	pF	maximum
Shunt capacitance	<1	pF	maximum
Mode of oscillation	—	—	fundamental

2.3 Design evaluation and optimization

Each design should initially be optimized and verified as different crystals, layouts, and printed circuit board characteristics can impact the frequency accuracy.

In evaluating a new layout and design, the first consideration is to center crystal loading such that the default load causes the oscillator frequency to be near its designed center frequency.

- External load capacitors, when present should be of equal value.
- The frequency accuracy of the reference oscillator must be observed to adjust the load and trim capacitance.

After a design has been characterized, it is good practice to verify the center frequency as part of the manufacturing final test. Unit-by-unit trimming is commonly not required if the design has been characterized properly. However, Freescale devices provide trim capability and it can be incorporated into the final test procedures.

3   Evaluated 32 MHz crystals

Freescale has evaluated crystals from several manufacturers that are available as standard part numbers for this application. provides this information.

Table 2. 32 MHz crystals

Manufacturer	Part Number	Package	Cut Tolerance (ppm)	Temperature Range	Comment
Nihon Dempa Kogyo (NDK)	NX3225SA-32MHz	3.2 x 2.5mm	±10	-20°C to 75°C	Type NX3225SA Spec No. EXS00A-CS07632
Nihon Dempa Kogyo (NDK)	NX2016SA-32MHz	2.0 x 1.6mm	±10	-20°C to 75°C	Type NX2016SA Spec No. EXS00A-CS07637

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