# Crystal oscillator issues for CC1000 and CC1010

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## Keywords

- *Crystal frequency*
- *Crystal tolerance*
- *Crystal temperature drift*
- *Drive level*
- *Start-up time*
- *Crystal aging*
- *Sensitivity vs. IF frequency*
- *Crystal loading*
- *Compensating for crystal frequency errors*

## Introduction

All Chipcon RF circuits use a PLL to generate the RF frequency. The reference frequency for the PLL is a crystal. If the reference frequency is incorrect, the RF frequency will also be incorrect. Due to the frequency multiplication in the PLL, the error will be multiplied and can degrade the performance of the RF link and/or can cause a radio regulation violation.

This application note covers some practical crystal oscillator issues when using Chipcon RF circuits. It will hopefully help the reader to choose the correct crystal (performance, cost) for the application.

The application note will also cover possible ways of compensating for crystal frequency errors and look at the effect of frequency errors for the RF link.

An Excel spread sheet was made for the calculations:
"AN_019_crystal_tolerance_calculator_1_0.xls"
The file can be downloaded from
www.chipcon.com

The application note 11, "Programming the CC1000 frequency for best sensitivity", also includes useful information about crystals – this also applies to the CC1010.

Chipcon is a supplier of RFICs for all kinds of short-range communication devices. Chipcon has a worldwide distribution network.

## Chipcon's crystal oscillator technology

All Chipcon RF ICs have an advanced amplitude regulated crystal oscillator. It works as follows: A relatively high current is used to start up the oscillations. When the amplitude builds up, the current is reduced to a level sufficient to maintain a 600 mVpp amplitude. This ensures a fast start-up and keeps the current consumption to a minimum. This scheme also makes the oscillator rather insensitive to ESR variations and ensures a minimum drive level. Please follow the crystal capacitance loading recommendations given in the datasheet.

## Crystal oscillator specifications

All crystal manufacturers specify their crystal in a very similar way. Below, we have tried to explain these figures of merit.

**Resonance mode**

A quarts crystal can be used to oscillate at any frequency between the series and the anti-resonance frequency (see other literature for more explanations) by adding capacitance. This is what the crystal industry calls "parallel mode/frequency". All Chipcon's crystal oscillators uses parallel mode crystals.

**Frequency**

Due to the on-chip PLL, you don't need a specific crystal frequency to generate a wanted RF frequency. However the on-chip bit synchroniser for CC1000/CC1010/CC1050 requires certain crystal frequencies to generate/demodulate certain data-rates. For the "standard" data-rates of 1.2 kbit/s, 2.4 kbit/s…..76.8 kbit these standard crystal frequency should be used : 3.6864 MHz, 7.3728 MHz, 11.0592 MHz and 14.7456 MHz (for CC1010 : In addition, 18.4320 MHz and 22.1184 MHz). Note that for CC1000/CC1010 you need to use 14.7456 MHz for data-rates above 38.4kbit/s. Chipcon recommends the 14.7456 frequency for CC1000/CC1010 unless there is a god reason not to use it.

For CC400/CC900 any crystal frequency between 4 MHz and 12 MHz can be used.
For CC1020 14.7456 MHz can be used as well as 6 other frequencies, see the datasheet.

**Initial tolerance**

Initial tolerance is the frequency error at a given temperature, usually room temperature (25 degrees C). The tolerance is given in ± ppm – Part Per Million. So at 1 MHz ±1 ppm is ±1 Hz, at 1 GHz ±1 ppm is ±1 kHz. The same crystal type is usually available in different tolerances. The lowest cost "microcontroller" crystals are usually 50 ppm or 100 ppm, while more expensive crystals are 5 ppm to 20 ppm. Even more accurate crystals are also available, but it is more likely that temperature drift will dominate the frequency error anyhow.

Initial frequency error can be removed in production by trimming using a variable capacitor or by programming the PLL (Phase Locked Loop), see chapter below: "How to compensate the frequency error in an crystal". This would allow cheaper crystal to be used, while still maintaining the RF performance, especially if manual labour can be avoided in the frequency adjustments.

**Frequency stability over temperature**

Frequency variation over temperature is also given in ± ppm. The same crystal type is usual available from a rather poor specification (for RF) of 100 ppm down to 5-10 ppm or even lower. The temperature range can be quite different from manufacturer to manufacturer, so read the specs carefully. The temperature range can be small: 0→50 ° C, to quite large -55 →105 ° C. It is possible to compensate for the drift by measuring the temperature and reprogramming the PLL, but it requires accurate knowledge about the temperature drift. Another possibility is to do calibration on different temperatures, but this is usually not possible for high volume products. One can buy temperature compensated crystal oscillators (TCXO) with excellent performance, but the price is comparable to a RF transceiver chip.

**Aging**

Aging is a frequency error mainly caused by stresses in the package. The specification is given in ppm/year. The frequency error will typically decrease exponentially, so aging is typically only a problem during the first year - unless the crystal is pre-aged to remove most of the aging. A typically spec is ±3-5ppm/year for the first year and half of this the next year and so on. It is impossible to compensate for aging, because it is hard to say what way the crystal will drift. Pre-aged crystals are available at relatively low cost. A typical pre-aged spec is ±1ppm/year for the first year.

**Loading the crystal**

The loading of a crystal is how much capacitance the crystal needs to "see" across it's terminals to resonate at the correct frequency. The loading for the crystal is realised by two capacitors, one from each crystal terminal to ground. Using the wrong loading will result in a frequency error (it will not damage the crystal). See the datasheet (CC1000/CC1010/CC1050) for the correct value of the capacitor for a specific loading. Note that parasitics due to different PCB types/layouts might make it necessary to adjust the values in the datasheet. Due to the use of standard values for capacitors and parasitics, it is difficult to get the correct loading. Some "loading error" (1-2ppm) is therefore to be expected. Note that the two loading capacitors do not have to be of the same value, but should be as close as possible.

The loading error can be compensated for, see chapter below: "How to compensate the frequency error in an crystal".

**Equivalent Series Resistance (ESR)**

This is a measure of the losses in the crystal. A maximum value is normally specified. The value is frequency dependent, lower crystal frequencies have higher ESR. A common value for 14.7456 MHZ is 30-60 ohms. Due to the amplitude regulation for Chipcon's crystal oscillators, the circuit will compensate for the losses in the crystal by using more current when necessary. You can actually get a feel for the ESR by measuring the crystal oscillator core current consumption. Production tests on our evaluation boards showed current variations from 60uA to above 100uA for different crystals running on the same frequency (11.0592 MHz). The amplitude remained the same (about 600 mVpp).

**Drive level**

Drive level is the maximum power dissipation recommended in the crystal. A higher value can damage the crystal. Due to the amplitude-regulated architecture, the drive level will be very low, below 10μW. This level is 10-500 times less than a "normal" crystal specification.

**The crystal package**

Crystals come in a variety of packages. Don't pick the smallest one if you don't need to, it is usually some trade offs involved when making things smaller.

## How to compensate the frequency error in a crystal

The reason for compensating the frequency error is to save the cost of buying a very good crystal or to meet the strict frequency drift regulations for narrowband system. There are basically 2 ways of compensating: By adding a trimmer capacitor in parallel with one of the loading crystal capacitors or using the PLL to correct the RF frequency.

By adding a trimmer capacitor, the reference crystal can be trimmed to the correct frequency. This will remove the initial frequency error and the loading frequency error for both RX and TX. The only error that is left is then the temperature drift and the aging. For a reference design see the CC1000/CC1050 EB and CC1010 EM. The drawback of this method is that the trimming usual requires manual operation.

When using the PLL to trim the crystal frequency, the reference frequency is left as it is, and the RF frequency is adjusted instead. This can be done due to the advanced fractional-N PLL for all Chipcon's RF circuits. The frequency resolution for the PLL less than 250 Hz. Note that only the transmit frequency can be compensated for in CC1000. In receive mode, an optimal frequency needs to be selected (see application note 11 – **Only** for CC1000/CC1010). The trimming can be done in the production test of the product:
Measure the TX frequency, adjust the RF frequency until desired frequency is reached and store the "corrected" frequency word in the μC or EEPROM. This method will also remove the initial frequency error and the loading frequency error (in TX only).

## Sensitivity vs. IF frequency

The crystal error will result in a frequency error in transmit mode, as well as error in the Local Oscillator (LO) in receive mode. Assume the LO frequency is correct and that the transmitted frequency is 10 ppm too high and we're operating at an RF frequency of 1000 MHz (to make it simple). If we assume low-side LO, we want the LO to be set to 1000 MHz – 150 kHz (CC1000 has 150 kHz IF frequency), that is 999.85 MHz. Since the transmitter is incorrect, we're transmitting at 1000.01 MHz. Instead of 150 kHz, the RF signal is mixed down to 1000.01-999.85 = 160 kHz.
This is just 10 kHz away from the wanted IF frequency, and does not cause any problems for the RF link in the case of wideband systems like the CC1000/CC1010. (For narrowband systems, possible with the CC1020, 10kHz could be the neighbour channel and be attenuated with 30 dB). The effect of a larger frequency error between the receiver and the transmitter (10ppm is not much!) will result in sensitivity degradation. The excel spreadsheet "AN_019_crystal_tolerance_calculator_1_0.xls" will help estimating the sensitivity degradation for CC1000/CC1010, taking into all the possible frequency errors.

## How to use an external clock (for example the μC crystal oscillator)

To save cost, the μC and the RF circuit can share the same crystal (does not apply to CC1010 since the uC and the RF is on the same chip). There are two ways of using an external source for the crystal oscillator signal:

A. Configure the chip as for internal oscillator and use a coupling capacitor (1 nF) between the CC1000/CC1050 and the external oscillator. The signal amplitude must be minimum 300 mVpp.
B. B. Configure the chip for external oscillator and use a rail-to-rail clock signal. In this case, do not use a coupling capacitor.

Note that for the case of just one crystal the crystal must be up and running on the uC before it can be used for the RF since the uC needs to program the registers for the chip.
Note also that all crystal oscillators have a start-up time. For CC1010/CC1000/CC1050 this time is specified in the datasheet. The start-up time for CC1010/CC1000/CC1050 depends on many factors, most important are the frequency and the loading of the crystal.

## How to use the spreadsheet

The spreadsheet can be downloaded from our web: **www.chipcon.com** . You will also find instructions on how to use the spreadsheet in the document itself.
Enter the values in the green fields. There are 3 different sections of inputs.

1. The first section is for the RF system, enter the RF frequency and how much in % (0-100) temperature difference that is "possible" between the receiver and the transmitter. If the transmitter and the receiver is placed in the same room, it is likely that they will have the same temperature, so enter a low number (0-20%). If the receiver is placed indoors and the transmitter is placed outdoors, then the temperature difference might be quite large (at least in Norway…), so enter a large number (50-100%)
2. The second section is for the crystal and you'll find every input described in this app note (initial tolerance, temperature drift, aging, loading errors).

3. In the last section, you need to specify whether you use some sort of compensation of the crystal in TX (se above).

The spreadsheet will calculate the resulting IF frequency error and based on a graph that shows the sensitivity vs. IF frequency, you can easily estimate the typical sensitivity loss due to the crystal errors. The curve applies to CC1000 and CC1010.

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