CRYSTAL SELECTION GUIDE FOR THE Si4x6x RF ICS

1. Introduction

The aim of this application note is to give a better understanding of crystal and TCXO interfacing to our Si4x6x ISM band transmitter, receiver and transceiver ICs. The most important parameters when selecting the proper crystal oscillator are the following:

Nominal Frequency: 25…32 MHz (typically 30 MHz; for more details please see section 4)
Equivalent Series Resistance: ESR: max. 80 Ω
Load Capacitance: Cload, C_L: max. 10 pF
Shunt Capacitance: C_0 (as low as possible, typically 3–4 pF)
Frequency Stability over Operating Temperature Range: typically ±10 ppm (depends on the application)

2. Theoretical Background

The 30 MHz crystal oscillator of the Si4x6x family uses the crystal in parallel resonance mode. In this mode, the resonator consists of the crystal itself and a “load capacitance.” Figure 1 shows this capacitance (CL) together with the electrical model of the crystal.

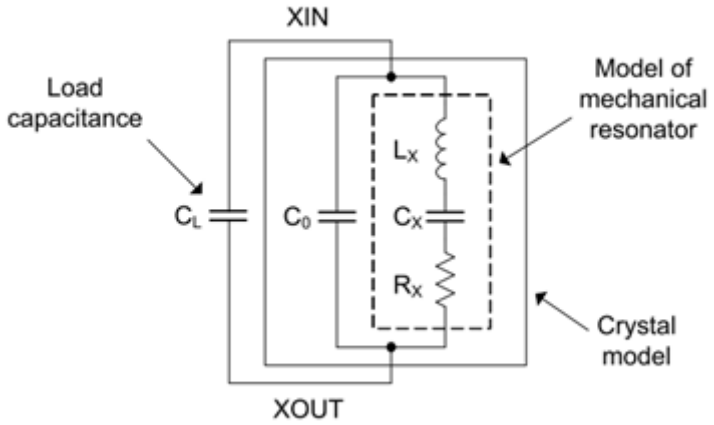


Figure 1. Crystal in Parallel Resonance Mode

The most commonly used names for the components in crystal model are:

L_x	Motional inductance
C_x	Motional capacitance
R_x	Loss resistance
C_0	Pin/holder capacitance

The addition of C_L detunes the mechanical resonator from the series resonance frequency, f_S, determined here by L_X and C_X. $f_P = f_S \times (1 + C_X / (2 \times (C_0 + C_L)))$.

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In order to get an accurate oscillation frequency, f_P, it is important to provide the required amount of load capacitance specified by the crystal manufacturer. Normally, C_X is not given in the data sheets, and there is only a maximum shown for C_0. Typical standard values of C_L are 10, 12, 16, 18, and 20 pF.

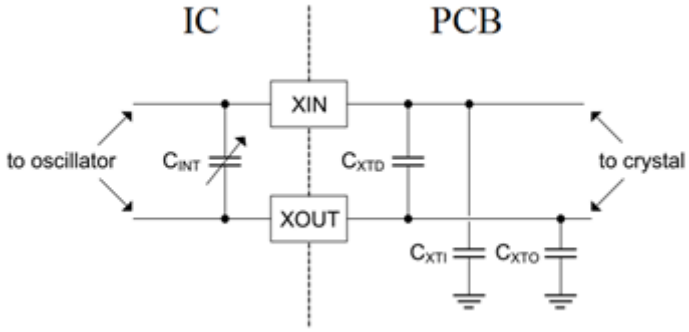


Figure 2. Resonator-Connected Capacitances

3. Si4x6x Oscillator's Features

The Si4x6x includes an integrated crystal oscillator with a fast start-up time of less than 250 µs. The design is differential with the required crystal load capacitance integrated on-chip to minimize the number of external components. By default, all that is required off-chip is the crystal. The default crystal frequency is 30 MHz, but the circuit is designed to handle any XTAL from 25 to 32 MHz. If a crystal with nominal frequency different than 30 MHz is used, the POWER_UP API boot command must be modified. The WDS calculator crystal frequency field must also be changed to reflect the frequency being used.

The crystal load capacitance can be digitally programmed to accommodate crystals with various load capacitance requirements and to adjust the frequency of the crystal oscillator. The tuning of the crystal load capacitance is programmed through the GLOBAL_XO_TUNE API property. The total internal capacitance is 11 pF and is adjustable in 127 steps (70 fF/step).

When tight frequency tolerance is required (e.g., narrow band applications) there are two possible options:

1. Use an external high precision reference (e.g., TCXO, OCXO).
2. Use the crystal frequency adjustment to compensate for crystal production tolerances. The frequency offset characteristics of the capacitor bank are demonstrated in Figure 3. Utilizing the on-chip temperature sensor and suitable control software, the temperature dependency of the crystal can be canceled.

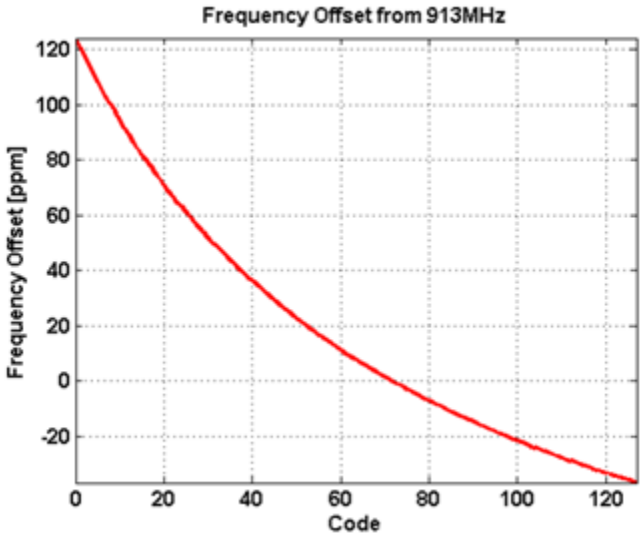


Figure 3. Capacitor Bank Frequency Offset Characteristics

When placing the crystal on the PCB layout and routing the crystal and radio interconnections, the designer must consider minimizing trace length, thus decreasing possible parasitic effects and EMC issues.

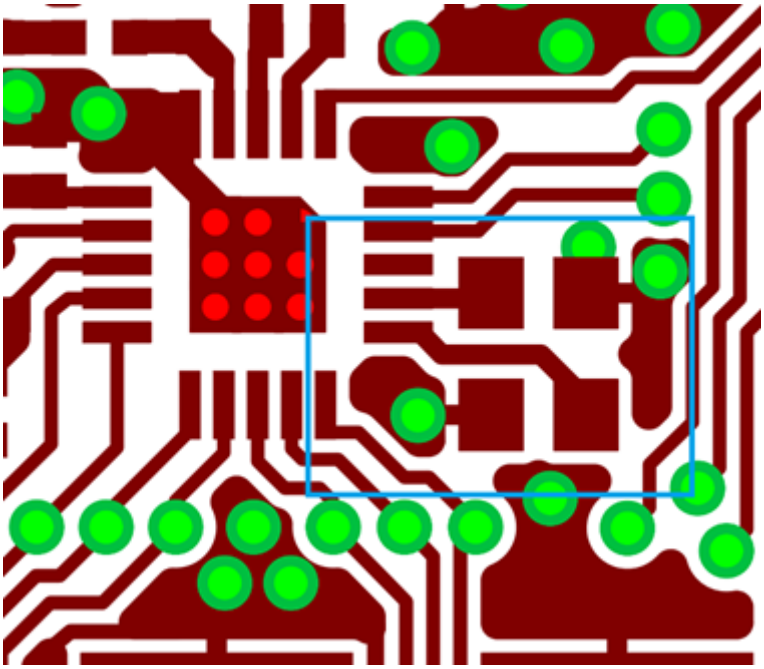


Figure 4. Reference Design Layout Example of a Crystal Connection

4. Frequency Selection

The recommended nominal crystal frequency is 30 MHz for each radio type. One exception is when the product is designed for the **868 MHz band**, where the recommended crystal frequency is **26 MHz**, as used in our reference designs as well. Due to the architecture of the Si4x6x, unwanted spurious emission may be seen at frequencies equal to the difference between the center frequency and the nearest crystal harmonic. Crystal harmonics can also desensitize the receiver and degrade sensitivity. It is suggested to carefully choose the crystal frequency to move its harmonics away from the desired radio frequency. Silicon Labs suggests using 26 MHz in the 868 MHz European band.

When selecting the reference crystal for an application, one of the most important questions is the accuracy. It depends on the radio link parameter's (data rate, deviation, RX filter bandwidth). The table below summarizes the verified, recommended crystals.

5. Recommended Crystal Types

Crystals						
Manufacturer	**Freq**	**Type**	**CL**	**ESR max**	**Tolerance**	**Operating Temp.**
TST	30 MHz	TZ1430E	10 pF	50 ohm	+/- 10 PPM	-20°C…+70°C
TST	26 MHz	TZ0234D	10 pF	60 ohm	+/- 20 PPM	-40°C…+85°C
River	30 MHz	FCX-04	10 pF	50 ohm	+/- 20 PPM	-20°C…+70°C
NDK	30 MHz	NX2520SA	10 pF	50 ohm	+/- 10 PPM	-10°C…+60°C
ECS	30 MHz	ECS-300-8-36CKM	8 pF	50 ohm	+/- 10 PPM	-20°C…+70°C
AVX Corp	30 MHz	CX2520DB	8 pF	50 ohm	+/- 15 PPM	-10°C…+70°C

To obtain the proper radio configurations, it is recommended to use WDS and configure the crystal tolerances for both ends of the link within the Radio Configuration Application (see Figure 5).

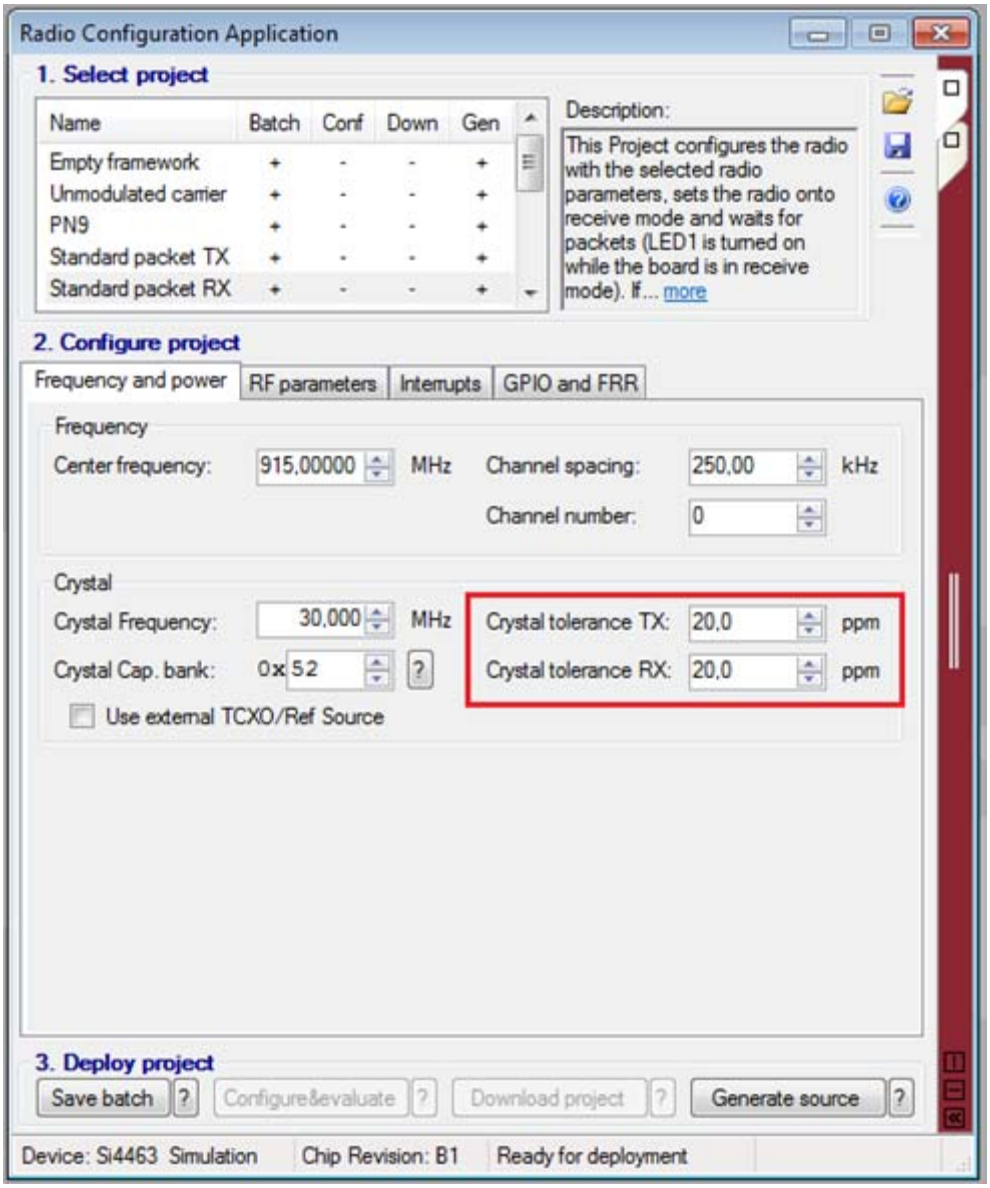


Figure 5. WDS Crystal Tolerance

6. Using an External Oscillator (TCXO)

In several narrow-band systems, the accuracy requirements cannot be achieved without compensating the temperature dependency of the crystal itself. A cost-effective method would be to utilize the on-chip temperature sensor and digitally adjust the crystal capacitance bank (GLOBAL_XO_TUNE API property) with a suitable software control loop. A more accurate but practical solution is to use a TCXO (temperature-compensated crystal oscillator).

A TCXO or external signal source can easily be used in place of a conventional XTAL and should be connected to the XIN pin. The incoming clock signal is recommended to have a peak-to-peak swing in the range of 600 mV to 1.4 V and ac-coupled to the XIN pin with a series capacitor. The maximum allowed swing on XIN is 1.8 V peak-to-peak. The XO capacitor bank should be set to 0 whenever an external drive is used on the XIN pin using the “GLOBAL_XO_TUNE” API property. In addition, the POWER_UP command should be invoked with the TCXO option whenever the external drive is used.

Beside the hardware layout considerations and TCXO selection the following process has to be followed for proper operation:

Transitioning from SLEEP to SPI_ACTIVE state:

1. Turn on the TCXO and wait for its settling time.
2. Transition from SLEEP to any active mode (SPI_ACTIVE, TUNE, RX, TX, etc.).
3. Send the following command to the radio: **POKE ‘xosc_cfg’ 0A**

Transitioning from any active to SLEEP mode:

1. Send the following command to the radio: **POKE ‘xosc_cfg’ FA**
2. Transition to SLEEP mode.
3. Turn off the TCXO to save current.

To obtain the proper radio configurations, it is recommended to use WDS and set the “Use external TCXO/Ref source” option within the Radio Configuration Application (see Figure 6).

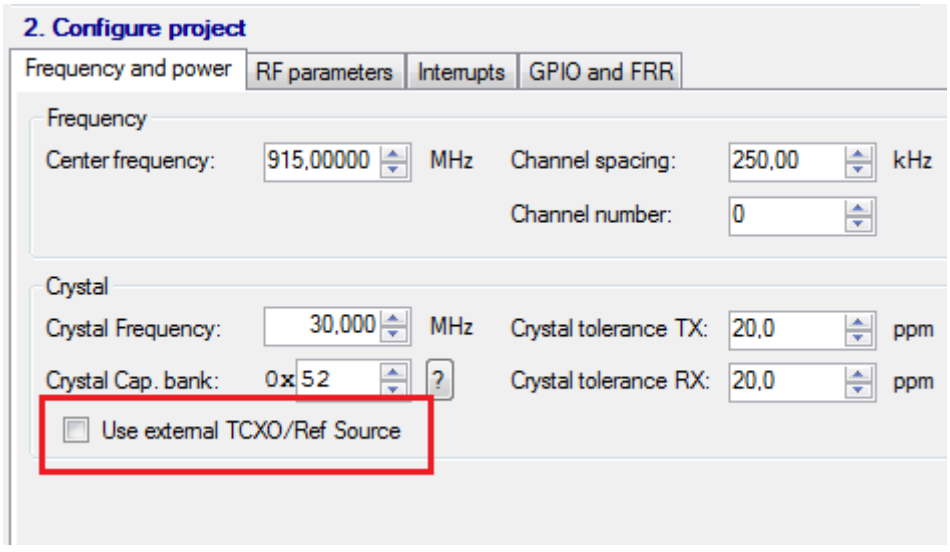


Figure 6. WDS setting for TCXO

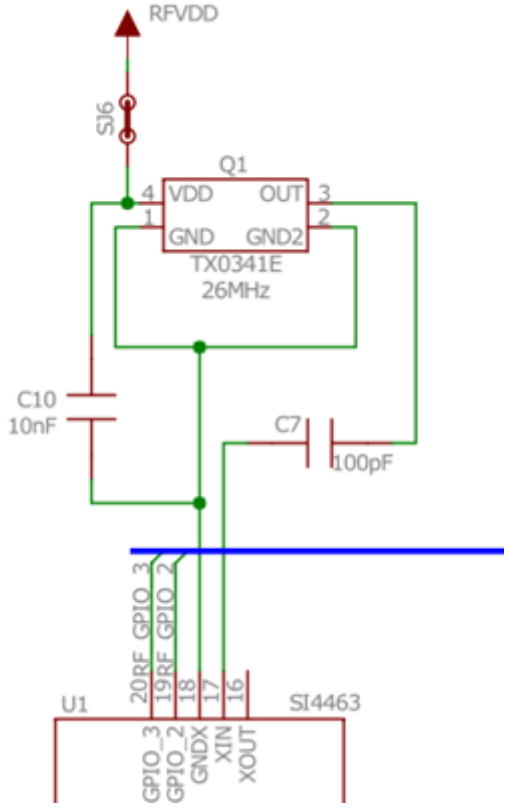


Figure 7. Reference Design Schematic with TCXO

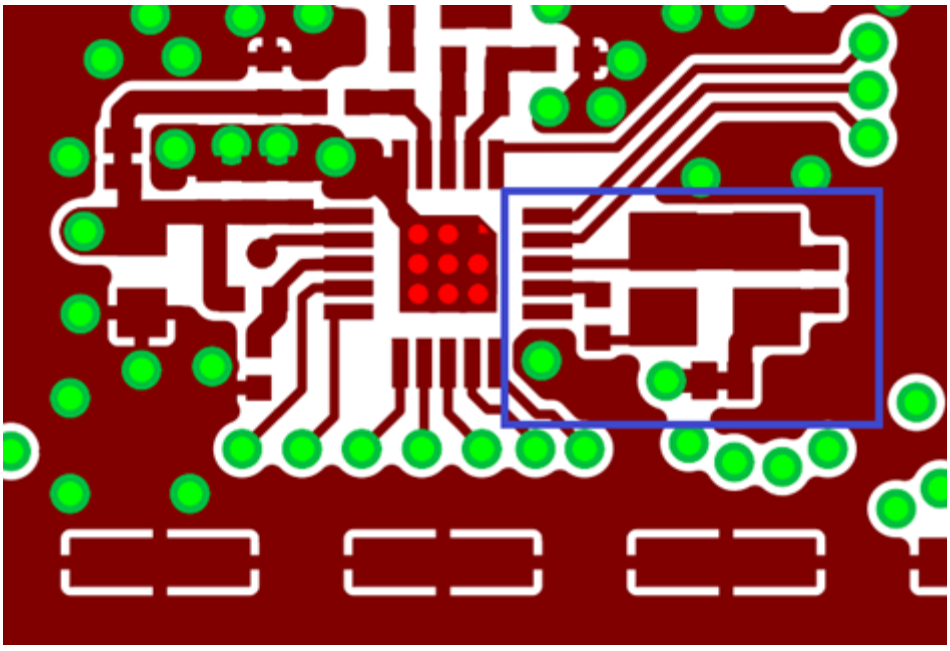


Figure 8. Reference Design Layout with TCXO

7. Recommended TCXO Types

The following table summarizes the recommended and verified TCXOs.

TCXOs						
Manufacturer	**Freq**	**Type**	**DC Current**	**Waveform**	**Tolerance**	**Operating Temp.**
TST	30 MHz	TX0338A	2mA	Clipped Sine	±2 PPM	-30°C…+75°C
TST	26 MHz	TX0341E	2mA	Clipped Sine	±2 PPM	-40°C…+85°C
Murata/RFM	26 MHz	XTC7006G-4	1,5mA	Clipped Sine	±2 PPM	-40°C…+85°C
Murata/RFM	30 MHz	XTC7002	2mA	Clipped Sine	±2 PPM	-30°C…+75°C
Golledge	30 MHz	GTXO83	2mA	Clipped Sine	±2.5 PPM	-30°C…+75°C

NOTES:

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