Recommended Crystal, TCXO, and OCXO Reference Manual for High-Performance Jitter Attenuators and Clock Generators

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The purpose of this document is to provide a list of crystals, TCXOs, and OCXOs which have been tested and qualified for use with Silicon Labs high-performance jitter attenuators and clock generators. Changes to this document will be accompanied by a Process Change Notice (PCN).

The information presented here is based on tested samples. Customers should monitor specification compliance and quality over time. Customers should also verify that the selected crystal or oscillator is a good match for their application.

Please refer to relevant data sheets, reference manuals, and application note, "AN905: Si534x External References: Optimizing Performance", for external reference layout recommendations.

RELATED DOCUMENTS

- Si534x Reference Manuals
- Si538x Reference Manuals
- Si539x Reference Manuals
- AN905: Si534X External References: Optimizing Performance
- AN1093: Achieving Low Jitter Using an Oscillator Reference with the Si5342-47 Jitter Attenuators

RELATED SILICON LABS PARTS

- Si5340/41/91 clock generators
- Si5342-47, Si5392-97 Jitter cleaners
- Si5342H/44H/71/72 Coherent optics clocks
- Si5348/83/83 SyncE clocks
- Si5380/81/86 Wireless clocks

1. Recommended Crystals

A crystal (XTAL) in timing refers to a quartz crystal that works on the piezo-electric effect: an electrical voltage across it causes a mechanical perturbation and this in turn causes an electrical voltage to develop across it. The XTAL needs to be driven by a circuit to sustain its oscillation. This provides a stable source of frequency and is used as a reference in phase locked loops.

The table below lists the presently recommended XTALs. XTALs that meet the specifications outlined in this document may be submitted to Silicon Labs for future qualification for use with the Si534x/7x/9x/83/84/88/89 clocks. Most of the part numbers in this table are custom generated for Silicon Labs. Part Family information is included in the table to enable searching through vendor websites. Users can also contact the vendor directly and ask for the specific part number listed.

Table 1.1. Recommended XTALS for All Si534x/7x/9x/83/84/88/89 Devices

Supplier	Part No	Part Family	Freq (MHz)	Initial Tol (±ppm)	Accuracy over -40 to +85 °C (±ppm)	C0, Max pF	ESR Max Ω	CL pF	Tested over Temp for Activity Dips?	Drive Level (µW)	Case Size (mm)
Connor Winfield	CS-043	CS-043	48	15	25	2.0	20	8	No	200	3.2 x 2.5
Connor Winfield	CS-044	CS-044	54	15	25	2.0	20	8	No	200	3.2 x 2.5
Hosonic	E3S48.000F08M22SI	E3SB	48	20	20	1.5	25	8	No	200	3.2 x 2.5
Hosonic	E2S48.000F08M22SI	E3SB	48	20	20	1.5	25	8	No	200	2.5 x 2.0
Hosonic	E3SB54.00 0F08M22SI	E3SB	48	20	20	1.5	25	8	No	200	3.2 x 2.5
Hosonic	E3SB54.00 0F08M22SI	E3SB	48	20	20	1.5	25	8	No	200	2.5 x 2.0
Kyocera	CX3225SB48000D0FPJC1	CX3225SB	48	10	15	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0WPSC1	CX3225SB	48	15	30	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0WPTC1	CX3225SB	48	30	60	2.0	23	8	No	200	3.2 x 2.5
Kyocera	CX3225SB54000D0FPJC1	CX3225SB	54	10	15	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0FPJC1	CX3225SB	54	15	30	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0WPSC1	CX3225SB	54	30	60	2.0	23	8	Yes	200	3.2 x 2.5
NDK	NX3225SA-48.000M-CS07559	NX3225SA	48	20	30	1.8	23	8	No	200	3.2 x 2.5
NDK	NX3225SA-54.000M-CS07551	NX3225SA	54	20	30	1.8	23	8	No	200	3.2 x 2.5
Taitien	S0242-X-002-3	S0242	48	20	20	2.0	23	8	No	200	3.2 x 2.5
Taitien	S0242-X-001-3	S0242	54	20	20	2.0	23	8	No	200	3.2 x 2.5
TXC	7M48070012	7M	48	10	15	2.0	22	8	No	200	3.2 x 2.5
TXC	7M48072002	7M	48	10	15	2.0	22	8	Yes	200	3.2 x 2.5
TXC	7M48072001	7M	48	20	30	2.0	22	8	Yes	200	3.2 x 2.5
TXC	7M54070010	7M	54	10	15	2.0	22	8	No	200	3.2 x 2.5
TXC	7M54072001	7M	54	20	30	2.0	22	8	Yes	200	3.2 x 2.5

Supplier	Part No	Part Family	Freq (MHz)	Initial Tol (±ppm)	Accuracy over -40 to +85 °C (±ppm)	C0, Max pF	ESR Max Ω	CL pF	Tested over Temp for Activity Dips?	Drive Level (µW)	Case Size (mm)
TXC	7M54072002	7M	54	20	30	2.0	22	8	Yes	200	3.2 x 2.5
TXC	7M54072003	7M	54	10	15	2.0	15	8	Yes	200	3.2x2.5
TXC	7M54072004	7M	54	10	15	2.0	15	8	Yes	300[1]	3.2x2.5
Siward	XTL571500-S315-006		54	50	50	2.0	20	8	No	200	3.2 x 2.5
Siward	XTL571500-S315-007		54	50	50	2.0	20	8	No	200	2.5 x 2.0

Note:

1. When the ESR max is 10 Ω, a XTAL rated to 300 µW is required. If the ESR max is 15 Ω, a XTAL rated to 350 µW is required.

Refer to Appendix A for information on XTAL specifications and how to choose the best XTAL for your application. In general, a XTAL meeting the requirements of the ESR vs. C0 figures in Appendix A and having a max power rating as specified in the applicable data sheet is guaranteed to oscillate.

For Silicon Labs Si534x/7x/9x P/Q grade devices, choose a XTAL that has a total lifetime accuracy of less than 100 ppm. This number includes initial offset, aging at hot temperature (85°C), temperature stability, pulling sensitivity, effects of reflow, and activity dips.

Some applications may require XTALs that have been tested incrementally over the entire temperature range to ensure that the change in XTAL resonant frequency over any 2 °C temperature difference is bounded. This is called testing for activity dips and can add cost to the XTAL. The Si534x/7x/9x/83/84/88/89 products are designed to work with both normally-tested XTALs as well as activity dip-tested XTALs.

Please refer to relevant data sheets, reference manuals, and AN905 for XTAL drive circuit and layout recommendations.

2. Recommended Oscillators

The most basic and precise timing reference is the XTAL. However, the XTAL alone will not sustain the oscillations to provide a stable clock. A driver circuit needs to be added to obtain a continuous and stable oscillation. This forms a basic XTAL oscillator (XO). XTAL oscillators come in many different versions based on their tunability and temperature stability.

Refer to Appendix B for information on XTAL oscillator specifications and how to choose the best XO for your application.

2.1 Recommended Stratum 3/3E OCXO/TCXOs

The table below is a list of low frequency Stratum 3 TCXOs and Stratum 3E OCXOs that have been approved for use with members of the Si534x/7x/8x/9x family. These devices, such as the Si5348, have a separate Reference Clock input distinct from the XA-XB interface.

Some of the part numbers in this table are custom generated for Silicon Labs. Part Family information is included in the table to enable searching through vendor websites. Users can also contact the vendor directly and ask for the specific part number listed.

Table 2.1. Recommended Stratum 3/3E Oscillators

Supplier	Part Number	Part Family	TCXO/ OCXO	Frequency (MHz)	Stability over Temp (±ppb)	Temp (°C)	Stratum	Package
Connor Winfield	OH300-50503CF-012.8M	OH300	OCXO	12.800	5	0/+70	3E	22x25.4
Connor Winfield	OH300-61003CF-012.8M	OH300	OCXO	12.800	10	-40/+85	3E	22x25.4
Epson	OG2522CAN CSGJHG 12.8000MB	OG2522CAN	OCXO	12.800	10	-40/+85	3E	22x25.4
NDK	NH14M09WA-12.8M-NSA3540A	NH14M09WA	OCXO	12.800	10	-20/+70	3E	9x15
NDK	NT14M09TA-12.8M-NSA3543A	NH14M09TA	OCXO	12.800	20	-40/+85	3E	9x15
Rakon	STP3158LF[1]	ROX2522S4	OCXO	12.800	10	-40/+85	3E	22x25.4
Rakon	STP3268LF[2]	ROX3827T3	OCXO	10.000	1	-40/+85	3E	22x25.5
Connor Winfield	T100F-012.8M	T100	TCXO	12.800	100	0/+70	3	5x7
Connor Winfield	T200F-012.8M	T200	TCXO	12.800	200	-40/+85	3	5x7
Epson	TG-5500CA-08N 12.8000MB	TG-5500CA	TCXO	12.800	280	-40/+85	3	5x7
NDK	NT7050BC-12.8M-NSA3517A	NT7050BC	TCXO	12.800	280	-40/+85	3	5x7
Rakon	E6127LF	RPT7050A	TCXO	12.800	280	-20/+70	3E	5x7
Rakon	E6518LF	RPT5032J	TCXO	12.800	280	-40/+85	3E	5x3

Note:

1. STP3158LF is used for Silicon Labs Compliance Testing for ITU and Telcordia standards.
2. The STP3268LF offers superior temperature and phase stability, resulting in improved MTIE TDEV noise generation performance which may be required in some applications.

2.2 Recommended Stratum 3 High Frequency TCXOs

The table below is a list of high frequency Stratum 3 TCXOs which have been approved for use with the Si534x/8x/9x family in general when connected at the XA input. See the appropriate Reference Manual for the TCXO to XA input interface circuit.

Some of the part numbers in this table are custom generated for Silicon Labs. Part Family information is included in the table to enable searching through vendor websites. Users can also contact the vendor directly and ask for the specific part number listed.

Table 2.2. Recommended Stratum 3/3E TCXOs

Supplier	Part Number	Part Family	TCXO/OCXO	Frequency (MHz)	Stability over Temp (±ppm)	Temp (°C)	Package Size (mm)
Epson	TG-5500CA-68N 49.1520MB	TG-5500CA	TCXO	49.152	0.25	-40 to 85	5x7
Epson	TG-5500CA-67N 40.0000MB	TG-5500CA	TCXO	40.000	0.25	-40 to 85	5x7
NDK	NT7050BB-40M-ENA4199B	NT7050BB	TCXO	40.000	1	-40 to 85	5x7
Rakon	513872	RTX7050A	TCXO	40.000	0.28	-40 to 85	5x7

2.3 Recommended XOs

The table below is a list of XOs which have been approved for use with the Si534x/8x/9x family in general when connected at the XA input. See the appropriate Reference Manual for the XO to XA input interface circuit.

Some of the part numbers in this table are custom generated for Silicon Labs. Part Family information is included in the table to enable searching through vendor websites. Users can also contact the vendor directly and ask for the specific part number listed.

Table 2.3. Recommende XOs

Supplier	Part No	Part Family	Freq (MHz)	Stability over Temp (± ppm)	Temp (°C)	Application	Package Size (mm)
NDK	NZ2520SDA	NZ2520SDA	54	30	-40 to 105	Wireless	2.5 x 2.0
TXC	7X54070001	7X	54	30	-40 to 105	Wireless	3.2 x 2.5

3. Appendix A—How to Select the Right XTAL for your Application

Selecting a XTAL involves investigating the XTAL for its properties and performance. The purpose of this section is to enumerate the properties of the XTAL and how it affects the final performance. XTALs operate by the piezo-electric effect, so both the electrical and the mechanical aspects of the XTAL play a role in determining its suitability for the given purpose.

Data Sheet Electrical Specifications

Frequency:

The nominal operating frequency of the XTAL is determined by the internal L-C resonance in the XTAL model, as discussed in the section below, XTAL Equivalent Model. XTALs can operate at either the fundamental frequency or at overtones of the fundamental. Fundamental XTALs generally have better jitter and phase noise performance.

Frequency Accuracy:

The construction and manufacturing process determines the accuracy and performance of the XTAL. These factors can be analyzed in terms of the variation they cause from the ideal operating point of the XTAL.

Frequency error is a cumulative value which is a combination of multiple factors. This number needs to be within the limit specified by the Si534x/7x/8x/9x to guarantee proper PLL operation and specified performance. Accuracy is represented in parts per million (ppm) or parts per billion (ppb).

ppm error = ((Actual frequency – ideal frequency) / ideal frequency) x 10^6

ppm error = ((Actual frequency – ideal frequency) / ideal frequency) x 10^9

Since the XTAL accuracy directly affects the output accuracy during free run, it is important that the XTAL error be tight on the temperature drift and total ppm error. The factors contributing to frequency accuracy are:

- **Initial Offset or Frequency tolerance:** Impurities in the XTAL growth, imprecision in the cutting process, and uneven thickness of the processed XTAL lead to slightly different nominal oscillation frequencies across a batch of XTALs. It is usually specified at typical room temperature of 25 °C.
- **Frequency Stability over Temperature**: The XTAL oscillation frequency varies with temperature as a third-order function. Data sheet specifications give the minimum and maximum variation above and below the initial frequency at 25 °C.
- **Aging:** XTALs are electromechanical devices and thus are subject to aging due to many internal and external factors. Aging is typically higher during the first hours of operation and slows down over time. Since aging is specified in multiple ways, the most appropriate value to use is a long-term aging spec at the highest temperature the XTAL endures in the system.
- **Pulling Sensitivity or Pull-ability or C_L mismatch.**: The oscillation frequency of the XTAL depends on the load capacitance and will be affected by the tolerance of the loading capacitors over the temperature range. It is usually expressed in ppm/pF of capacitance variation.
- **Effects of High-Temperature Reflow:** The reflow process subjects the XTAL to high temperature soldering followed by cooling. This may cause a small shift in the frequency, specified in ppm. This specification may also list how many reflows are accounted for in the measurement to account for re-work.
- **Activity Dips (Frequency Perturbation):** XTAL oscillation levels vary a small amount across the temperature range, generally called “Activity Dips”. For highest performance applications, these may need to be tested by the XTAL manufacturer prior to using in the application. However, many applications do not require this extra test.

Total frequency error is a sum of these individual errors in addition to errors in the reference clock.

Let’s consider an example to understand how to calculate the total error. Let’s say that a 48 MHz XTAL has a frequency tolerance of ±13 ppm, frequency stability of ±30 ppm over temperature, long term aging at 115 °C of ±15 ppm, pulling sensitivity of 17 ppm/pF, frequency perturbation of ±2 ppm, and a frequency drift after reflow of ±2 ppm. Assume a 1.2 pF tolerance of the load capacitor, which is a reasonable estimate of 15% for a 8 pF nominal value.

Total error from XTAL is a sum of all these factors, which amounts to 13 + 30 + 15 + (1.2 *17) + 2 + 2 = 82.4 ppm.

Operating Temperature: This is the temperature range that guarantees the operation of the XTAL per data sheet specifications. This temperature range should be wide enough to meet the expected system operating temperature range.

XTAL Equivalent Model

A quartz XTAL can be modelled electrically as a series RLC in parallel with a capacitance indicating the connections as shown in the figure below.

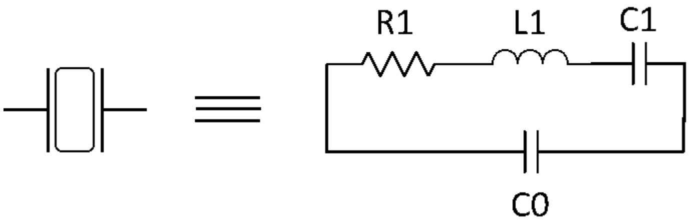

Figure 3.1. XTAL Symbol and its Equivalent Electrical Model

L1 (Motional Inductance) and C1 (Motional Capacitance): L1 and C1 represent the values that comprise the XTAL's electrical LC model. These values determine the resonance frequency and Quality Factor, Q, along with ESR of the XTAL.

$$f_{resonance} = \frac{1}{2\pi\sqrt{(L_1 C_1)}}$$

CO (Shunt Capacitance): All XTALs have small electrodes that connect the XTAL to the package pins. The electrodes form a shunt capacitance in parallel with the XTAL's LCR model. C0 and C1, along with L1, resonate at a frequency known as anti-resonance frequency.

ESR (Equivalent Series Resistance): The equivalent impedance of the XTAL at resonance is the Equivalent Series Resistance. It is mostly dominated by the resistive component R1 given that the ratio of C1/C0 is very small.

$$ESR = R_1\left(1 + \frac{C_1}{C_0}\right)^2$$

For a stable oscillation to take place, the driving oscillator must have a negative impedance 3 to 4 times higher than the ESR of the XTAL. Figure 4.2 shows the maximum ESR allowed to ensure stable oscillation for XTALs in the 48 MHz to 54 MHz range. In this plot, the shunt capacitance C0 is found on the horizontal axis, while the maximum ESR is shown on the vertical axis. To ensure stable oscillation, the XTAL must have an ESR below the curve at the maximum C0 specified for that XTAL. Using a XTAL above this curve may not ensure stable oscillation over all conditions.

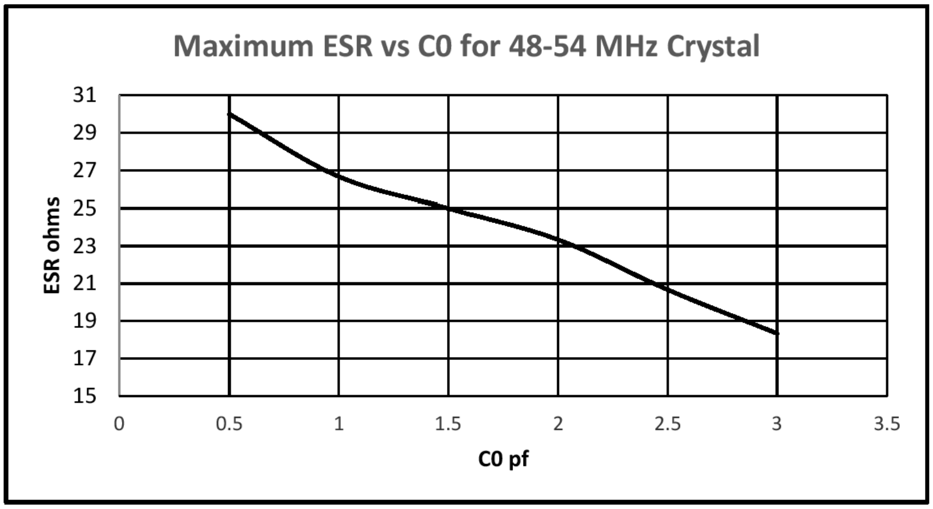

Figure 3.2. Maximum ESR vs Shunt Capacitance, C0 for 48-54 MHz XTAL

Similarly, Figure 4.3 shows the maximum ESR allowed to ensure stable oscillation for XTALs in the 25 MHz range.

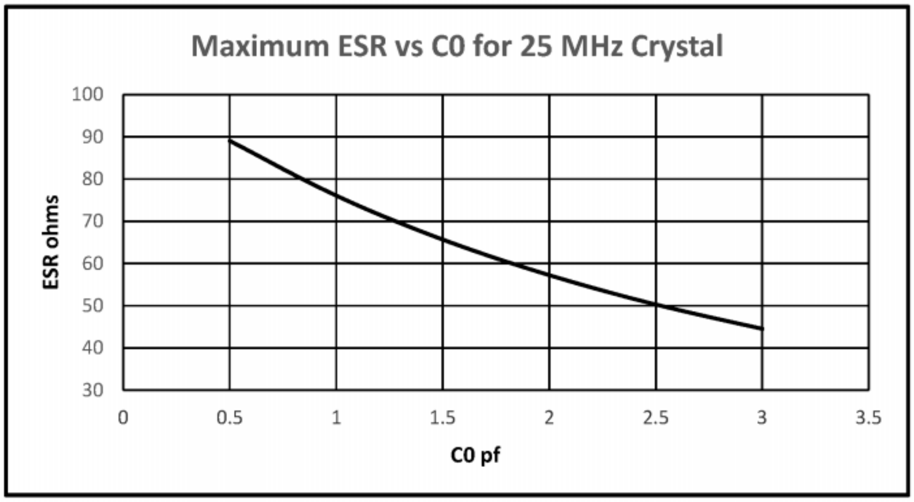

Figure 3.3. Maximum ESR vs Shunt Capacitance, C0 for 25 MHz XTAL

Q (Quality Factor): This determines the width of the frequency resonance peak of the XTAL. Higher Q gives narrower width and higher accuracy. It is defined as the ratio of reactance to series resistance at the resonant frequency. XTALs typically have a high Q of around 70,000 to 200,000.

$$Q = \frac{\omega L_1}{R_1} = \frac{1}{R_1} sqrt\left(L_1 / C_1\right)$$

A high Q implies a better close in phase noise. It also means less frequency shift for a change in oscillator load capacitance and less shift due to other external factors such as oscillator supply voltage. Higher ESR reduces Q.

CL (Load Capacitance): This is the additional capacitance needed to load the XTAL for proper oscillation. This specification should match the loading provided internally by the built-in Si534x/7x/8x/9x oscillator, usually 8pF. Mismatch of the loading capacitance shifts the XTAL oscillation frequency.

Drive Level: The power dissipated in the XTAL must be limited or the XTAL may become less reliable. The maximum drive level a XTAL must tolerate is usually specified in its data sheet in units of micro-Watts (μW). Power dissipated in the XTAL may increase for high-ESR XTALs.

Aside from these electrical specifications, XTAL vendors also specify mechanical performance and manufacturing information. XTAL dimensions could also be important as this affects where the XTAL will be placed. Smaller XTALs can be placed close to the Si534x/7x/8x/9x and thereby reduce the trace length.

XTAL Physical Size

XTALs come in many sizes, and include both thru-hole components with leads as well as surface mount components. The most common surface mount packages are rectangular 4-pin packages with a welded or soldered metal lid. Two of the four pins are used to connect to each side of the XTAL. The remaining 2 pins are connected to the XTAL shield pins on the Si534x/7x/8x/9x devices, usually labeled as “X1” and “X2”. These packages are specified in terms of the X and Y dimensions of the package. For example, a common case size may be specified either as “3.2 mm x 2.5 mm”, or simplified to “3225”. Similarly, there are 2520, 2016, 1612, etc., sizes. For the larger package sizes, usually there is little effect on the electrical parameters of the XTAL. However, at smaller sizes, the ESR and Q may be affected due to the physically smaller XTAL required to fit in these packages.

Steps to Choose the Right XTAL for your Application

1. The nominal XTAL frequency must match the value set in the ClockBuilder™ Pro (CBPro) frequency plan on the Application/Reference page of CBPro. The Si534x/7x/8x/9x cannot operate in a stable way if the XTAL frequency is different.
2. The total XTAL variation taking all factors into account must meet the value specified in the Si534x/7x/8x/9x device data sheet to ensure the best performance.
3. The XTAL maximum ESR must be below the C0/ESR curve. Higher ESR XTALs may not start reliably over all conditions.
4. The XTAL CL should match the value given in the Si534x/7x/8x/9x data sheet to ensure the correct oscillation frequency. However, XTALs with up to CL = 12 pF can be used by adding extra capacitance externally.
5. The XTAL drive level must be specified high enough to operate at the value specified in the Si534x/7x/8x/9x data sheet to ensure long-term reliable behavior.

4. Appendix B—How to Select the Right XTAL Oscillator for your Application

Introduction to XTAL Oscillators

XTAL Oscillator (XO): This is the most basic oscillator type which has a XTAL and a driver circuit in the package. The frequency stability is in the order of tens of ppm. These are very cost effective.

Temperature Compensated XTAL Oscillator (TCXO): As the name suggests, the oscillator is compensated for the change in its temperature. From the properties of XTALs, we know that the frequency changes with temperature and load capacitance. In the case of a TCXO, the temperature effect is balanced by purposeful capacitive loading, which enhances the frequency accuracy compared to an XO. Close to 1 ppm of accuracy can be obtained, however, it comes at an additional cost.

Oven Controlled XTAL Oscillator (OCXO): This has an oven built into the package and, instead of compensating for the temperature effects, it heats the oven to the zero-ppm temperature of the XTAL. In this case, the XTAL used needs to have its zero-ppm temperature higher than the expected ambient as the oven cannot cool the XTAL. These have a very high stability, in the order of ppb and slow aging as well. There is also a double oven version of this oscillator, namely the oven controlled OCXO which places the entire OCXO inside the oven to maintain the temperature. The oven and the control circuit add significant cost to the OCXO and are usually the most expensive amongst the oscillators.

Voltage Controlled XTAL Oscillator (VCXO): This is an extension to the XO with additional tunability. The frequency of the VCXO can be adjusted within 100s to 1000s of ppm by applying a control voltage, however, the tuning range is not as wide as a VCO. These oscillators are usually used as a reference to the 2nd PLL in a cascaded PLL. The cost for these oscillators falls somewhere between an XO and a TXCO.

The table below summarizes the difference between different types of oscillators.

Table 4.1. XO Comparison

Parameter	XO	TCXO	OCXO
Frequency Accuracy (Tolerance)	20-50 ppm	1-5 ppm	Less than 1 ppm
Frequency Stability over Temperature	10-20 ppm	10-100 ppb	1-10 ppb
Power	Low < 50 mW	>100 mW but <1 W	2-4 W initial, 1-2 W once stabilized
Start-up time	5-10 ms	10-20 ms	5-10 minutes
Cost	Low	Medium	High
Size	Medium	Medium	Large

Similar to the process for choosing a XTAL, the XO also needs to be evaluated for its properties and performance versus the requirements.

Data Sheet Electrical Specifications

Frequency: The frequency of operation is determined by resonance of the XTAL inside the oscillator. Oscillators come in various frequencies ranging from kHz to MHz.

Frequency Accuracy and Stability: In timing and synchronization applications, frequency accuracy is one of the major concerns. Even small frequency deviations can cause a loss of sync. Hence, it is of utmost importance that the frequency remains stable over time and temperature.

This error is defined in terms of ppm (parts per million) or ppb (parts per billion).

ppm error = ((Actual frequency – ideal frequency) / ideal frequency) x 10^6

ppm error = ((Actual frequency – ideal frequency) / ideal frequency) x 10^9

The factors that contribute to this error are:

Initial Tolerance: This is due to the XTAL inside the oscillator. The imprecision of the cut and uneven width of the XTAL leads to an inherent frequency offset. This is defined at room temperature of 25 °C.

Temperature Stability: The variation arises due to the XTAL. The data sheet spec indicates the minimum and maximum variation above and below the 0 ppm temperature. For a simple XO, the stability follows the XTAL's 3rd order temperature curve. The maximum deviation is in tens of ppm.

For the TCXO, this 3rd order curve is compensated by changing the loading capacitance. Thus, TCXO has a better temperature stability over a simple XO, in the order of 0.1 ppm. The OCXO has the best temp stability as the XTAL inside the oven is maintained around its 0 ppm temperature. The accuracy of OCXO is around 0.01 ppm.

Supply Voltage Sensitivity: The change in the nominal frequency due to power supply variations defines this sensitivity. Usually, ±5% of supply voltage variation is tolerated and any noise in the power supply directly elevates the output phase noise. Thus, it is always recommended to use a clean and filtered power supply. The OCXO have a sensitivity in tens of ppb and TCXO typically have it around 50 ppb. For an XO, it is usually combined with the overall accuracy spec indicating that it's not very significant.

Load Sensitivity: The change in the load capacitance influences the nominal frequency, although not significantly. For a ±10% of the load condition change (standard load is usually 10 pF || 10 kΩ), the change in frequency (in ppb) defines load sensitivity. This value is tens of ppb for an OCXO and hundreds of ppb for a TCXO. For an XO, it is usually combined with the overall accuracy spec.

Reflow Sensitivity: The oscillator is subjected to high temperature followed by a cool down during reflow soldering. This can cause a frequency shift called the reflow sensitivity. It is expressed in ppm.

Aging: The XTAL inside the oscillator is an electromechanical device and thus is subject to aging. Aging is typically higher during the first hours of operation and slows down over time. Since aging is specified in multiple ways, the most appropriate value to use is a long-term aging spec at the highest temperature the oscillator endures in the system.

Activity Dips: A sudden change in the value of the output from the oscillator is termed as activity dip. The vendor must test for dips and specify the value.

Let us look at an example. Suppose a typical 40 MHz TCXO has an initial tolerance of 1 ppm, temperature stability of 0.3 ppm, supply voltage tolerance of 0.1 ppm, load sensitivity for a maximum 10% load change of 0.2 ppm, a per reflow shift of 1 ppm and 1ppm aging. The overall error from this TCXO is the sum of individual errors.

Total error = 1 + 0.3 + 0.1 + 0.2 + 1 + 1 = 3.6ppm

Output Characteristics: The output can be a differential or a single-ended type. All the Si53x/4x/7x/8x chips have a differential input for the Inx and XA/XB pins. A differential signal helps reduce the common mode noise. However, a low cost single-ended output XO can also be interfaced using an attenuator circuit to limit the maximum swing. Refer to section 5 of application note, ("AN905: External References: Optimizing Performance) for more details. A slew rate of 400 V/s (minimum) on the XA/XB pins is recommended to attain the best phase noise performance from the chip. When using the attenuator circuit to curtail the swing, care must be taken so that the load impedance by the circuit meets the oscillator load specifications.

Operating Temperature: This is the range of temperature which guarantees the operation of the oscillator per the datasheet specs. Operating temperature range should accommodate the system temperature range.

Power: The power consumption is added to differentiate between the OCXO and other oscillators. Since the OCXO has an oven built in, it initially consumes high power to heat up till the frequency settles. Since the oven is always present, the overall power consumed by OCXO is higher than others. Sometimes, OCXO and TCXO have a control voltage pin similar to VCXO that can be used to pull the frequency and thus needs an additional low noise power supply.

Startup Time: Although there is no standard to define the minimum start-up time, based on the application, this time would make a difference. An OCXO takes tens of minutes to stabilize to the correct frequency due to heat-up time for the oven. The other oscillators take milli-seconds to reach the stable frequency.

Phase Noise Performance: Phase noise provides the cleanliness of the clock signal spectrum. It is defined as power at an offset from the main carrier frequency in terms of dBc/Hz. The input clock dominates the area below the outer-loop bandwidth, whereas the reference oscillator dominates the area above the outer loop bandwidth and within the inner loop bandwidth. For wireless applications, the close-in phase noise (around 100-1000 Hz) needs to be optimized. For ethernet and SONET applications, the 12 kHz to 20 MHz band is of interest. Apart from these measurements, any spurs from the input and reference degrades the output phase noise.

Phase noise integrated over the frequency band of interests yields RMS jitter. The band of integration and the RMS value is specified by different standards.

Wander Generation: The ITU-T GR.8262 standard specifies the wander generated in locked mode in terms of MTIE and TDEV. This measures the wander generated by this timing source alone. The device is locked to a wander-free input with a very low (3Hz or 100mHz) outer-loop bandwidth. Thus, the choice of reference plays an important role as the wander on the output comes directly from the reference. So, the reference oscillator needs to meet the defined wander specification at room temperature and over varying temperature as well.

Long Term Holdover Accuracy: ITU-T GR.8262 standard specifies wander in another term: long-term phase transient in holdover mode. It is the phase difference in the output clock with respect to the last input clock edge just before the moment it loses the input. The stability of Si53x/4x/7x/8x in holdover depends directly on the stability of the reference. So, it is necessary to test the reference accuracy. Section 11 of the ITU-T GR.8262 specifies the limits.

Jitter/Wander Transfer: This is a function of the timing chip. The jitter and wander at the output of the Si53x/4x/7x/8x depends on the jitter from the input until the outer-loop cutoff frequency. So, the jitter from the input below the outer-loop cut-off is important to meet the values at the output. ITU-T GR.8262 section 10 explains transfer in more detail.

Jitter/Wander Tolerance: This is again a function of the timing chip which determined how much input jitter can be tolerated until it loses lock. ITU-T GR.8262 section 9 specifies the tolerance masks for ethernet applications.

Steps to Choose the Right XTAL Oscillator for your Application

1. Choose the type of oscillator you need for your application. You can use Table 4.1 XO Comparison on page 13 as initial guidance.
2. Table 4.2 on page 16 outlines the important oscillator specifications you should consider for different applications.

Table 4.2. Oscillator Specifications

Application	Phase Noise	Spurs	Jitter/Wander	Accuracy
Wired communication (Ethernet, SDH, OTN etc.)	Usually not specified.	Should be low enough so jitter contribution is minimal.	The standards' primary requirement is the RMS jitter in 12 k to 20 M offset. [1]	Specified by the communications standards being used.
Wireless communication (LTE, 5G, microwave etc.)	Low offset: 100 Hz phase noise is important. Need to meet phase noise mask requirements up to 10 MHz[1]	Needs to meet maximum spur mask up to 100 MHz offset[1]	Jitter and Wander are not specified.	Total variation from all factors should be within ±100 ppm.
Synchronization (Sync-E, IEEE-1588 etc.)	Usually not specified.	Should be low enough so jitter contribution is minimal.	Need to have high stability TCXO, OCXO for low wander. G.8262 specifies a wander and holdover mask to be met for compliance.[1]	The Sync-E standard dictates a ± 4.6 ppm accuracy.[1]

Note:

1. Indicates the most important factor for the application

3. The peak-to-peak amplitude should be verified and an attenuator should be used if needed. See the reference manual for the Silicon Labs device being used.
4. The slew rate needs to meet the data sheet specification for the Silicon Labs device being used.
5. The phase noise from the XO determines the output phase noise above the DSPLL bandwidth up to approximately 1 MHz. The XO needs to have approximately 20 dB margin in the phase noise to accommodate the additive phase noise from the device.

5. Revision History

Revision 1.1

September, 2018

- Added Si537x/9x devices coverage.
- Added appendices explaining how to choose the right crystal and crystal oscillator for end application.
- Removed discontinued parts from recommended part tables.
- Added new parts to recommended part tables.
- Added information in recommended part tables indicating part family to make these parts easier to find on vendor website.

Revision 1.0

January, 2017

- Initial release.

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Silicon Laboratories Inc.
400 West Cesar Chavez
Austin, TX 78701
USA

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