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

The purpose of this document is to provide a list of Crystals (XTALs), Crystal Oscillators (XOs), Temperature Compensated Crystal Oscillators (TCXOs), and Oven Controlled Crystal Oscillators (OCXO), which have been tested and qualified for use with Silicon Labs high-performance jitter attenuators and clock generators.

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 requirements.

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

RELATED DOCUMENTS

- Si538x Reference Manuals
- Si539x Reference Manuals
- Si5371/72 Reference Manual
- AN905: 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
- Si5348/83/84/88/89 Network Synchronizer Clocks
- Si5380/81/82/86 Wireless Clocks

1. Recommended Crystals (XTALs)

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 following figure shows the crystal reference connected to the XA/XB of the clock.

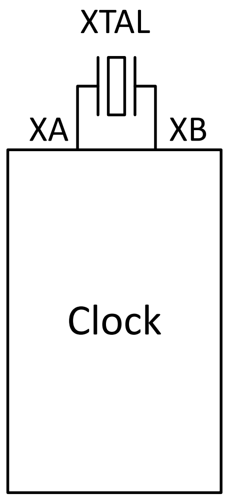

Figure 1.1. Clock with XTAL Reference on XA/XB

Table 1.1 Recommended Crystals, XTALs[1] on page 3 lists the XTALs that are recommended for use as the IC reference on the XA/XB pins of Si534x/7x/83/84/88/89/9x devices. To deliver optimum performance, either these recommended XTALS or those that meet the selection criteria in 4. Appendix A—How to Select the Right XTAL for your Application should be used.

For Silicon Labs Si539x P Grade devices, only a 48 MHz reference can be used. In addition, choose a reference that has total lifetime frequency characteristics, including initial accuracy, reflow, temperature, and activity dips, of less than 100 ppm.

XTALs that meet the specifications outlined in this document may be submitted to Silicon Labs for future qualification for use with the clocks listed above. 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.

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: External References: Optimizing Performance for XTAL drive circuit and layout recommendations.

Refer to 4. Appendix A—How to Select the Right XTAL for your Application for information on XTAL specifications and how to choose the best XTAL for your application. In general, an 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.

Table 1.1. Recommended Crystals, XTALs[1]

Supplier	Part Number	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 Max (µW)	Package Size (mm)
Conner Win-field	CS-043	CS-043	48	15	25	2.0	20	8	No	200	3.2 x 2.5
Conner Win-field	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	48	20	20.0	1.5	25	8	No	200	3.2 x 2.5
Hosonic	E3SB54.00	0F08M22SI	48	20	20.0	1.5	25	8	No	200	2.5 x 2.0
Kyocera	CX3225SB48000D0F PJC1	CX3225SB	48	10	15	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0W PSC1	CX3225SB	48	15	30	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0W PTC1	CX3225SB	48	30	60	2.0	23	8	No	200	3.2 x 2.5
Kyocera	CX3225SB54000D0F PJC1	CX3225SB	54	10	15	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0F PJC1	CX3225SB	54	15	30	2.0	23	8	Yes	200	3.2 x 2.5
Kyocera	CX3225SB48000D0W PSC1	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

Supplier	Part Number	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 Max (µW)	Package Size (mm)
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
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	3.2 x 2.5
TXC	7M54072004	7M	54	10	15	2.0	15	8	Yes	300 (1)	3.2 x 2.5
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.

2. Recommended Oscillators (XOs)

There are some applications that require better close-in phase noise performance. For these applications, a crystal oscillator (XO), can be used as the XA/XB source instead of a XTAL. Some customers also tend to prefer to use an XO instead of a crystal for its superior reliability and performance over temperature.

Compared to an externally mounted XTAL, an XO will have less total frequency error when taking into account all factors. Using an XO instead of a XTAL will:

- Deliver better accuracy in holdover since the accuracy of an XO is far better than that of a XTAL
- Produce output clocks with lower phase noise for offsets less than 5 kHz.
- Deliver greater immunity to vibration and airflow effects. This may result in lower phase noise below ~50 Hz.
- Deliver better temperature stability with the frequency changes of an XO being less than that of a XTAL. Because of this, a jitter attenuator device can have a lower bandwidth and still filter out these oscillation frequency changes.

The jitter of the XO applied to the XA input has a great effect on the output jitter/phase noise for offset frequencies up to ~1.5 MHz. The table below gives expected output jitter from different XOs so that lower output jitter can be achieved if required by the application. XOs come in many different versions based on their specifications and temperature stability. The following figure shows the crystal reference connected to the XA of the clock.

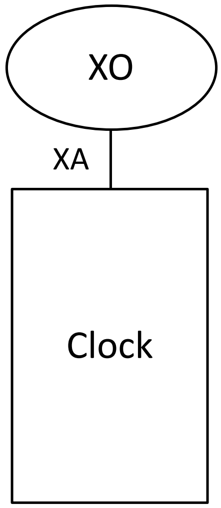

Figure 2.1. Clock with XO Reference on XA Input

Note: See the appropriate Product Reference Manual for input connections and specification limits.

Consult the applicable Silicon Labs product Reference Manual for rise/fall times, input circuits, input level specifications, and performance tradeoffs.

AN905: External References: Optimizing Performance provides additional information on optimizing performance of external XO references.

The table below lists the XOs that are recommended for use as the IC reference on the XA/XB pins of Si534x/7x/8x/9x devices. To deliver optimum performance, either these recommended XOs or refer to 5. Appendix B—How to Select the Right XTAL Oscillator for your Application for information on XO specifications and how to choose the best XO for your application.

Note: 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 XOs References on XA Input

Supplier	Part No.	Part Family	Freq (MHz)	Stability over Temp (±ppm)	Temp °C	Total Frequency Stability (±ppm)[1]	Package Size (mm)	Recommended for Use with Silicon Labs Clocks
NDK	NZ2520SDA-54 M-CUS5094C	NZ2520SDA	54	30	–40/105	50	2.5 x 2.0	Note 2
TXC	7X54070001	7X	54	30	–40/105	50	3.2 x 2.5	Note 2
NDK	NZ2520SDA-48 M-CUS5242A	NZ2520SDA	48	30	–40/105	50	2.5 x 2.0	Note 3
TXC	7X4807007	7X	48	30	–40/105	50	3.2 x 2.5	Note 3

Note:

1. Includes initial accuracy, temperature, aging and soldering effects
2. Required for use with the Si5381/82/86, but may be used with other devices.
3. Recommended for use on XA/XB input for the following devices: Si534x/7x/8x/95.

3. Recommended TCXOs/OCXOs

Some applications require low wander in addition to the traditional low jitter requirement. For these applications, it may be necessary to use a TCXO or an OCXO as a reference.

Note: Consult the applicable Silicon Labs product Reference Manual for rise/fall time, input circuits, input level specifications and performance tradeoffs.

Si5348/83/84/88/89 have two separate inputs: (REF/REFb) for the TCXO/OCXO to deliver a clock with low wander and the XA/XB input with a traditional crystal to deliver a low jitter clock. To deliver optimum performance use a recommended TCXOs/OCXOs or refer to 5. Appendix B—How to Select the Right XTAL Oscillator for your Application for information on TCXO/OCXO specifications and how to choose the best device for your application.

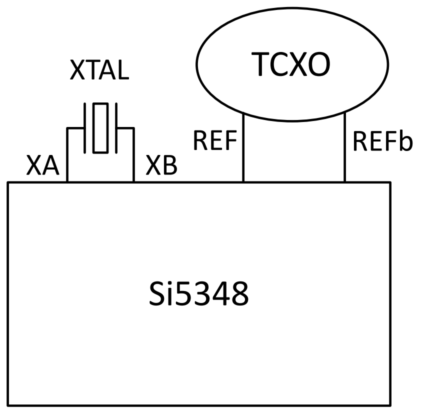

Figure 3.1. Network Synthesizer with TCXO and Crystal Reference

For the Si539x, since there is no separate REF input, the TCXO can be placed on the XA input.

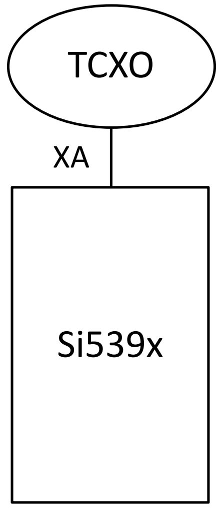

Figure 3.2. Clock with TCXO Reference on XA Input

3.1 TCXOs

A TCXO may be used as a reference on XA in place of an XTAL or XO. In addition to which connection and which product, there are several other tradeoffs that must be considered. These include PLL bandwidth, jitter and wander performance, holdover, and lock time.

Consult the applicable Silicon Labs product Reference Manual for rise/fall time, input circuits, input level specifications and performance trade-offs.

The table below lists the TCXOs that have been approved for use with members of the Si534x/7x/8x/9x family.

AN905: External References: Optimizing Performance provides additional information on optimizing the performance of external TCXO references.

Note: 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 web sites. Users can also contact vendors directly and ask for specific listed part numbers.

Table 3.1. Recommended TXCOs

Supplier	Part Number	Part Family	TCXO	Freq (MHz)	Stability over Temp (±ppb)	Temp °C	Stratum	Package Size (mm)	G.8262 Options 1 and 2 Compliant[1, 2]	G.8262.1 Compliant[1, 2]	Recommended for Use with Silicon Labs Clocks
Conner Winfield	T100F-012.8M	T100	TCXO	12.8	100	0/+70	3	5 x 7	Yes	TBD[3]	Note 4
Conner Winfield	T200F-012.8M	T200	TCXO	12.8	200	–40/85	3	5 x 7	Yes	TBD[3]	Note 4
Epson	TG-5500CA-08N 12.8000MB	TG-5500CA	TCXO	12.8	280	–40/85	3	5 x 7	Yes	TBD[3]	Note 4
NDK	NT7050BC-12.8M-NSA3517A	NT7050BC	TCXO	12.8	280	–40/85	3	5 x 7	Yes	TBD[3]	Note 4
Rakon	E6127LF	RPT7050A	TCXO	12.8	280	–40/85	3	5 x 7	Yes	TBD[3]	Note 4
Rakon	E6518LF	RPT5032J	TCXO	12.8	280	–40/85	3	5 x 3	Yes	TBD[3]	Note 4
DAPU	T75B-V319-12.80MHz	T75B-V319	TCXO	12.8	280	–40/85	3	5 x 7	Yes	Yes	Note 4
DAPU	T75B-S319-12.80MHz-S	T75B-S319	TCXO	12.8	280	–40/85	3	5 x 7	Yes	No	Note 4
Epson	TG-5500CA-68N 49.1520MB	TG-5500CA	TCXO	49.152	250	–40/85	3	5 x 7	Yes	TBD[3]	Notes 5, 6
Epson	TG-5500CA-67N 40.0000MB	TG-5500CA	TCXO	40	250	–40/85	3	5 x 7	Yes	TBD[3]	Notes 5, 6
Rakon	513872	RTX7050A	TCXO	40	280	–40/85	3	5 x 7	Yes	Yes	Note 6
TXC	7N48071002	7N	TCXO	48.0231	280	–40/105	3	7 x 5	TBD[3]	TBD[3]	Note 5
TXC	7N48071001	7N	TCXO	48	280	–40/105	3	7 x 5	TBD[3]	TBD[3]	Note 6

Supplier	Part Number	Part Family	TCXO	Freq (MHz)	Stability over Temp (±ppb)	Temp °C	Stratum	Package Size (mm)	G.8262 Options 1 and 2 Compliant[1, 2]	G.8262.1 Compliant[1, 2]	Recommended for Use with Silicon Labs Clocks

Note:

1. Contact factory for ITU-T G.8262 EEC Option 1, 2 (SyncE) and ITU-T G.8262.1 eEEC (Enchanced SyncE) compliance reports.
2. TCXOs that are shown to meet the G.8262 and G.8262.1 standards exceed the minimum performance requirements called out in those standards. Customers should note that some TCXO's provide greater margin to the standards requirements than others and should factor this into their TCXO selection based on their requirements.
3. TBD. Devices have not been tested to this standard.
4. Low-frequency TCXOs recommended for use on REF input for the following devices: Si5348/83/84/88/89.
5. High-frequency TCXOs recommended for use on XA input for the following devices: Si5381/82/86.
6. High-frequency TCXOs recommended for use on REF input for the following devices: Si5392-97, Si5342-47, Si5371/72. Verify that Si5392-97, Si5342-47, and Si5371/72 device output jitter meets customer requirements when using TCXOs on XA input.

3.2 OCXOs

Consult the applicable Silicon Labs product Reference Manual for rise/fall time, input circuits, input level specifications and performance trade-offs. AN905 provides additional information on optimizing performance of external OCXO references.

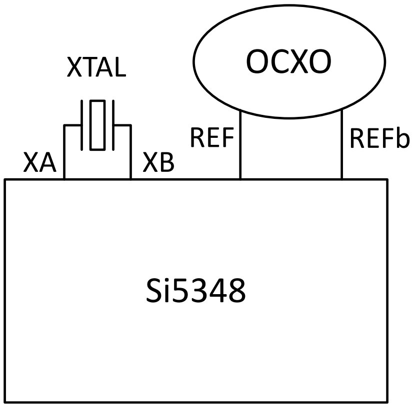

Figure 3.3. Network Synchronizer with OCXO and Crystal Reference

Table 3.2 Recommended OCXOs on page 12 lists the OCXOs that have been approved for use with members of the Si5348/83/84/88/89 devices and are connected to the REF input connections.

Note: 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 web sites. Users can also contact the vendor directly and ask for specific listed part numbers.

Table 3.2. Recommended OCXOs

Supplier	Part Number	Part Family	TCXO/ OCXO	Freq (MHz)	Stability over Temp (±ppb)	Temp °C	Stratum	Package Size (mm)	G.8262 Options 1 and 2 Compliant[1, 2]	G.8262.1 Compliant[1, 2]	Recommended for Use with Silicon Labs Clocks
Conner Winfield	OH300-50503CF-0 12.8M	OH300	OCXO	12.8	5	0/+70	3E	22 x 25.4	Yes	TBD[3]	Notes 4, 5
Conner Winfield	OH300-61003CF-0 12.8M	OH300	OCXO	12.8	10	–40/85	3E	22 x 25.4	Yes	TBD[3]	Notes 4, 5
Epson	OG2522CAN CSGJHG 12.8000MB	OG2522CAN	OCXO	12.8	10	–40/85	3E	22 x 25.4	Yes	TBD[3]	Notes 4, 5
NDK	NH14M09WA-12.8 M-NSA3540A	NH14M09W A	OCXO	12.8	10	–20/70	3E	9 x 15	Yes	TBD[3]	Notes 4, 5
NDK	NT14M09TA-12.8 M-NSA3543A	NH14M09TA	OCXO	12.8	20	–40/85	3	9 x 15	Yes	TBD[3]	Notes 4, 5
Rakon	STP3158LF[6]	ROX2522S4	OCXO	12.8	10	–40/85	3E	22 x 25.4	Yes	Yes	Notes 4, 5
Rakon	STP3268LF[7]	ROX3827T3	OCXO	10	1	–40/85	3E	38 x 27	Yes	TBD[3]	Notes 4, 5
DAPU	O22S-K319-12.8MHz-S	O22S-K319	OCXO	12.8	10	–40/85	3E	22 x 25.4	Yes	Yes	Notes 4, 5
DAPU	O22S-L119-10.0MHz-S	O22S-L119	OCXO	10	10	–40/85	3E	22 x 25.4	Yes	Yes	Notes 4, 5

Supplier	Part Number	Part Family	TCXO/ OCXO	Freq (MHz)	Stability over Temp (±ppb)	Temp °C	Stratum	Package Size (mm)	G.8262 Options 1 and 2 Compliant[1, 2]	G.8262.1 Compliant[1, 2]	Recommended for Use with Silicon Labs Clocks

Note:

1. Contact factory for ITU-T G.8262 EEC Option 1, 2 (SyncE) and ITU-T G.8262.1 eEEC (Enchanced SyncE) compliance reports.
2. OCXOs that are shown to meet the G.8262 and G.8262.1 standards exceed the minimum performance requirements called out in those standards. Customers should note that some OCXOs provide greater margin to the standards requirements than others and should factor this into their OCXO selection based on their requirements.
3. TBD. Devices have not been tested to this standard.
4. Recommended for use on REF input for the following devices: Si5348/83/84/88/89.
5. Recommended for use on XA input for the following devices: Si5392-97, Si5371/72. Verify Si5392-97, Si5371/72 device output jitter meets customer requirements when using OCXOs on XA input.
6. STP3158LF is used for Silicon Labs Compliance Testing for ITU and Telcordia standards.
7. The STP3268LF offers superior temperature and phase stability, resulting in improved MTIE TDEV noise generation performance, which may be required in some applications.

4. 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

ppb 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 year of operation and slows down over time. Since aging is specified in multiple ways, the most appropriate value to use is a 10-year 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.

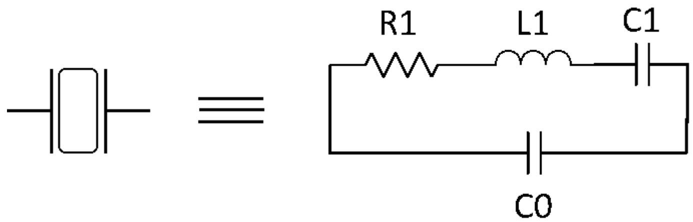

Figure 4.1. XTAL Symbol and its Equivalent Electrical Model

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.

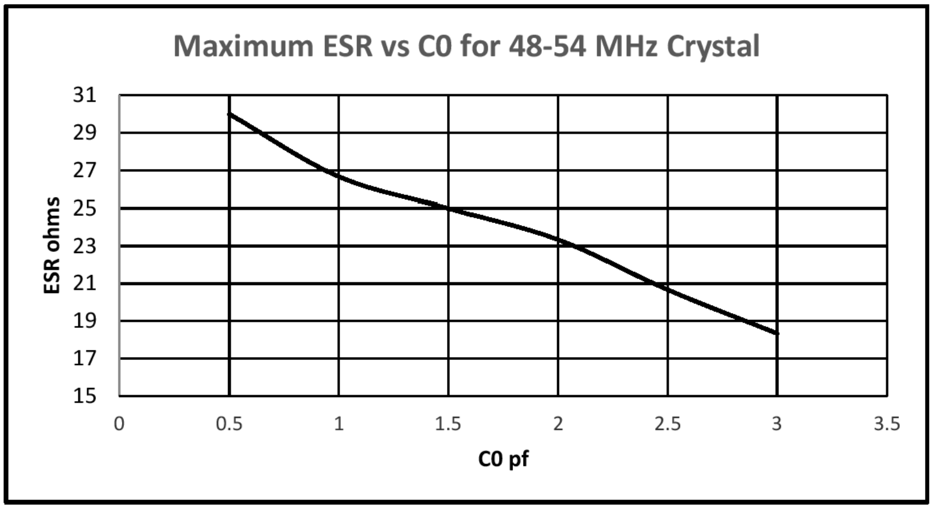

Figure 4.2. Maximum ESR vs Shunt Capacitance, C0 for 48-54 MHz XTAL

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

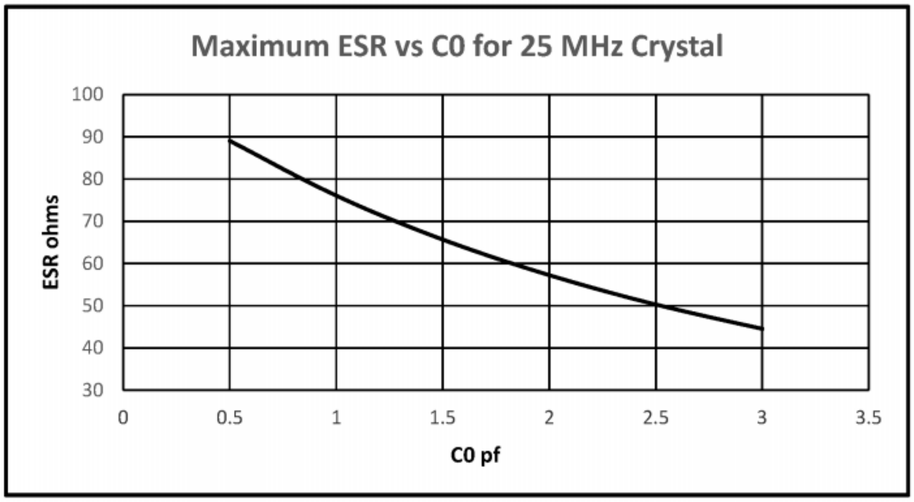

Figure 4.3. Maximum ESR vs Shunt Capacitance, C0 for 25 MHz XTAL

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.

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

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. XTALs with ESR higher than this curve 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.
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.

5. 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 on 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. Sub-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, on 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 is usually more than a TXCO but can be expensive depending on specifications.

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

Table 5.1. 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	10–280 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 the 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

ppb 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, typically 100 to 500 ppb. 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 1 to 10 ppb.

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 data sheet 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 milliseconds to reach the stable frequency.

Phase Noise Performance: Phase noise provides a measure of 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 (3 Hz or 100 mHz) 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 5.1 XO Comparison on page 18 as initial guidance.
2. Table 5.2 on page 21 outlines the important oscillator specifications you should consider for different applications.
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 may have a large impact on the output phase noise/jitter up to ~1.5 MHz.

Table 5.2. 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.

6. Revision History

Revision 1.2

January, 2020

- Front Page
  - Removed statement that says changes to this document require Silabs to issue a Product Change Notice (PCN). This document provides recommendations for Crystals, XOs, TCXOs, and OCXOs devices to use with Silabs products. It also has recommended selection criteria to help customers choose appropriate references for use with Silabs products. Customers must use their own selection and qualification processes for references used with Silabs products. Any reference used with a Silabs product must meet the specification requirements in the appropriate Silabs product data sheet.
  - Minor changes to clarify text.
  - Added Si5371/72 to Related Documents.
  - Added Si5348/83/84/88/89 Network Synchronizer Clocks and added Si5382 to Related Silicon Labs Parts.
- 1. Recommended Crystals (XTALs)
  - Added Figure 1.1 showing the crystal reference connected to the XA/XB of the clock.
  - Added text description of Table 1.1 and minor changes to clarify text.
  - Removed Si534x/7x Q grade from second paragraph. This section only applies to Silicon Si539x P grade devices.
- Table 1.1 Recommended Crystals, XTALs[1] on page 3
  - Changed table title; no device changes made.
  - Corrected typo by adding negative sign to low-end temperature specification.
- 2. Recommended Oscillators (XOs)
  - Replaced text to clarify use of XO.
  - Added Figure 2.1 Clock with XO Reference on XA Input on page 5.
  - Removed TXO/OCXO from this section and created Section 3 for these devices.
- 3. Recommended TCXOs/OCXOs
  - New section and text description for Recommended OCXO/TCXOs.
  - Added Figures 3.1 and 3.2 to clarify where TCXOs can be used in various Silabs products.
- 3.1 TCXOs
  - New separate section for TCXO’s. Added new text section to clarify use of TCXOs.
  - Added 3.1 TCXOs.
- Table 3.1 Recommended TXCOs on page 9
  - Combined previous Table 2.2 Recommended High Frequency TCXO Oscillators into Table 3.1, so all TCXO’s are in one table.
  - Added recommended devices: DAPU T75B-V319-12.80MHz, DAPU T75B-S319-12.80MHz-S, TXC 7N48071002, and TXC 7N48071001.
  - Added/updated Table Notes 1-6, and TBD.
  - Added columns: G.8262 Option 1 & 2 Compliance, G.8262.1 Compliance, Recommended for use with Silabs Clocks.
  - Corrected typo by adding negative sign to low-end temperature specification.

- 3.2 OCXOs
  - New separate section for OCXO’s. Added new text section to clarify use of OCXOs.
  - Added Figure 3.3 Network Synchronizer with OCXO and Crystal Reference on page 11.
  - Added Table 3.2 Recommended OCXOs on page 12
    - Added new recommended devices to table: DAPU O22S-K319-12.8MHz-S and DAPU O22S-L119-10.0MHz-S
    - Correct package size for Rakon STP3268LF.
    - Added/updated Table Notes 1-7 and TBD.
    - Added table columns: G.8262 Option 1 & 2 Compliance, G.8262.1 Compliance, Recommended for use with Silicon Labs Clocks.
    - Corrected typo by adding negative sign to low-end temperature specification.
    - Updated NDK NT114M09TA-12.8M-NSA3543A to Stratum 3.
  - 4. Appendix A—How to Select the Right XTAL for your Application
    - Updated "Aging" section to clarify text.
  - 5. Appendix B—How to Select the Right XTAL Oscillator for your Application
    - Minor text updates to clarify recommendations.
    - Updated Note 5 in Table 5.2 Oscillator Specifications on page 21 to clarify XO phase noise impact on clock output phase noise.

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.

ClockBuilder Pro

One-click access to Timing tools, documentation, software, source code libraries & more. Available for Windows and iOS (CBGo only).

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