List of CTS Oscillators for Telecom Timing and Synchronization

Stratum Levels for Telecom Synchronized Network, Wireless Timing and Sync, and Timing over Packet

1. Foreword

This document provides a list of possible CTS oscillators for various Stratum Levels, Wireless Synchronization and ToP (Timing over Packet) applications, which include the Stratum 2, Stratum 3E, Stratum 3, GSM, WCDMA, TD-SCDMA, CDMA2000, WiMAX, LTE, and the ToP (Timing over Packet). This list has been categorized based on applicable standards.

2. Stratum Hierarchy *

Clocks for North American synchronized networks are categorized into four basic "stratum" levels (i.e., stratum 1, 2, 3 and 4), where stratum 1 clocks are the most accurate and stratum 4 clocks are the least accurate. In addition to these four basic levels, there are two enhanced stratum classifications (i.e., stratum 3E and 4E), a level for Transit Node Clocks (TNCs) that falls between the stratum 2 and 3 levels, and another level for SONET Minimum Clocks (SMCs) that falls between the stratum 3 and 4 levels. All of these levels (which are described further below) have been standardized and their basic performance parameters are defined in ANSI T1.101. In general, the performance parameters for the various levels have been established to assure that synchronization can be transmitted through the network from the most accurate clocks, through intermediate clocks, to the least accurate clocks.

Stratum 2, 3E and 3 clocks form the major distributive part of service provider synchronization networks. These clocks are generally deployed in NEs (Network Elements) in pairs (i.e., as independent, redundant units, each of which consists of an oscillator and the functions for controlling that oscillator).

In general, the stratum 3E level was defined to be compatible with previously existing stratum 3 clocks (i.e., it has the same pull-in/hold-in requirements as stratum 3). However, the stratum 3E requirements on filtering of wander and holdover are significantly tighter than those for stratum 3. GR-436-CORE recommends that stratum 3E clocks be the minimum clocks used for Building Integrated Timing Supply (BITS) applications. In addition, it is recommended that stratum 3E or higher quality clocks not be used in NEs other than a BITS (e.g., it is recommended that transport NEs use stratum 3 or lower quality clocks).

3. Terms and Definitions *

3.1 Free-run accuracy

The accuracy of a clock is a measure of its ability to generate, in the absence of any reference, a frequency as close as possible to the nominal frequency. Frequency accuracy is expressed and defined quantitatively in terms of maximum fractional frequency offset, as discussed in Section 3.2. Table 4-1, 4-4, 4-7 lists the free-run accuracy values for the various clock stratum levels (Stratum 2, 3E, 3).

Free-run accuracy represents the maximum long-term (20 years) deviation limit from the nominal frequency with no outside frequency reference (Free Run Mode).

3.2 Frequency Accuracy

Accuracy is used in this document to indicate the degree to which the frequency of a clock may deviate from its ideal or desired value. Accuracy is usually used to specify the frequency deviation of a clock in the free-run mode. (See Section 3.6 for a discussion of modes.) Accuracy is defined such that the magnitude of the fractional frequency offset of a clock does not exceed the specified number, where:

fractional frequency offset = $(f-f_d)/f_d$
f = actual frequency output of a clock
f_d = ideal or desired frequency.

3.3 Frequency Drift

Drift is a measure of how a clock's frequency accuracy (or offset) changes with time. Drift is typically used (along with an initial holdover accuracy or offset limitation and possibly a temperature-related factor) to limit the frequency offset of a clock in the holdover mode.

3.4 Holdover stability

Holdover stability represents the maximum change in the clock frequency over time after the loss of all frequency references (Holdover Mode). In most cases the values listed here are composite values, and more detailed criteria appear in the referenced section or document.

Holdover frequency stability is a measure of a clock's performance while in the holdover mode of operation (which is defined as below in Section 3.5), and is expressed and defined quantitatively in terms of maximum fractional frequency offset and (in some cases) drift. Table 4-1, 4-4, 4-7 lists the composite holdover stability values that are applicable for the various clock stratum levels. These values and the holdover stability requirements contained in this section apply while a stratum 2, 3E or 3 clock1 is operating in the holdover mode, but had been locked to a stratum 1 quality signal for a time period sufficient to establish the clock's holdover value.

3.5 Holdover mode

The holdover mode is the operating condition of a clock that has lost its references and is using data previously acquired (when it was operating in the normal mode) to control its output signal. In general, the stored data or "holdover value" used by a clock in the holdover mode is an average value obtained over some period of time (in order to reduce the effects of any short-term variations that might occur in the reference frequency during normal operations).

3.6 Free-run mode

Free-run mode - The free-run mode of a clock is its operating condition when the output signal is totally internally controlled, with no influence of a present or previous reference. The free-run mode is the normal mode for a stratum 1 clock. Under certain unusual conditions, a network synchronization coordinator may choose to operate a clock of any other stratum level in the free-run mode without the alarms usually associated with that mode.

3.7 Pull-in range

Pull-in range is a measure of the maximum input frequency deviation from the nominal clock rate that can be overcome by a clock to pull itself into synchronization with a reference signal. This requirement applies with the clock free-run frequency at the extremes of its accuracy limits.

3.8 Wander

Wander is defined in ANSI T1.101 as the long-term variations of a digital signal's significant instants from their ideal positions in time. Long-term variations are those that are of low frequency (e.g., less than 10 Hz). Wander is usually specified and measured in terms of Maximum Time Interval Error (MTIE) and Time Deviation (TDEV).

3.9 Time Interval Error (TIE)

TIE is defined as the variation in the time delay of a given signal relative to an ideal timing signal over a particular time period. This time period is referred to as the observation time, S. Phase-time errors that are small, relative to those that cause a slip, are frequently expressed as TIE and may be measured in units of nanoseconds (ns), microseconds (µs) or UI. Figure 3-1 shows an example of TIE and also of MTIE, both of which are functions of the observation time S.

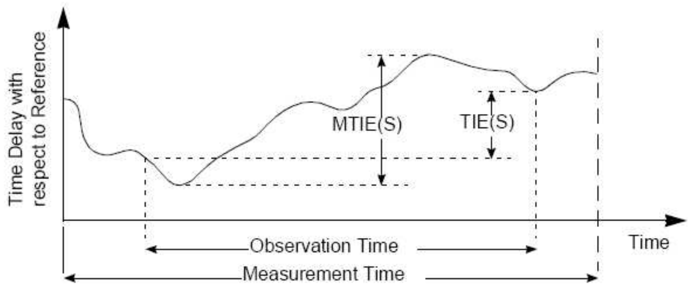


Figure 3-1: TIE and MTIE Example

3.10 Maximum Time Interval Error (MTIE)

MTIE finds the peak-to-peak variations in the time delay of a signal for a given window of time (the observation time) as shown in Figure 3-1. Therefore, it is particularly useful for specifying transients, bounding maximum wander and controlling frequency offsets. For more information on MTIE refer to Annex C in ANSI T1.101.

3.11 Time Deviation (TDEV)

TDEV [or $\delta x(\tau)$] is expressed in units of time (e.g., nanoseconds), and is the square root of Time Variance (TVAR), which is mathematically defined in Section 3.12. The TDEV at a given integration time is essentially a calculation of the rms energy of a timing signal's phase noise as measured through a bandpass filter, with the characteristics of the filter determined by the integration time. Therefore, TDEV is particularly useful for specifying the spectral content of phase noise. This is necessary for wander transfer requirements that specify how much filtering a clock must perform. It is also helpful in wander generation requirements to limit the wander that is generated at various frequencies so that it can be filtered by downstream clocks and network wander accumulation can be controlled. Additional information on TDEV is available in Informative Annex D of ANSI T1.101.

In evaluating TDEV results, it is important to realize that TDEV is a statistical parameter and as such has a limited confidence that must be taken into account. In general, TDEV results have a higher confidence when calculated from data collected over a longer measurement period (i.e., the confidence of a measurement improves as the ratio of the measurement period to integration time increases). However, the exact relationship is an issue that is under study. Until any additional guidelines are developed, one approach is to only use TDEV results for integration times that are some particular fraction of the total test time. For example, a lab testing a product for conformance to the applicable wander generation requirements may decide to use only integration times up to one tenth of the total test time. Therefore, to measure TDEV for integration times up to 10,000 seconds, 100,000 seconds of data would be needed.

3.12 Time Variance (TVAR)

TVAR [or $\delta x^2(\tau)$] is equal to TDEV squared and is a measure of the expected time variation of a signal as a function of integration time. TVAR can also provide information about the spectral content of the phase-time noise of a signal, and is expressed in units of time squared.

* Per GR-1244-CORE

4. Various Stratum Levels, Wireless Synchronization and ToP requirements and recommended CTS Oscillators

4.1 Various Stratum Levels

As described above, clocks for North American synchronized networks are categorized into four basic "stratum" levels (i.e., stratum 1, 2, 3 and 4), where stratum 1 clocks are the most accurate and stratum 4 clocks are the least accurate.
Stratum 2, 3E and 3 clocks form the major distributive part of service provider synchronization networks. These clocks are generally deployed in NEs (Network Elements) in pairs (i.e., as independent, redundant units, each of which consists of an oscillator and the functions for controlling that oscillator).
Stratum1 and 4 is intentionally not discussed herein.

4.1.1 Stratum 2

Stratum 2 requirements

Level	Free-Run Accuracy	Holdover Stability	Minimum Pull-in and Hold-in Range	Filtering	Output Phase Transients
Stratum 2	±1.6×10E-8 (±0.025 Hz @ 1.544 MHz)	±1×10E-10/day	±1.6×10E-8	Yes, 0.001 Hz	MTIE≤150 ns

Table 4-1: Stratum 2 requirements

Stratum Timing Definitions based on Telcordia GR-1244-CORE, Issue 4, Oct. 2009						
Stratum Level	**Free-Run Accuracy (Note 1)**	**Holdover Stability (Note 2)**	**Pull-In Range (Note 3)**	**Initial Offset (Note 4)**	**Temperature Stability (Note 5)**	**Drift (Note 6)**
Stratum 2	±1.6×10E-8	±1×10E-10/day	±1.6×10E-8	-	-	-

Table 4-2: Stratum 2 Timing Definitions based on Telcordia GR-1244-CORE

Notes (same as below):
1. Free-Run Accuracy: maximum offset from nominal frequency for a typical duration of 20 years.
2. Holdover Stability: maximum change in frequency upon loss of reference.
3. Pull-In Range: minimum APR (Absolute Pull Range) required to lock with reference.
4. Initial Offset: initial frequency offset in the first minute or so after loss of reference.
5. Temperature Stability: over the entire operating temperature range with all other parameters remaining fairly constant.
6. Drift: maximum change in frequency, related to aging and non-temperature environmental effects, when the temperature is held to within ±5°F.

Recommended CTS Oscillators for Stratum 2 Applications

Oscillator Platform	Standard Frequencies (MHz)	Temp. Stability	Temperature Range	Aging	Package Size
Model 121 DOCXO	5, 10, 15	±0.1ppb	-20° to +70℃	<0.05 ppb/day	51x51x25mm
Model 126	5, 10	0.2 ppb pk-pk	-10° to +80℃	<0.05ppb/day	51x51x15mm

Table 4-3: Recommended CTS Oscillators for Stratum 2 Applications

4.1.2 Stratum 3E

Level	Free-Run Accuracy	Holdover Stability	Minimum Pull-in and Hold-in Range	Filtering	Output Phase Transients
Stratum 3E	±4.6×10E-6 (±7.1 Hz @ 1.544 MHz)	±1.2×10E-8 for the initial 24 hours of holdover	±4.6×10E-6	Yes, 0.001 Hz	MTIE≤150 ns

Table 4-4: Stratum 3E requirements

Stratum Timing Definitions based on Telcordia GR-1244-CORE, Issue 4, Oct. 2009						
Stratum Level	**Free-Run Accuracy**	**Holdover Stability**	**Pull-In Range**	**Initial Offset**	**Temperature Stability**	**Drift**
Stratum 3E	±4.6×10E-6	±12×10E-9/day	±4.6×10E-6	±1×10E-9	±10×10E-9	±1×10E-9/day

Table4-5: Stratum 3E Timing Definitions based on Telcordia GR-1244-CORE

Recommended CTS Oscillators for Stratum 3E Applications

Oscillator Platform	Standard Frequencies (MHz)	Temp. Stability	Temperature Range	Aging	Package Size
Model 196	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±5 ppb	-40° to +80℃	<0.5 ppb/day	36x27x13 mm
Model 118	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±8 ppb	-40° to +80℃	<1 ppb/day	25x25x13 mm
Model 119	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±10 ppb ±20 ppb	0° to +70℃ -40° to +85℃	<1 ppb/day	22x25.4x12 mm
Model 138	12.8,19.44, 20,25	±5 ppb	-40° to +80℃	<1 ppb/day	20 x 12 x 11mm
1180026-XXX**	20	10 ppb pk-pk	0° to +70℃ -40° to +85℃	<1 ppb/day	25x25x13 mm 25x25x18 mm
1190100-XXX**	20	10ppb pk-pk	-20° to +70℃ -40° to +85℃	<1 ppb/day	22x25.4x12 mm
1380100-XXX**	20	10ppb pk-pk	-20° to +70℃ -40° to +85℃	<1 ppb/day	20x12x11 mm

Table 4-6: Recommended CTS Oscillators for Stratum 3E Applications

**: XXX represent the specific p/n for the series.

4.1.3 Stratum 3

Level	Free-Run Accuracy	Holdover Stability	Minimum Pull-in and Hold-in Range	Filtering	Output Phase Transients
Stratum 3	±4.6×10E-6 (±7.1 Hz @ 1.544 MHz)	<255 slips (±3.7×10E-7) for the initial 24 hours of holdover	±4.6×10E-6	Yes, 3 Hz	MTIE≤1.0µs

Table 4-7: Stratum 3 requirements

Stratum Timing Definitions based on Telcordia GR-1244-CORE, Issue 4, Oct. 2009						
Stratum Level	**Free-Run Accuracy**	**Holdover Stability**	**Pull-In Range**	**Initial Offset**	**Temperature Stability**	**Drift**
Stratum 3	±4.6×10E-6	±370×10E-9/day	±4.6×10E-6	±50×10E-9	±280×10E-9	±40×10E-9/day

Table4-8: Stratum 3 Timing Definitions based on Telcordia GR-1244-CORE

Recommended CTS Oscillators for Stratum 3 Applications

Oscillator Platform	Standard Frequencies (MHz)	Temp. Stability	Temperature Range	Aging	Package Size
Model 114 AT-OCXO	10, 12.8, 20, 16.384	±250 ppb	-40° to +85°C	<5 ppb/day	20x13x12 mm
Model 574 AT-TCXO	10, 12.8, 16.384, 19.44, 20	±280 ppb	-10° to +70°C	<5 ppb/day	9x14x5.5 mm
Model 117 AT-OCXO	10.0, 10.24, 12.8, 16.384, 19.44, 20, 26.0, 32.768, 38.88	± 250 ppb	-40 to 85° C	<5 ppb/day	26x26x13mm
Model 03-42126-XXX	10, 12.8, 20, 16.384	±250 ppb	-40° to +85°C	<5 ppb/day	20x13x12 mm

Table 4-9: Recommended CTS Oscillators for Stratum 3 Applications

4.2 Wireless Synchronization

4.2.1 Requirements of different wireless standards for clock synchronization

Wireless standards	Frequency accuracy	Phase accuracy
GSM	50×10E-9	NA
WCDMA	50×10E-9	NA
TD-SCDMA	50×10E-9	3µs
CDMA2000	50×10E-9	3µs
WiMax FDD	50×10E-9	NA
WiMax TDD	50×10E-9	1µs
LTE	50×10E-9	0.1～0.4µs (TBD)

Table 4-10: Requirements of different wireless standards for clock synchronization

4.2.2 Synchronization in 4G/TDD-LTE

Possible synchronization requirements in LTE:

1) Synchronization requirements in ALL-IP network
2) Synchronization requirements in distributing Base Station (mesh topology among base stations)
3) Synchronization requirements in distributing BBU & RRU
4) Synchronization requirements in radio interfaces

Note: *synchronization requirement in LTE is under discussion.*

Synchronization requirements of LTE in different positions

Layer	Sub Items	Frequency Accuracy	Phase Accuracy
Network Sync	E1	50ppm	-
	STM-N	4.6ppm	-
	PTN	Not so strict	-
Node Sync	Controller-Base station	If provide location service, TBD	If provide location service, TBD
		50ppb(Time alignment over Iu)	1.5us(Time alignment over Iu)
	Inter-Base station	50ppb	3us(TD-SCDMA&TDD LTE)
	BS-Reference clock	50ppb	1.5us(TD-SCDMA&TDD LTE)
Radio interface	GSM	50ppb	-
	TD-SCDMA	50ppb	3us
	TDD LTE	50ppb	3us

Table 4-11: Synchronization requirements of LTE in different positions

4.2.3 Recommended CTS Oscillators for Wireless Synchronizations

Oscillator Platform	Standard Frequencies (MHz)	Temp. Stability	Temperature Range	Aging	Package Size
Model 125	5, 10, 15	0.4 ppb pk-pk	-10° to +70℃	<0.1ppb/day	51x51x25mm
Model 127	5, 10, 15	0.8 ppb pk-pk	-10° to +75℃	<0.1 ppb/day	36x24x20mm
Model 126	5, 10	0.2 ppb pk-pk	-10° to +80℃	<0.05ppb/day	51x51x15mm
Model 196	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±5 ppb	-40° to +80℃	<0.5 ppb/day	36x27x13 mm
Model 118	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±8 ppb	-40° to +80℃	<1 ppb/day	25x25x13 mm
Model 119	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±10 ppb ±20 ppb	0° to +70℃ -40° to +85℃	<1 ppb/day	22x25.4x12 mm

Table 4-12: Recommended CTS Oscillators for Wireless Synchronizations

4.3 ToP (Timing over Packet)

4.3.1 Define a way to validate the XO for each class of operation

- Re-use ANSI T1.101, Telcordia GR-1244-CORE and ITU-T G.812 metrics & masks

IEEE-1588 Timing over Packet requirements

	How to Validate XO				
Category	**-3dB cut-off for measurement**	**Wander Generation**		**Holderover Stability**	
Sub-Cat		**MTIE**	**TDEV**	**Constant Temp.(±5°F or ±2.8°C)**	**Variable Temp**
Units	[MHz]	[ns]	[ns]	[ns/s^2]	[ppb]
CW_10	10	100 (see mask)	10 (see mask)	46.4 x 10E-5	280
CW_30	3	100 (see mask)	10 (see mask)	11.6 x 10E-5	280
CW_100	1	100 (see mask)	10 (see mask)	1.16 x 10E-5	10
CW_300	0.3	100 (see mask)	10 (see mask)	0.58 x 10E-5	10
CW_1000	0.1	100 (see mask)	10 (see mask)	1.16 x 10E-6	0.1
Notes	Use PLL or post-filter TIE High-pass for wander gen.	G.812 Type III / Fig 1 GR-1244 / Fig 5-5	G.812 Type III / Fig 2 GR-1244 / Fig 5-4	G.812 Type II / Fig 10 G.812 Type III / Table 24 GR-1244 / Fig 5-1 GR-1244 / Fig 5-3 Stratum 3E 1 ppb/day	-40 to +85 deg C Stratum 2 0.1 ppb Stratum 3E 10 ppb Stratum 3 280 ppb

Table 4-13: IEEE-1588 Timing over Packet requirements

4.3.2 Recommended CTS Oscillators for ToP

Oscillator Platform	Standard Frequencies (MHz)	Temp. Stability	Temperature Range	Aging	Package Size
For Sub-Cat CW_1000					
Model 121 DOCXO	5, 10, 15	±0.1ppb	-20° to +70℃	<0.05 ppb/day	51x51x25mm
Model 126	5, 10, 15	< 2X10-10	-5 to 70℃	< 8X10-11/day	51x51x15.5mm
For Sub-Cat CW_100 and CW_300					
Model 196	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±5 ppb	-40° to +80℃	<0.5 ppb/day	36x27x13 mm
Model 118	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±8 ppb	-40° to +80℃	<1 ppb/day	25x25x13 mm
Model 119	10, 12.8, 13, 15, 16.384, 20, 26, 32.768	±10 ppb ±20 ppb	0° to +70℃ -40° to +85℃	<1 ppb/day	22x25.4x12 mm
Model 138	12.8, 19.44, 20, 25	±5 ppb	-40° to +80℃	<1 ppb/day	20 x 12 x 11mm
1180026-XXX**	20	10 ppb pk-pk	0° to +70℃ -40° to +85℃	<1 ppb/day	25x25x18 mm 25x25x13 mm
1190100-XXX**	20	10ppb pk-pk	-20° to +70℃ -40° to +85℃	<1 ppb/day	22x25.4x12 mm
1380100-XXX**	20	10ppb pk-pk	-20° to +70℃ -40° to +85℃	<1 ppb/day	20x12x11 mm
For Sub-Cat CW_10 and CW_30					
Model 114 AT-OCXO	10, 12.8, 20, 16.384	±250 ppb	-40° to +85℃	<5 ppb/day	20x13x12 mm
Model 574 AT-TCXO	10, 12.8, 16.384, 19.44, 20	±280 ppb	-10° to +70℃	<5 ppb/day	9x14x5.5 mm
Model 117 AT-OCXO	10.0, 10.24, 12.8, 16.384, 19.44, 20, 26.0, 32.768, 38.88	± 250 ppb	-40 to 85° C	<5 ppb/day	26x26x13mm
Model 03-42126-XXX**	10, 12.8, 20, 16.384	±250 ppb	-40° to +85℃	<5 ppb/day	20x13x12 mm

Table 4-14: Recommended CTS Oscillators for IEEE-1588 ToP

**: XXX represent the specific p/n for the series.

Each OCXO Model noted above is a versatile platform. Many of the performance specifications are able to be modified for more custom applications.

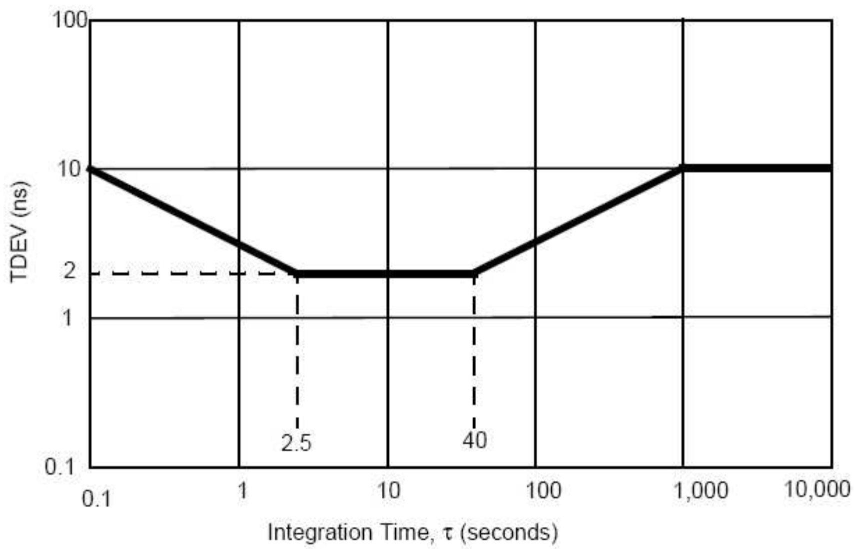
Appendix:

Wander Generation

Please be noted that the Wander Generation performance, both MTIE and TDEV, are very important considerations for both Stratum 3E and ToP.

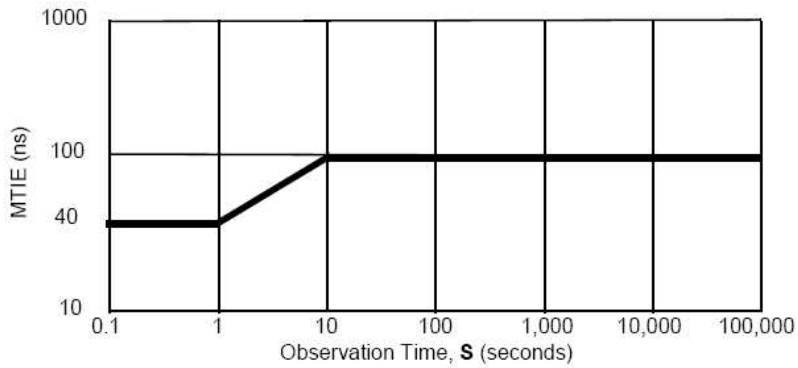
Wander generation is the process whereby wander appears at the output of a clock in the absence of input wander.

In general, the intent of these requirements is not to specify the amount of filtering that a clock may provide, but to limit the amount of wander the clock generates.



Integration Time, τ (seconds)	**TDEV (nanoseconds)**
$\tau < 0.1$	N/A
$0.1 \le \tau < 2.5$	$3.2 \times \tau^{-0.5}$
$2.5 \le \tau < 40$	2
$40 \le \tau < 1000$	$0.32 \times \tau^{0.5}$
$1000 \le \tau < 10000$	10
$10000 \le \tau$	No Specification

Figure A-1. Stratum 3E Wander Generation - TDEV



Observation Time, S (seconds)	**MTIE (nanoseconds)**
S < 0.1	N/A
0.1 ≤ **S** < 1	40
1 ≤ **S** < 10	$40 \times S^{0.40}$
10 ≤ **S** < 1000	100
1000 ≤ **S**	100

Figure A-2. Stratum 3E Wander Generation - MTIE

CTS also has an extensive line of TCXOs, VCXO's and Clock Oscillators that serve telecom timing and synchronization applications. For more information and data sheets for these products, as well as for the Models listed above, please visit http://www.ctscorp.com/components/default.htm or contact one of the individuals below.

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