Time & Frequency Measurements for Oscillator Manufacturers using CNT-91

White paper from Pendulum Instruments

February 2008

1. Background

Instruments for measurement of time or frequency are used for many different purposes at oscillator manufacturers, at different departments:

- Adjustment and verification of frequency (production)
- Frequency verification to specs (QC – Quality Control)
- Long term stability (ageing) of oscillators (production / QC)
- Temperature stability measurements of oscillators (R&D / QC)
- Short-term-stability test; ADEV vs τ (R&D or production)
- Start-up performance (R&D / QC)
- Wander parameter measurements (TIE, TDEV) in clock modules for telecom (R&D / QC)
- Verification of frequency purity (finding frequency micro-glitches) in R&D
- PLL parameter testing (R&D)
- Phase comparisons of frequency standard clocks (Cal lab)
- Calibration of other instruments (Cal lab)

Several different instruments have traditionally been used for different types of measurements like:

- Frequency only counters
- Timer-counters
- Phase comparators
- ADEV-test sets
- Modulation domain analyzers
- SDH synchronization testers
- etc.

With the CNT-91 from Pendulum Instruments, you can perform all these measurements, with or without the optional Modulation Domain SW TimeView in one single instrument, combining the essential properties of the instruments listed above.

The following pages will show some examples where the CNT-91 will give highest possible performance for typical measurements in oscillator R&D and manufacturing processes.

2. CNT-91

- 50 ps single-shot time resolution for very accurate phase comparisons of reference clocks
- 12 digits/s resolution for ultra-fast frequency measurements
- zero-dead-time measurements for fast measurements and frequency/phase glitch capturing
- built-in TIE measurements to measure TIE and TDEV for network clocks
- up to 4k individual results/s over GPIB for fast data transfer
- up to 10k streaming block measurements/s continuously
- modulation domain analysis (with optional TimeView^{TM} SW) to replace HP53310A in existing lab set-ups
- HP53132A emulation mode, for plug and play replacement in older test systems

CNT-91 is the ideal tool for all companies manufacturing oscillators and clock modules.

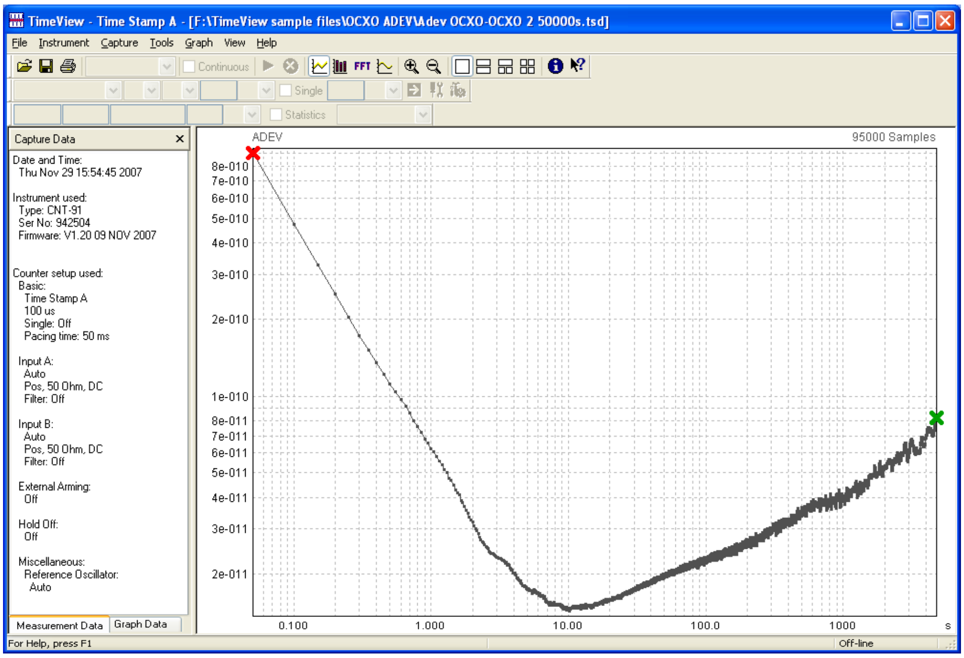
In production test stations, the high resolution and measurement speed, together with HP53132A GPIB emulation mode, makes CNT-91 the best choice for frequency adjustment and verification.

In the Quality Control Dept, the CNT-91 – with or without TimeView – can be used for all types of verification of frequency or time parameters, e.g. ageing over days, weeks or months, frequency variation due to environmental changes of e.g. temperature, verification of Wander parameters (TIE, TDEV) on sample tests, verification of short-term stability (ADEV), etc

In the calibration lab, the high 50 ps time interval resolution enables accurate and fast phase comparisons between in-house frequency standards. The measurement versatility makes CNT-91 the ideal calibrator for frequency time-bases in e.g. generators, spectrum analyzers etc. or for time-interval or phase calibrations.

In R&D, the modulation domain SW (TimeView^{TM}) enables fast and high resolution measurements of frequency vs time, to e.g. characterize start-up behaviour of oscillators, automatic measurements of short term stability (ADEV vs τ), analysis of clock PLL design in the design phase, sample testing of wander parameters (TIE, TDEV), detection of frequency glitches, etc.

3. TimeView™ Modulation Domain Analysis SW


TimeView - Time Stamp A - [F:\TimeView sample files\OCXO ADEV\Adev OCXO-OCXO 2 50000s.tsd]

Capture Data

Date and Time:
Thu Nov 29 15:54:45 2007

Instrument used:
Type: CNT-91
Ser No: 942504
Firmware: V1.20 09 NOV 2007

Counter setup used:
Basic:
Time Stamp A
100 us
Single: Off
Pacing time: 50 ms

Input A:
Auto
Pos, 50 Ohm, DC
Filter: Off

Input B:
Auto
Pos, 50 Ohm, DC
Filter: Off

External Arming:
Off

Hold Off:
Off

Miscellaneous:
Reference Oscillator:
Auto

For Help, press F1

Figure 1. A TimeView plot of ADEV vs τ for an OCXO

What TimeView does:

For R&D engineers, the optional *TimeView™ Modulation Domain Analysis SW* provides valuable insight in an oscillator's short-term and start-up behaviour, which no other type of instrument can do.

Furthermore TimeView can monitor ageing, measure TIE (for network clocks) and find any frequency anomaly (glitches, phase shifts) in oscillators

How TimeView works:

TimeView takes the zero-dead-time frequency, time or phase data from CNT-91, and displays and processes the data.

The basic presentation mode is to show the variation of frequency, time or phase vs time. This unique *modulation domain presentation mode*, is unique for a modulation domain analyzer (like the combination of CNT-91 and TimeView) and reveals signal properties that complement the traditional time domain (oscilloscope view) or frequency domain (spectrum analyzer view).

The *statistics presentation mode* presents numerical statistics and histogram presentation to reveal jitter types and possible modulation

The *FFT presentation* detects both intentional and unwanted modulation of the oscillator frequency

The *timestamp presentation mode* is used to e.g. calculate short-term stability ADEV over τ. See plot in figure 1 above

4. Ultra-fast frequency adjustment and testing in production

High-volume production testing of oscillators is made in automated test system using custom designed test jigs for several oscillators, that are either measured in parallel or sequentially switched. Total throughput is limited by the handler, the measurement time, the oscillator-switching overhead, and the data transfer time. In these measurements, bus **measurement speed** and **resolution** are key parameters. CNT-91 offers ultimate resolution (1E-11 at just 100 ms measuring time), and GPIB bus speed (up to 4k low-resolution measurements/s).

To verify frequency to 8 significant digits requires only 5 ms of measurement

Fast switching between FREQ A and FREQ B

A fast way of doing frequency measurements on oscillator-DUTs (DUT = Device Under Test), is to let the handler connect two oscillators at a time to one counter, to input A respectively input B. That means the test sequence is:

Connect DUT 1 and 2 to input A and B, measure A, measure B,
switch to DUT 3 and 4 to input A and B, measure A, measure B, etc

Instead of:

Connect DUT 1 to input A, measure A,
switch to DUT 2 to input A, measure A,
switch to DUT 3, etc

In CNT-91, the switching time to make first a measurement on A then on B is <30 ms, which should be compared to the time it takes the handler to switch DUTs

Short start time-out to detect faulty DUTs

One of the problems with fast production test of oscillators is that a DUT can be faulty. That means you let the handler connect the DUT to the counter, you start the measurement and - nothing happens. The oscillator under test is broken and gives no output signal. Some counters may more or less wait forever until the controller aborts the started frequency measurement. Other counters have programmable time-out and can abort the measurement automatically.

One problem with time-out settings in traditional counters is that they define the time when the measurement should have *stopped*, not started, and the time-out time must be longer than the gate time (measuring time). For example, if the measuring time is 500 ms, the time-out should be set to e.g. 600 ms, meaning you need to wait 600 ms before you know that the DUT is broken.

CNT-91 can set time-out both for start and stop of the measurement, and can be set to a *very short start time-out-time out of just 10 ms*, to quickly detect faulty oscillators

Low volume production testing

For low volume production testing, you may see semi-automatic test stations, with manual handling of the DUTs, and sometimes even manual read-out. In these applications, the CNT-91 offers some unique advantages, like:

- *graphical representation of test limits on the built-in display*
- *USB connector to the PC running test SW (no need to invest in GPIB-cards)*

5. Oscillator start-up measurements

A common task in oscillator manufacturing is to verify the oscillators start-up performance. In other words, how long time after switch-on is the oscillator operating with ”satisfactory” frequency accuracy. The accuracy limits are typically in the order of one or a few ppm.

The Pendulum Instrument CNT-91 timer/counter/analyzer provides a very cost-effective solution to this measurement problem, via the unique feature of continuous timestamping.

The CNT-91 has a *very-high resolution* also for short measurement times, and the *unique Frequency-back-to-back* (FREQ BtB) measurement function. With this function, you avoid the dead time between measurements, which is found in the “normal” Frequency measurement function.

Set-up

1. Connect the oscillator under test (DUT) to the CNT-91 and supply voltage as shown in figure 2

2. Connect the CNT-91 via USB or GPIB to a PC running an application program, e.g. TimeView^{TM}.

3. Set a suitable measurement time that fits the required resolution. E.g. 50 microseconds for 1 ppm resolution/sample in CNT-91

4. Set an array size with a suitable number of samples (define the total time to capture frequency data). E.g. 200 Samples and 50 microseconds Frequency back-to-back measurements gives a total time for the measurement of 50µs * 200 = 10 ms

5. Switch on supply voltage to DUT, start to measure, and get the data

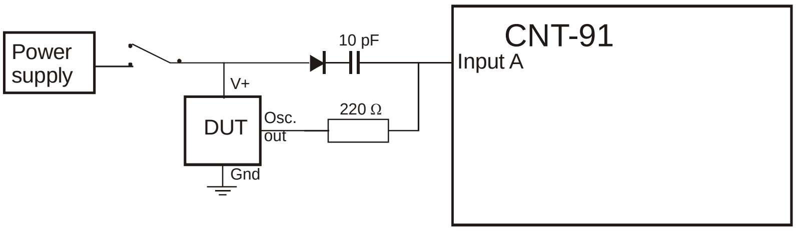


Figure 2. Set-up for Oscillator start-up measurements

The supply voltage change (a positive slope through the capacitor) is transferred to the counters measurement input as a trigger slope, and generates first timestamp (time 0 ns), the following timestamps are generated by the oscillations of the DUT.

The timestamps are taken at intervals defined by the set measuring time. See figure 3

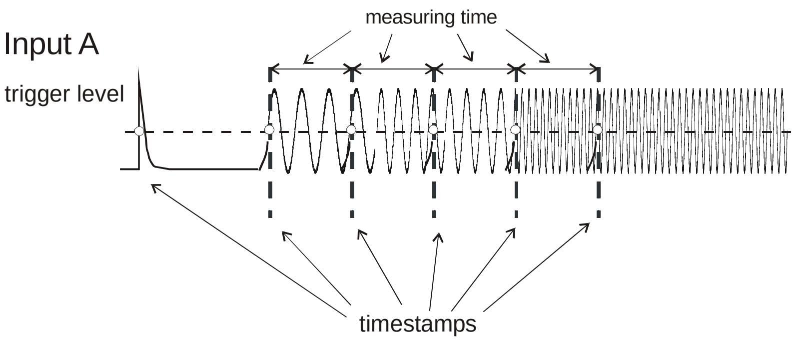
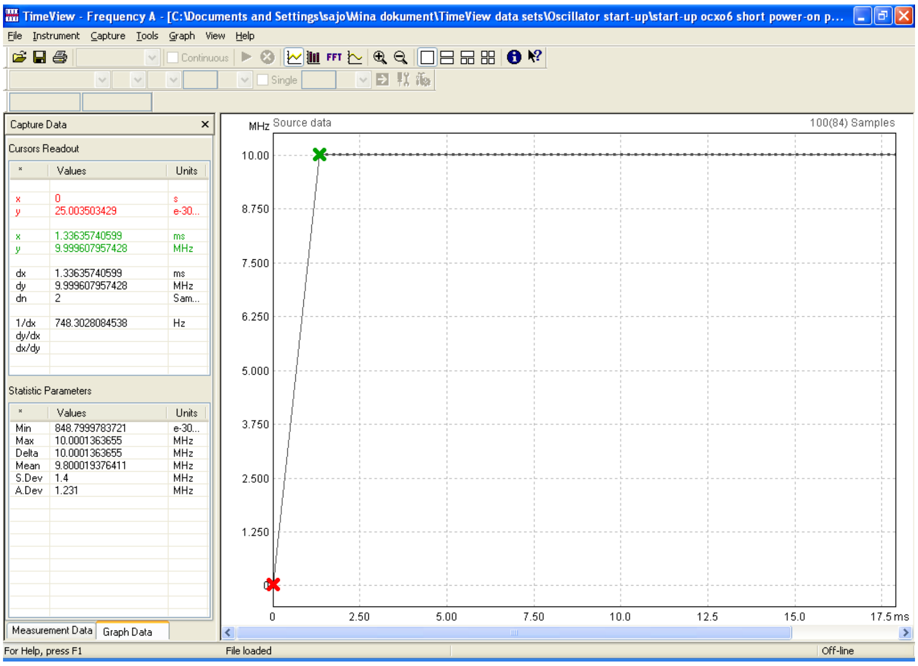


Figure 3. The set measuring time defines the time between samples

Using TimeView to measure oscillator warm-up

TimeView is set up for Frequency BtB measurements and free-run data capture. An example with a 10 MHz TCXO as DUT, using 200 µs measuring time is shown below (fig. 4):



TimeView - Frequency A - [C:\Documents and Settings\sajo\Mina dokument\TimeView data sets\Oscillator start-up\start-up ocxo6 short power-on p...

Capture Data

Cursors Readout

*	Values	Units
x	0	s
y	25.003503429	e-30...
x	1.33635740599	ms
y	9.999607957428	MHz
dx	1.33635740599	ms
dy	9.999607957428	MHz
dn	2	Sam...
1/dx	748.3028084538	Hz
dy/dx		
dx/dy		

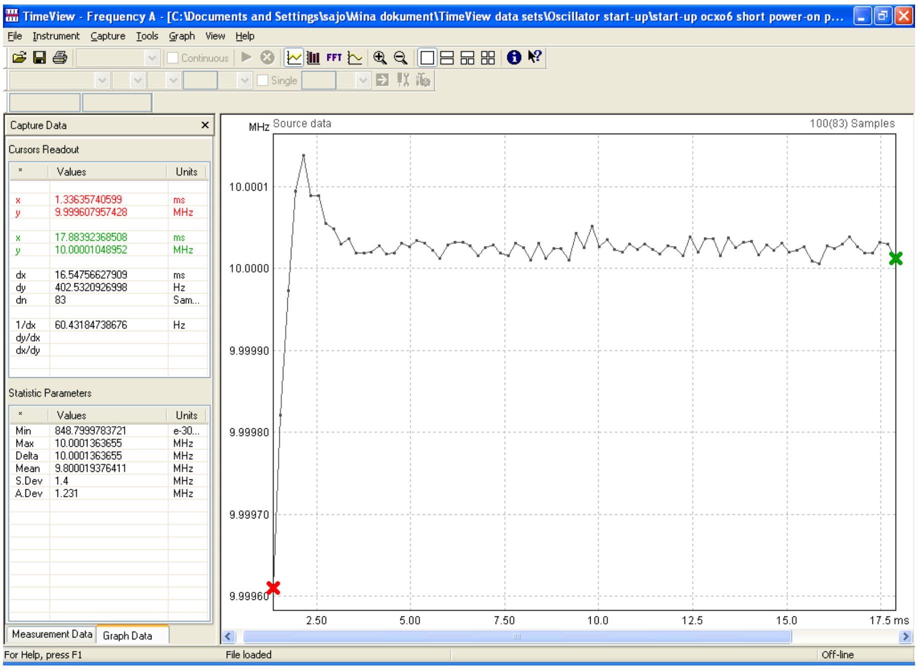
Statistic Parameters

*	Values	Units
Min	848.7999783721	e-30...
Max	10.0001363655	MHz
Delta	10.0001363655	MHz
Mean	9.800019376411	MHz
S.Dev	1.4	MHz
A.Dev	1.231	MHz

Figure 4. TCXO output frequency vs time after power up (leftmost red cursor)

The TimeView graph shows the frequency samples (Y) over a time axis (X). The first sample is the time-stamped power-on trigger (red cursor) and also the origin of the TimeView time scale.

The following samples are a sequence of 200 µs measurements starting after approx 1.3 ms (green cursor X-read-out), when the oscillator starts to generate its first oscillations. A zoom-in in the above graph reveals more details (fig. 5):



TimeView - Frequency A - [C:\Documents and Settings\sajo\Mina dokument\TimeView data sets\Oscillator start-up\start-up ocxo6 short power-on p...

Capture Data

Cursors Readout

*	Values	Units
x	1.33635740599	ms
y	9.999607957428	MHz
x	17.88392368508	ms
y	10.00001048952	MHz
dx	16.54756627909	ms
dy	402.5320926998	Hz
dn	83	Sam...
1/dx	60.43184738676	Hz
dy/dx		
dx/dy		

Statistic Parameters

*	Values	Units
Min	848.7999783721	e-30...
Max	10.0001363655	MHz
Delta	10.0001363655	MHz
Mean	9.800019376411	MHz
S.Dev	1.4	MHz
A.Dev	1.231	MHz

Figure 5. Zoom-in on start-up frequency plot

6. Wander parameter measurements (TIE, TDEV) in clock modules for telecom

Oscillators and clock modules intended for use in synchronous telecom networks, sometimes has an additional specification for wander parameters (sometimes MTIE, but most often TDEV). These wander parameters are post-processed results of the basic *TIE-measurement* (TIE = Time Interval Error). TIE is the time difference between the trigger event (normally the zero-crossing) of the actual clock or data signal, compared to the ideal clock signal. TIE =0 for the first value taken at time t=0, and TIE is thereafter the accumulated phase difference relative the first sample taken.

CNT-91 is the only counter on the market with built-in TIE-measurements, thanks to the continuous zero-dead-time measurement principle. TIE is calculated in CNT-91 as

$$TIE(i) = T_i - T_0 - \frac{E_i - E_0}{Freq_{nom}}$$

Continuous Time-stamping Zero dead-time

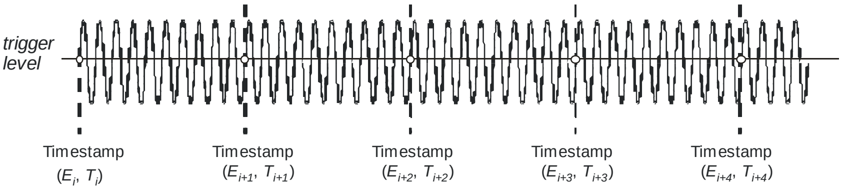
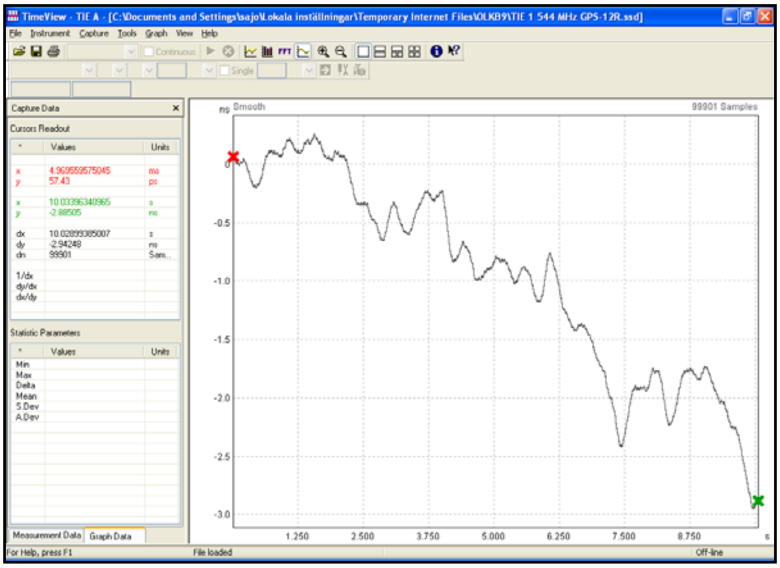


Figure 6. Zero-dead-time timestamping is an absolute must for TIE-measurements

For e.g. a Stratum 1 type of 1.544 MHz clock, each zero crossing should ideally occur with a time difference of exactly 647.668 393 782 383 ns between trigger events. The ideal time stamp, for e.g. 10 million trigger events from start of measurement, should be 6.476 683 937 8 s.

Now assume that the timestamp of the actual signal for the 10 millionth time stamp is 6.476 683 100 0. That means that the TIE for time t = 6.48s equals 837.8 ns (the difference between actual and ideal clock.

The TimeView^{TM} SW is an ideal tool to display TIE in a lab environment. See figure 7 below. The TIE file can be exported into a spreadsheet program, e.g. Excel, for further processing.


TimeView - TIE A - [C:\Documents and Settings\sajo\Lokala inställningar\Temporary Internet Files\OLKB9\TIE 1 544 MHz GPS-12R.ssd]

Cursors Readout

*	Values	Units
x	4.969559575045	ms
y	57.43	ps
x	10.03396340965	s
y	-2.88505	ns
dx	10.02899385007	s
dy	-2.94248	ns
dn	99901	Sam...
1/dx		
dy/dx		
dx/dy		

Statistic Parameters

*	Values	Units
Min		
Max		
Delta		
Mean		
S.Dev		
A.Dev		

For Help, press F1 File loaded Off-line

Figure 7. A TIE vs time graph in TimeView

7. Short-term stability testing (ADEV vs τ)

Short-term stability of oscillators is measured as Allan Deviation (ADEV) for various measurement times. Correct ADEV calculation assumes zero-dead-time or back-to-back measurements, which means that traditional counters cannot be used. Only zero-dead-time timestamping counters.

ADEV is the RMS of the difference between any two back-to-back frequency samples f_k and $f_k + \tau$, each of length τ, over any 2τ period.

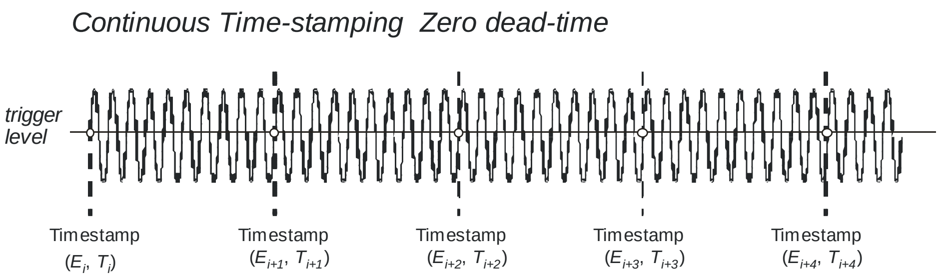

Continuous Time-stamping Zero dead-time

Figure 9. Frequency back-to-back is easily calculated from timestamp data

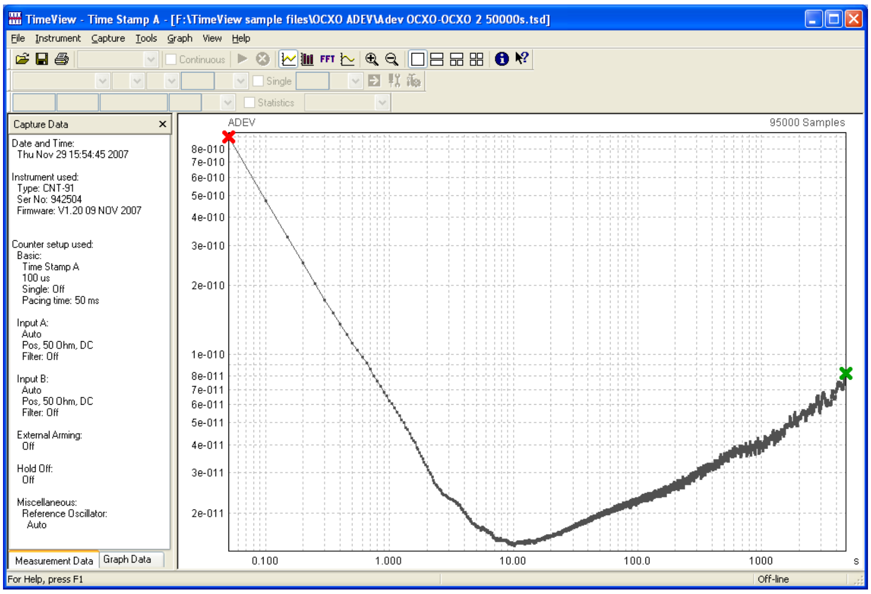
Frequency back-to-back samples f_i over τ seconds each, are calculated as:

$$f_i = \frac{E_i - E_{i-1}}{T_i - T_{i-1}}$$

With TimeView and CNT-91 you can make automatic calculation of short-term stability (σ_y or ADEV vs τ) of any frequency source up to 20 GHz, using the built-in formula:

$$\sigma_y^2(\tau) \approx \frac{1}{2(n-1)} \sum_{k=0}^{k=n-1} (y(t_k + \tau) - y(t_k))^2$$

$y(k)$ is the *fractional frequency* deviation $[\, y(k) = (f_k - f_{ref}) / f_{ref} \,]$


TimeView - Time Stamp A - [F:\TimeView sample files\OCXO ADEV\Adev OCXO-OCXO 2 50000s.tsd]

Capture Data

Date and Time:
Thu Nov 29 15:54:45 2007

Instrument used:
Type: CNT-91
Ser No: 942504
Firmware: V1.20 09 NOV 2007

Counter setup used:
Basic:
Time Stamp A
100 us
Single: Off
Pacing time: 50 ms

Input A:
Auto
Pos, 50 Ohm, DC
Filter: Off

Input B:
Auto
Pos, 50 Ohm, DC
Filter: Off

External Arming:
Off

Hold Off:
Off

Miscellaneous:
Reference Oscillator:
Auto

For Help, press F1

Figure 10. A TimeView plot of ADEV up to 5000s, showing a typical OCXO behaviour

8. Conclusion

The CNT-91 zero-dead-time timer/counter/analyzer, with or without the TimeView Modulation Domain SW, can be used for several measurements common in oscillator manufacturing:

- Adjustment and verification of frequency (production)
- Frequency verification to specs (QC – Quality Control)
- Long term stability (ageing) of oscillators (production / QC)
- Temperature stability measurements of oscillators (R&D / QC)
- Short-term-stability test; ADEV vs τ (R&D or production)
- Start-up performance (R&D / QC)
- Wander parameter measurements (TIE, TDEV) in clock modules for telecom (R&D / QC)
- Verification of frequency purity (finding frequency micro-glitches) in R&D
- PLL parameter testing (R&D)
- Phase comparisons of frequency standard clocks (Cal lab)
- Calibration of other instruments (Cal lab)

CNT-91 Timer/Counter/Analyzer features

- The highest resolution and speed available in any timer/counter on the market
- The only Modulation Domain Analyzer currently on the market
- The only zero-dead-time frequency back-to-back counter on the market
- The lowest-cost ADEV vs t tester on the market
- And - last but not least – the CNT-91 provides a very **cost-effective** solution