Operational Performance of GPS Steered Rubidium Oscillators

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Abstract

The use of the GPS Steered Rubidium Oscillator as a Time and Frequency Standard for the NASA Satellite Laser Ranging Network had been proposed as early as 1994. This is when initial field-testing was done at the Greenbelt station, operating a custom GPS Steered Rubidium Oscillator concurrently with the stations Cesium Beam Standard (HP 5061A). As this technology made steady improvements, it was decided in May of 1999 to replace all of the networks aging Cesium Beam Standards with the TrueTime XL-DC GPS Time and Frequency Receiver. This poster will describe the basic theory of operation of the GPS Steered Rubidium Oscillator. It will offer examples of actual system performance of the XL-DC units installed at various NASA SLR Partnered Stations. Also it will show pre and post Selective Availability performance, as well as laboratory data detailing Allan Deviation and phase performance of various GPS steered oscillators.

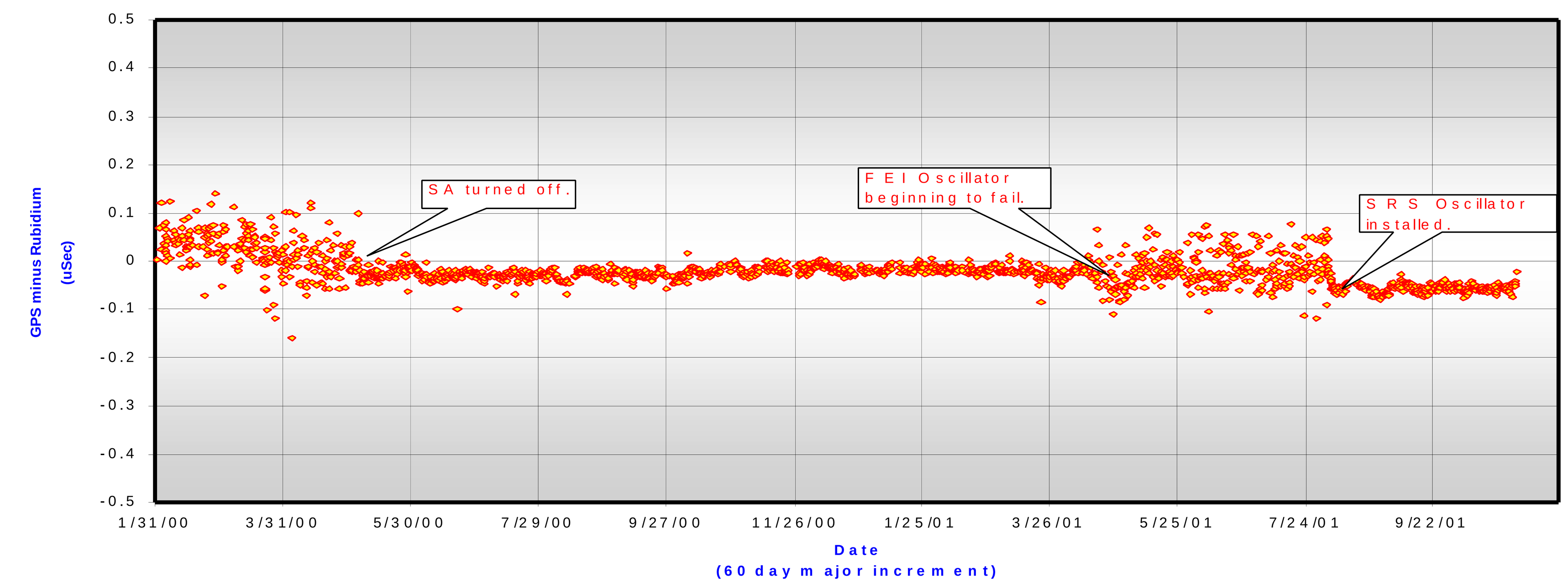
Introduction

The NASA SLR network XL-DC Time and Frequency units provide accurate time and frequency through the use of the NAVSTAR Global Positioning System (GPS) and an integrated Rubidium oscillator. This time and frequency is traceable to the Master Clock Ensemble at the United States Naval Observatory (UNSO). These systems utilize the Coarse Acquisition (C/A) 1575.42 MHz Link 1 (L1) signals transmitted by GPS to derive accurate time, frequency and position. The GPS utility is usable on a worldwide basis under any weather conditions.

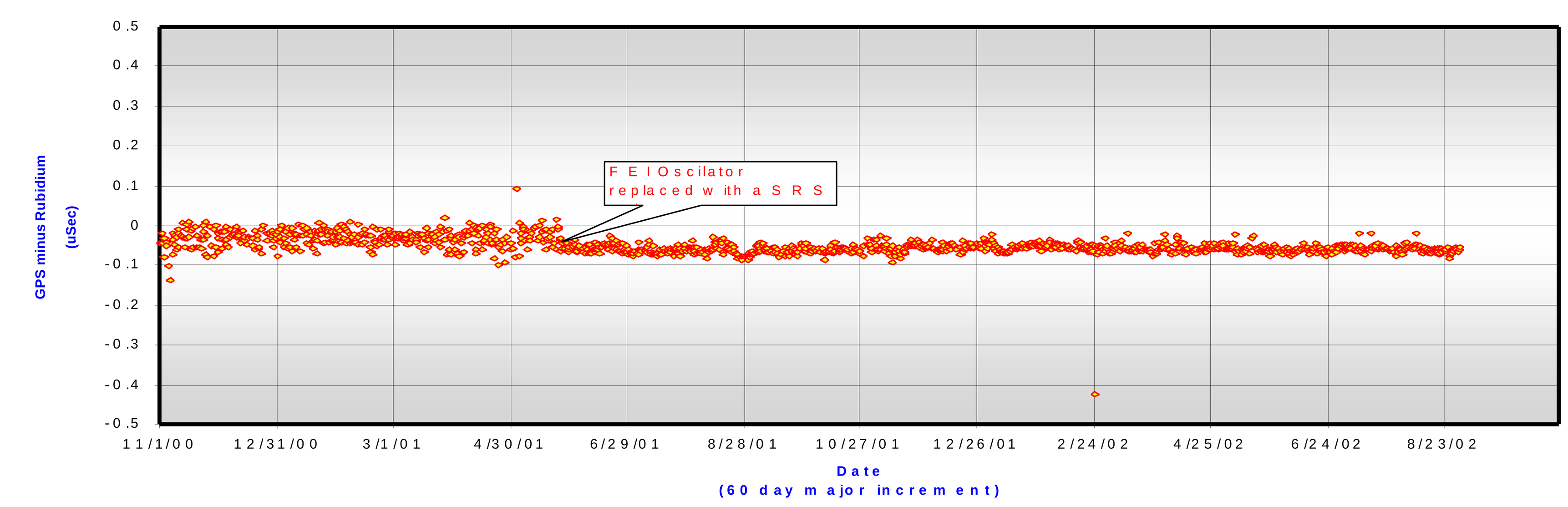
Basic Operation

- The satellite search begins; multiple satellites are searched until the first satellite is acquired.
- With the first satellite acquired, data lock is attempted. Satellite Doppler compensation is adjusted until data can be read from the satellite. (Satellite Doppler compensation, the change in the 1575.42 MHz frequency due to apparent satellite velocity as seen from ground-based receivers, is typically 0 to ± 5 KHz.)
- With the first data lock GPS time is acquired to the 20 mS level of accuracy. At this point download of the almanac data for the entire satellite constellation begins.
- During loading of the almanac, satellite searching continues. If a second satellite is found, and data lock is achieved, then the position of the unit can be placed into the correct hemisphere. This greatly narrows the search for possible satellites.
- When the third satellite is acquired, a rough position solution exists. This position assumes an ellipsoid height of 0 meters. This rough position fix is referred to as a 2-D position fix.
- The remaining visible satellites are rapidly found based on the 2-D fix, almanac data, and the time. This then produces the 3-D position fix, and synchronization to UTC begins. The XL-DC unit can use up to six satellites for this 3-D fix. The XL-DC will continue to improve its position by averaging time and position data for approximately 24 hours ("Auto" mode). This averaging produces increasingly more accurate and stable time and frequency outputs. (Should the satellite constellation visibility degrade while the unit is refining its position, time, and frequency, these 0-D and 2-D fixes are not applied to the position average, but do affect the steering of the time and frequency outputs.)
- After the 24-hour position refinement mode is complete, the unit enters the "Time" mode. At this juncture, position averaging ceases and a "fixed reference" position is used for all subsequent calculations of time and frequency. Each position update thereafter is tested against the reference position to insure that no movement of the units antenna has occurred. During the Time mode up to six satellites are used for timing solutions. This is the process that most greatly reduces the effects of Selective Availability (SA) if present, improving the accuracy of the time and frequency outputs. Satellites are chosen based on their height as seen from the reference location.
- Should the unit be unable to track satellites, its timing accuracy will be dependant on the stability and accuracy of the units Rubidium oscillator. This stability and accuracy is largely dependent on the GPS steering information that was being utilized just prior to the loss of satellite signal. (Temperature stability and the last DAC number applied are the most important factors.) The oscillator control algorithm employed phase locks the output of the oscillator to UTC. Fine adjustments to this output frequency (C-Field), are performed by the core GPS module, which produces the 16 bit DAC voltage that is applied to the rubidium oscillators Electronic Tuning Control input. Low phase noise cleanup of the output frequency is accomplished by phase locking the rubidium oscillators output frequency to the output of a quartz voltage controlled oscillator. This PLL circuit will reject the phase noise inherent in atomic oscillators.

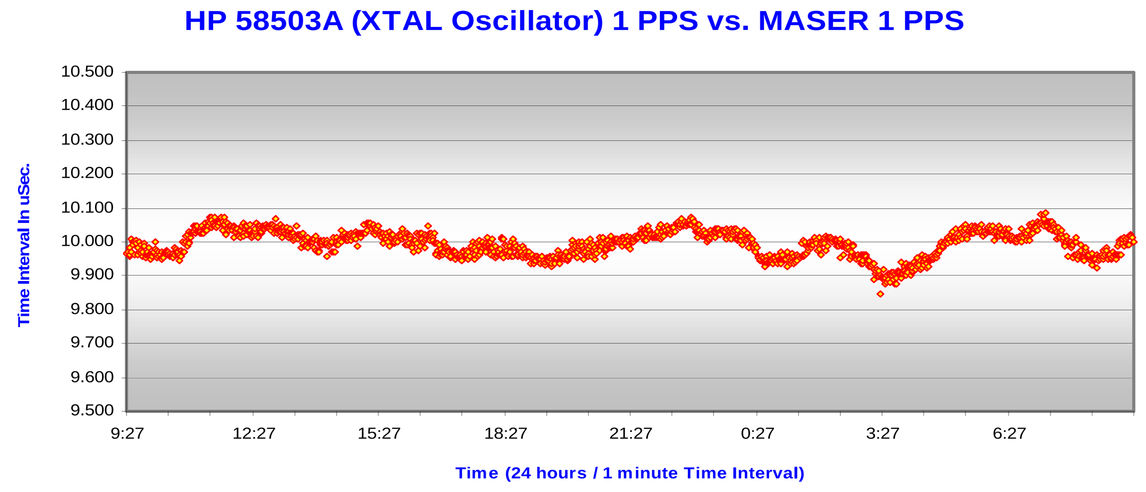
MOBLAS-4 STATION TIME POSITION
1 February '00 through 31 October '01



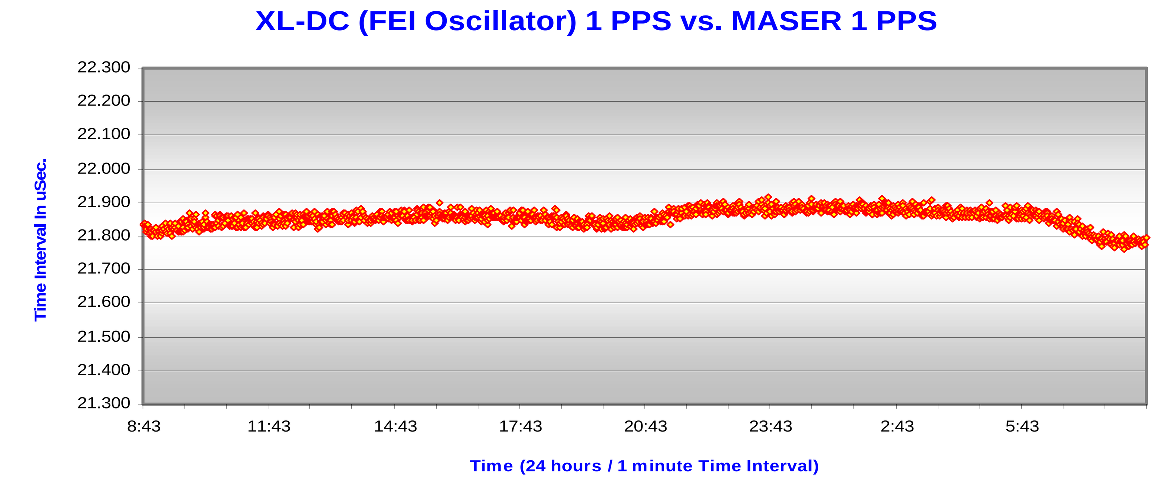
MOBLAS-5 STATION TIME POSITION
1 November '00 through 31 August '02



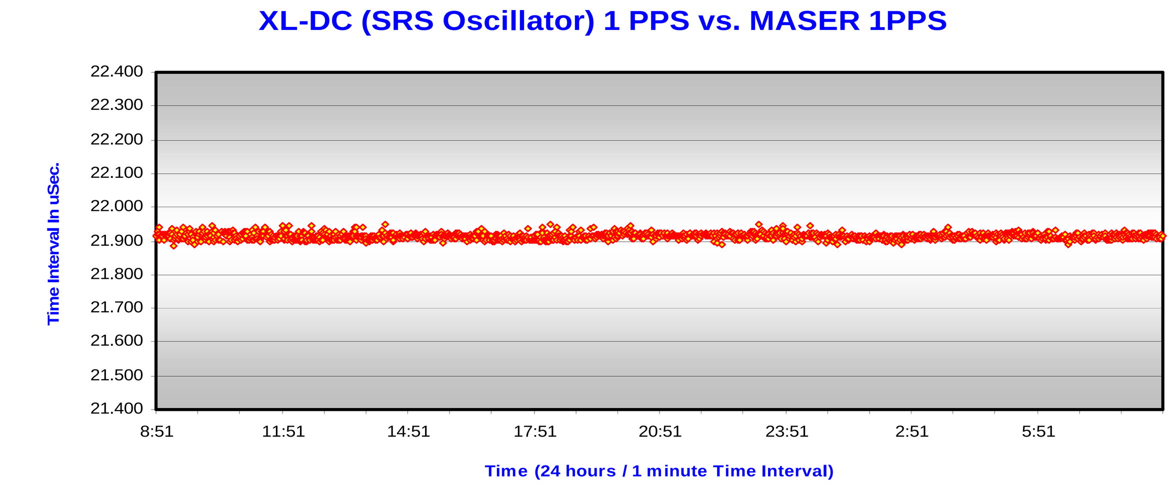
HP 58503A (XTAL Oscillator) 1 PPS vs. MASER 1 PPS



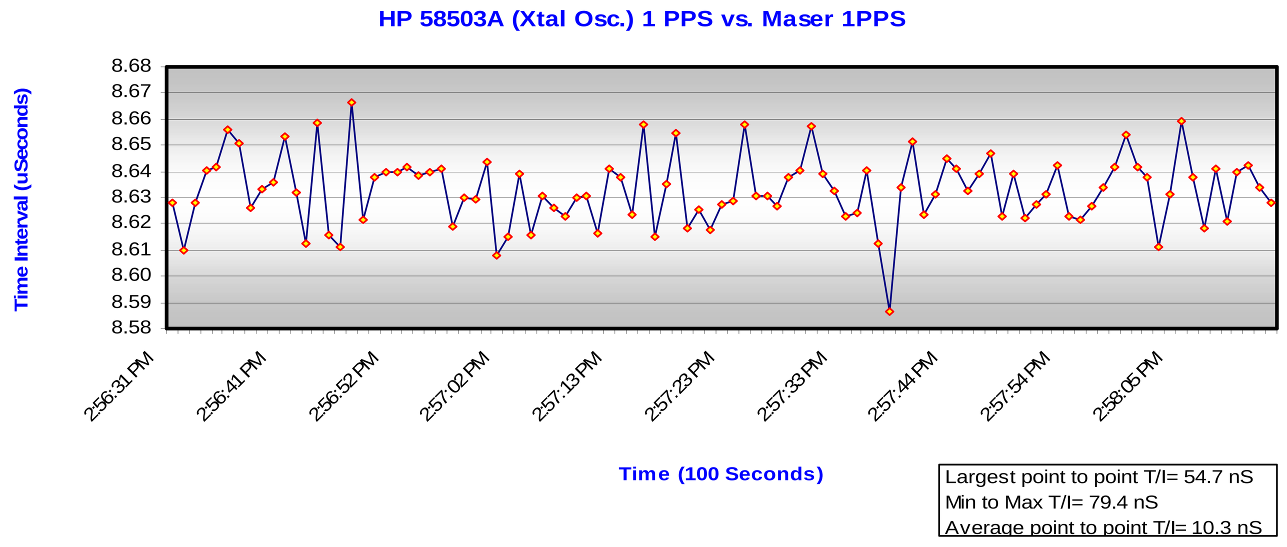
XL-DC (FEI Oscillator) 1 PPS vs. MASER 1 PPS



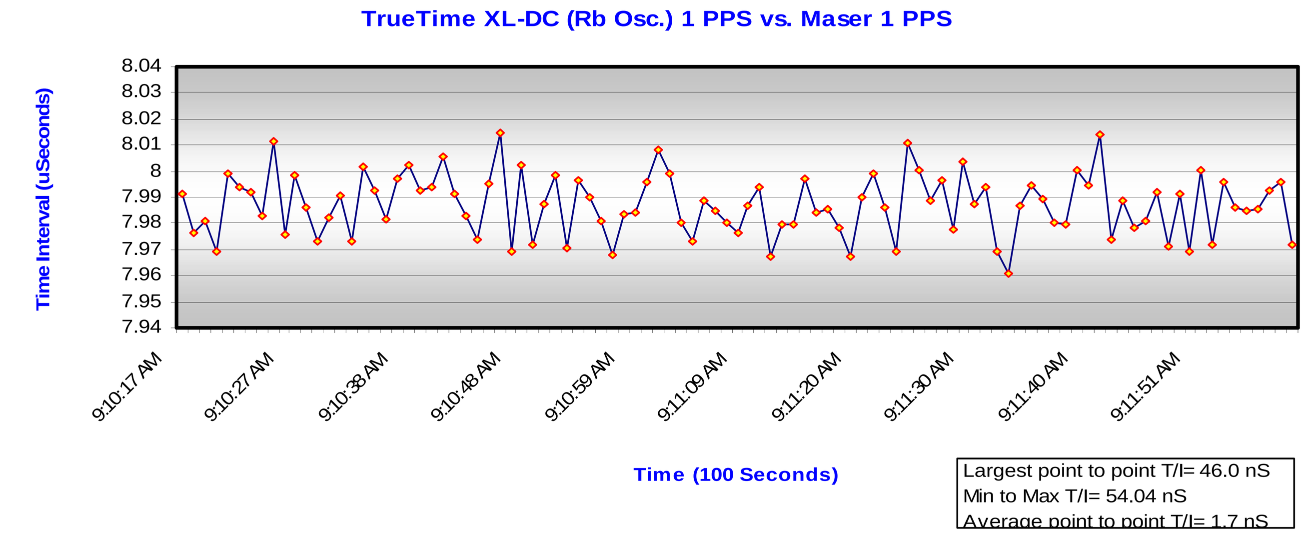
XL-DC (SRS Oscillator) 1 PPS vs. MASER 1PPS



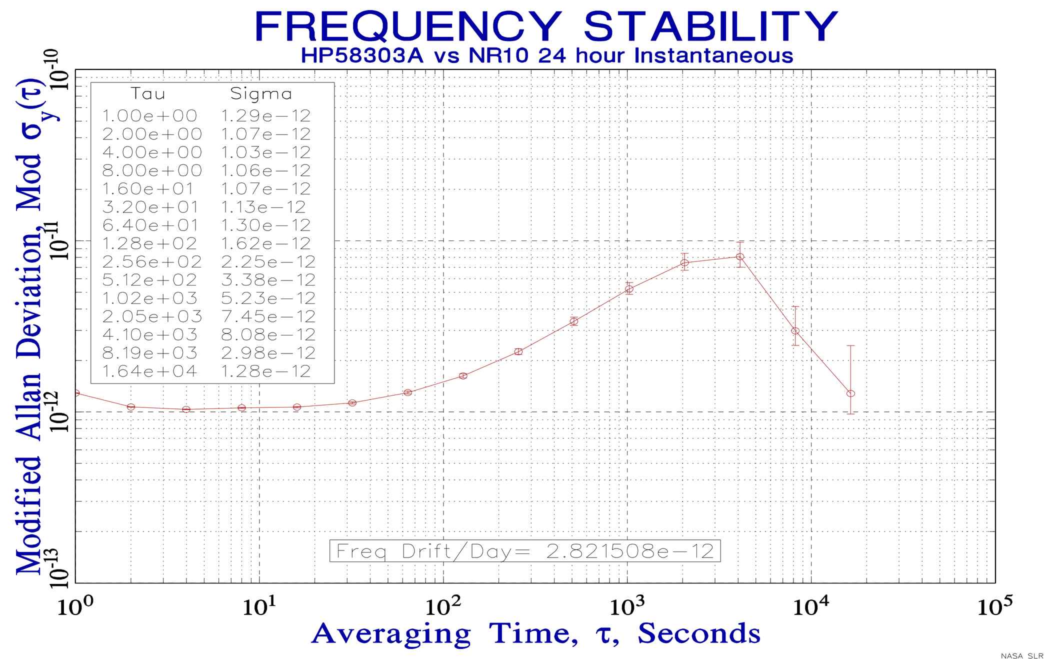
SHORT TERM TIME PERFORMANCE
HP 58503A (Xtal Osc.) 1 PPS vs. Maser 1PPS



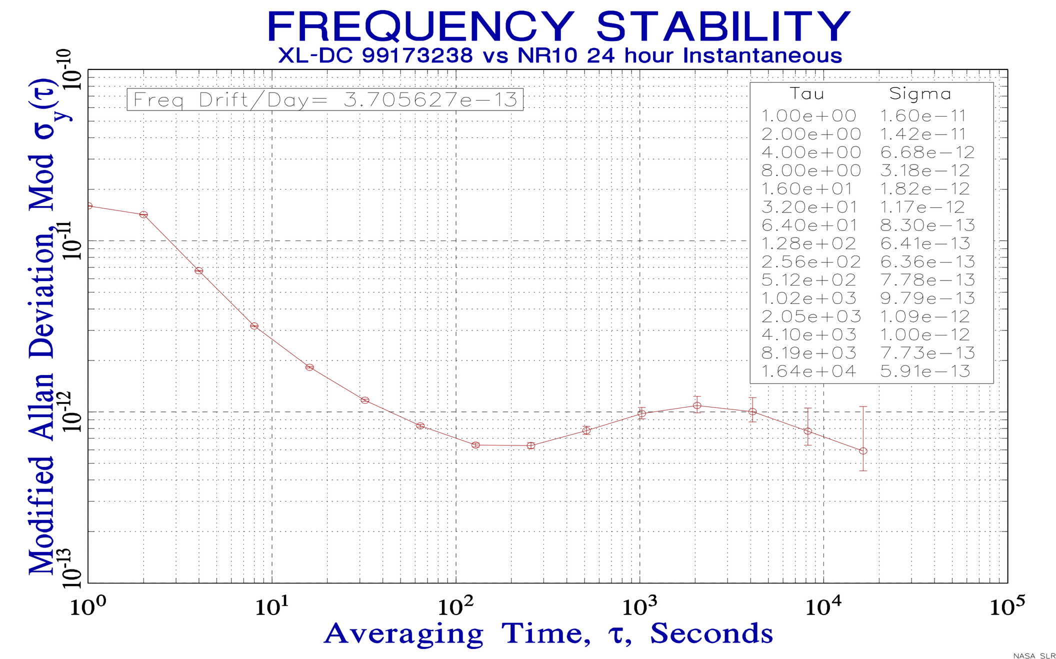
SHORT TERM TIME PERFORMANCE
TrueTime XL-DC (Rb Osc.) 1 PPS vs. Maser 1 PPS



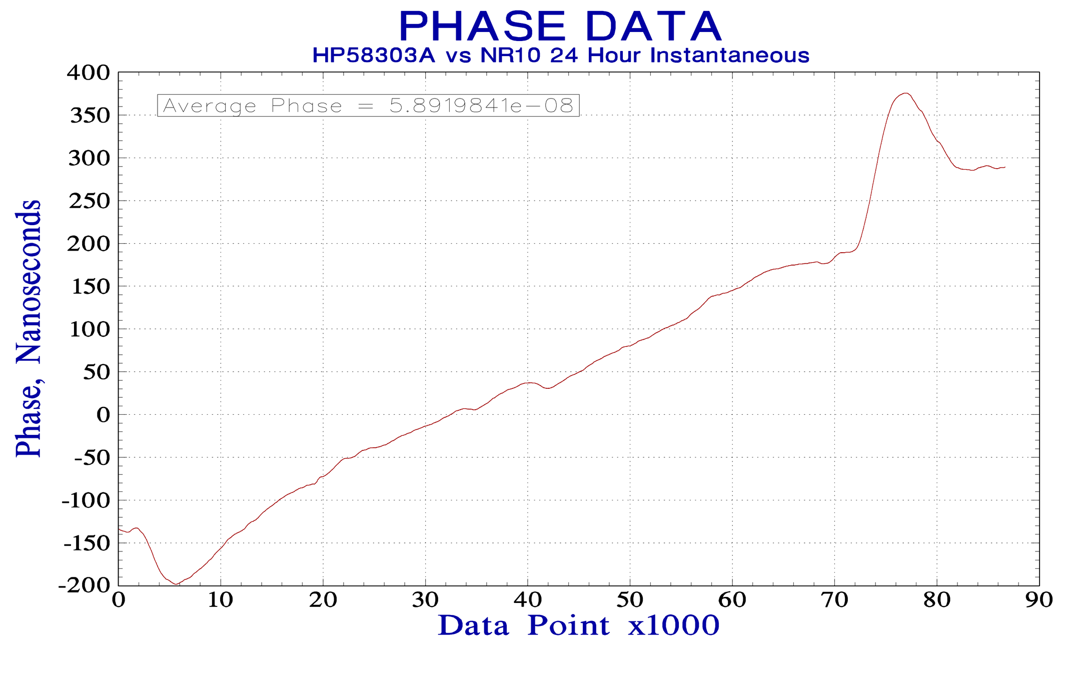
FREQUENCY STABILITY
HP58303A vs NR10 24 hour Instantaneous



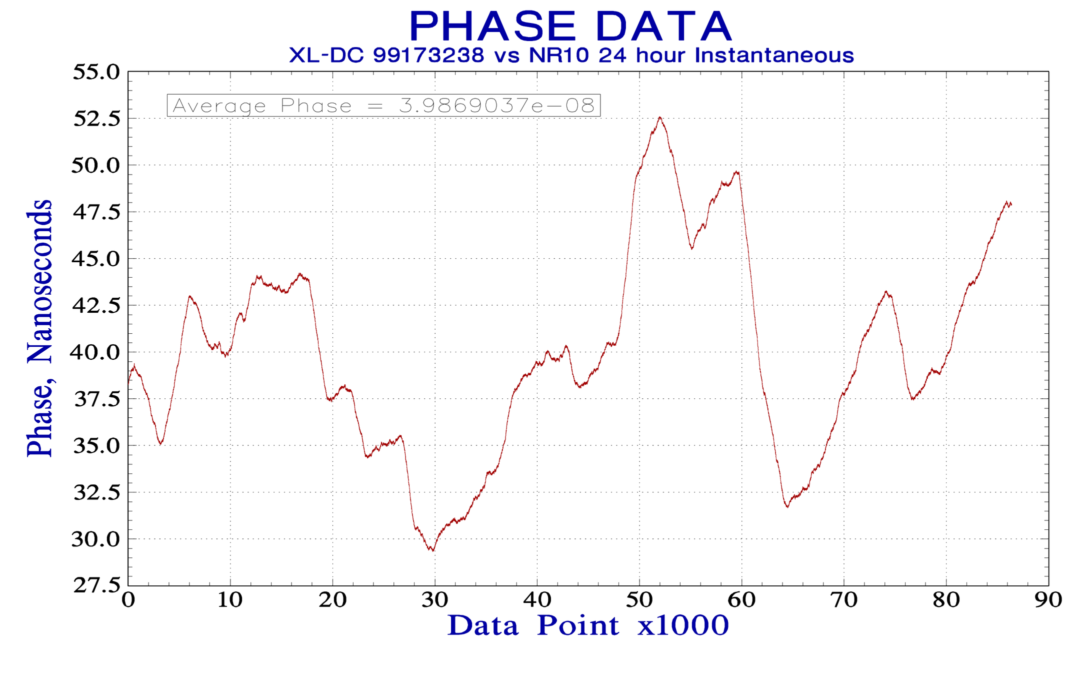
FREQUENCY STABILITY
XL-DC 99173238 vs NR10 24 hour Instantaneous



PHASE DATA
HP58303A vs NR10 24 Hour Instantaneous



PHASE DATA
XL-DC 99173238 vs NR10 24 Hour Instantaneous



Testing Methodology

A Dual Mixer Time Difference (DMTD) system was used to generate the data for the Frequency Stability, and the Phase Data plots. This DMTD system was the TSC 5110A Time Interval Analyzer. The software package "Stable32", from Hamilton Technical Services was used to perform the data analysis. The setup for the DMTD system is briefly described as follows:

- The outputs of the two oscillators, NR10 (MASER reference) and the XL-DC (DUT), are inserted into the ports of a pair of double balanced mixers.
- A third oscillator (synthesizer), with separate symmetric buffered outputs is also inserted into the remaining ports of the pair of double balanced mixers.
- The common oscillators frequency is offset by a desired amount from the other two oscillators. This produces two different beat frequencies from the two mixers.
- These two beat frequencies will be out of phase by an amount proportional to the time difference between the MASER and the XL-DC; excluding the differential phase shift that may be inserted. Additionally, the beat frequencies differ in frequency by an amount equal to the frequency difference between the MASER and the XL-DC. This is the data recorded for analysis.

The Simple Time Difference method was used to gather the data for the Time Interval type of plots. This system consisted of an Agilent 53132A Universal Counter, an Agilent 82340 GPIB Interface Card, and the HP BenchLink Meter software package (Ver. 1.1) running on an personal computer (Windows 98 O/S). The basic setup for the STD system is as follows:

- The 1 PPS on time signal from NR10 MASER was inserted as the reference on input A of the Universal Counter. The counter was set to read a level of 1.00 volt, Auto Trigger to OFF, Sensitivity to LOW, and Common to OFF.
- The above settings are duplicated for the input B, which is our DUT, the XL-DC.
- Additionally both channels are set to 50 ohms, DC, X10 attenuation is set to OFF, and the 100 KHz Filter is set to OFF.
- The counter is set to read the Time Interval 1 to 2. **No averaging or math is applied.**

The Station Time Position plots were generated from timing data reported on the respective stations Laser Operating Report (LOR).

Acknowledgements

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References

Howe, D.A., Allan, D.W., and Barnes, J.A., *Properties of Oscillator Signals and Measurement Methods*, NIST, Boulder CO

TrueTime Inc., *Application Note 24: Precision Time and Frequency Using GPS*, Santa Rosa CA

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