EVALUATION OF THE ACCURACY OF GPS-DISCIPLINED TIMING USING A GNSS SIMULATOR

Staffan Johansson, *Tekno-Studium Sweden AB*
Tim Klimasewski, *Spectracom*

ABSTRACT

Today's time and frequency references are commonly designed as GPSDOs (GPS-Disciplined Oscillators). A GPSDO consists of a GPS-timing receiver with a 1 PPS output (1 pulse per second) used to frequency discipline a stable tunable local oscillator, normally an OCXO (ovenized crystal oscillator) or a Rubidium oscillator. The goal of such a device is to provide precise reference frequencies such as 5 or 10 MHz for metrology applications and 1.544 or 2.048 MHz for telecom applications. The frequency outputs have excellent short-term stability from the local oscillator and excellent long term stability from the received GPS-signal.

The GPSDO also has a time reference output, a 1 PPS signal, which is phase aligned with the 1 PPS signal from the internal GPS-receiver. The positive edge of the 1 PPS pulse should ideally coincide with the on-time mark of the GPS-second, thus bringing the GPS time scale, and ultimately the UTC time scale, to the user.

In this paper, we describe a method to calibrate the offset and stability of the 1 PPS time reference of commercial GPSDOs. As a **reference source**, a GNSS-simulator is used to provide the GPS RF-signals and a separate 1 PPS time reference. As a **calibrator**, a frequency calibrator/analyzer is used to compare the GPS 1 PPS to the 1 PPS output from the device under test (DUT).

The measurement results on an actual test object showed that it took approximately 4 minutes from a cold start for the GPSDO 1 PPS output to align to UTC-time, and the offset in the 1 PPS pulse position between the DUT and the reference was -6 ns with a random uncertainty of 600 ps (rms) and a systematic uncertainty of ±10 ns.

EQUIPMENT DESCRIPTION AND SET-UP

Device Under Test (GPSDO)

Figure 1 — Pendulum GPS-12R/HS Rubidium Frequency Standard

The tested GPSDO is the Pendulum GPS-12R/HS Rubidium Frequency Standard commercially available from Spectracom. It contains the Resolution-T GPS L1 timing receiver from Trimble, providing accurate GPS-time and a 1 PPS output specified to have an uncertainty of 15 ns (rms) to GPS/ UTC-time. The receiver board can adjust its 1 PPS output to compensate for the delay in the antenna cable.

This 1 PPS output from the receiver board is fed to the 1 PPS input of the PRS-10 Rubidium Frequency Reference from Stanford Research. The 1 PPS input is used to frequency discipline the PRS-10 to provide a drift-free frequency output with excellent long-term stability. The PRS-10 has also a 1 PPS output which is phase aligned with the 1 PPS input coming from the GPS-receiver. It is also possible to phase step the 1 PPS output with a resolution of 1ns. The maximum difference between the 1 PPS input and the 1 PPS output, is specified to be <10 ns.

The 1 PPS output from PRS-10 is buffered and made available on the front panel of the GPS-12R/HS. The reference frequency of 5 or 10 MHz derived from the disciplined Rubidium oscillator is present on the back side.

In the measurement, the GPS-receiver in the GPS-12R/HS was cold started when power switching the unit from stand-by to ON. The local oscillator is powered in stand-by mode, so the Rubidium oscillator required no initial warm up. The stand-by time before measurement was more than 24 hours.

The GPS Reference

Figure 2 – GSG-62 GNSS Simulator

The device supplying the reference GPS RF signal to the DUT, and the reference 1 PPS pulse to the Calibrator, is the Spectracom GSG-62 GNSS Simulator. It was set to simulate a full GPS L1 constellation.

The GSG-62 contains a high-performance OCXO timebase, but can also accept an external 10 MHz reference from another source, such as a Rubidium clock. In these measurements, the Rubidium clock from the calibrator supplied the 10 MHz reference.

The simulator scenario for the GPS-RF signal was static, meaning that no trajectory, or motion path, of the GPS-receiver was simulated. This is also the normal operating condition for a GPSDO used for reference frequency or timing applications.

The GSG-62 supplies a 1 PPS output that is aligned to the on-time change of GPS-second in the RF-signal, after compensation for internal delays. The 1 PPS position has a resolution of 5 ns. The uncertainty of the 1 PPS pulse offset vs. the change in the RF-signal is specified to be <10 ns.

Note that the uncertainty of the 1 PPS pulse position can be reduced to <1 ns by a special calibration method described in reference 3.

The Calibrator

Figure 3 – Pendulum CNT-91R Frequency Calibrator/Analyzer

The calibrator comparing the two 1 PPS signals, one from the Reference and from the DUT, is the Pendulum CNT-91R Frequency Calibrator/Analyzer, a Timer/Counter with integrated Rubidium reference. The measurement resolution for the time interval measurements is 50 ps (rms). It features a zero-dead-time time-stamping technique with an uncertainty of <35 ps per timestamp.

The measurement data was collected via an analysis software package known as TimeView™ which can acquire up to 250,000 measurement results per second, and present measurement-vs-time graphs, histogram distribution, calculated Allan Deviation plots and more.

MEASUREMENT SETUP

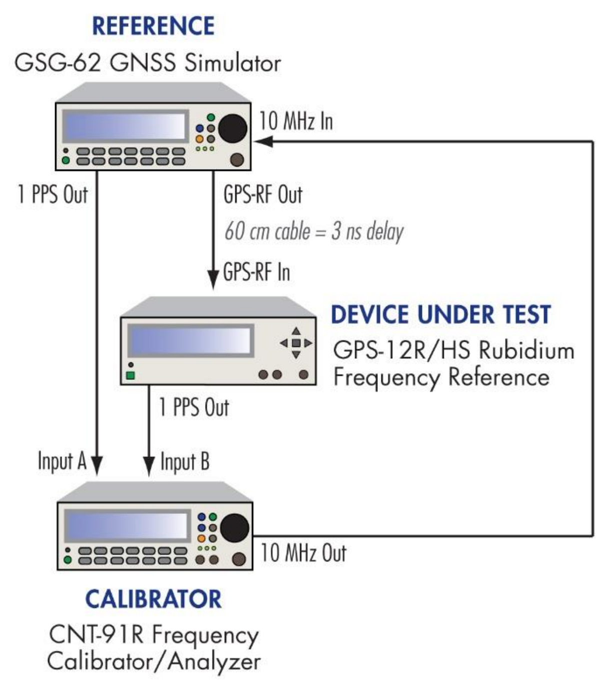

Figure 4 – Measurement setup

MEASUREMENT RESULTS

Time Difference between the 1 PPS Outputs

The time interval between the positive slopes of the 1 PPS output from the Reference and the DUT is shown in the TimeView plot in figure 5. Initially, immediately following the cold start, the DUT has a random position of its 1 PPS output. The initial offset to the reference is 338 ms (Y-axis shows time interval, X-axis shows elapsed time). After 262 seconds the offset drops to -2.8 ns. This is the time for the GPS-receiver to acquire enough satellites to make a position fix in this specific test.

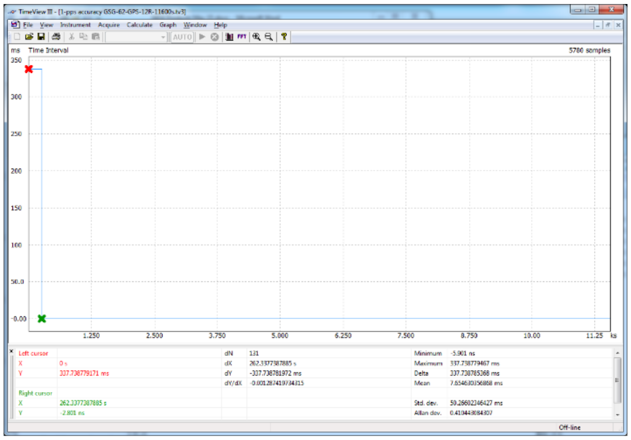

Figure 5 – Time Interval Delay between the 1 PPS signals of Reference and DUT

Zooming in on the 1 PPS time interval, after the position fix, reveals that the 1 PPS output difference between reference and DUT is fairly stable around -3 ns, with fluctuations of +1.5 ns to -3 ns. The average time interval is -2.9 ns and the standard deviation is 0.6 ns. See figure 6.

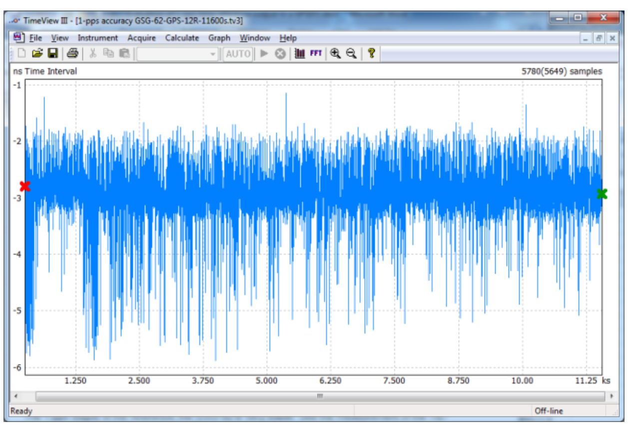

Figure 6 – Zoom-in on the variations of time delay between reference and DUT

Thus the measured time interval is -2.9 ns with a 1-σ uncertainty of 0.6 ns, before compensations.

This time interval delay between the reference 1 PPS and the DUT 1 PPS, must be compensated for the length of the GPS-RF-cable. This cable was a standard RG58 with a length of 60 cm, and a propagation velocity of 66%, meaning a delay of the RF-signal in the cable of close to 3ns.

The delay between DUT and Reference after compensation is thus -5.9 ns, still with a 1σ uncertainty of 0.6 ns. (The DUT received the RF-signal after 3 ns, and should thus be expected to generate its 1 PPS 3ns *after* the reference, but generated instead the 1 PPS 2.9 ns *before* the reference).

The cables connecting the two 1 PPS outputs to the Calibrator had equal length.

Stability of 1 PPS Output from Reference

The 1 PPS reference pulse output from the GSG-62 is very stable. See the measurement of the TIE-variations (TIE=Time Interval Error) of the reference 1 PPS output in figure 7.

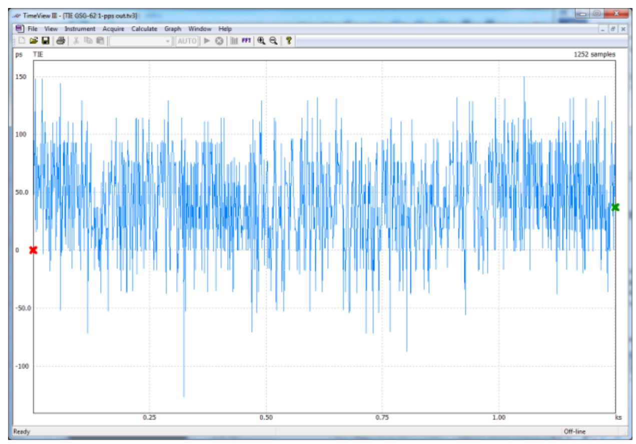

Figure 7 – Stability of the reference 1 PPS output (TIE measurement)

The maximum variation (MTIE) over the total observation time is 280 ps, and the rms jitter is approx. 40 ps indicating very high **time stability**. The calibrator has a specification of 50 ps (rms) for random uncertainty of TIE measurements, so the 40 ps result is probably the practical limit of the actual measurement system, when the GSG-62 internal timebase is locked to the calibrator.

Stability of 1 PPS from DUT

The 1 PPS output stability of the DUT shows bigger variations, see figure 8.

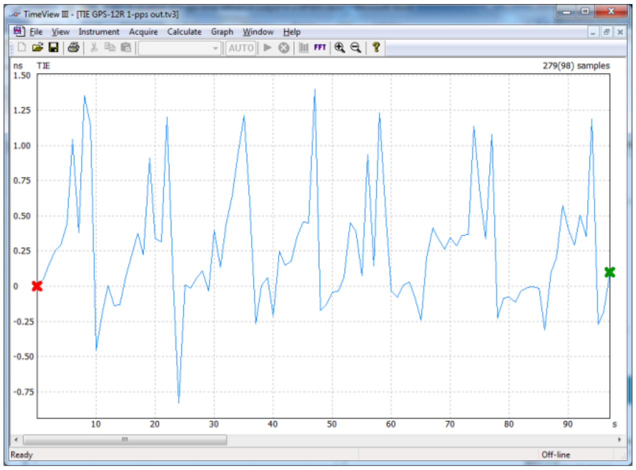

Figure 8 – Stability of the 1 PPS from the DUT (TIE measurement)

The maximum variation (MTIE) of the 1 PPS signal **time output** over the observation time is 2.3 ns, which is an acceptable value for most applications.

From Figure 7 and 8 we can conclude that the sudden variations in the time interval measurement in figure 6, in the order of nanoseconds, are caused by variations in the DUT output, not in the reference.

However the normal **frequency output** of 10 or 5 MHz from the DUT, has a much higher stability with a specified ADEV of 2E-11@1s.

Measurement uncertainties

Calibrator: The uncertainties of any time measurement, whether Time Interval or TIE, are:

Random	50 ps rms
Systematic (Time Interval)	<500 ps (input channel mismatch)
Systematic (TIE – DUT)	<(2E-11)*(time) (time base uncertainty - newly calibrated Rubidium)
Systematic (TIE – REF)	0 (Reference and Calibrator have same time base)

Reference: The uncertainty of the 1 PPS reference pulse position relative the simulated GPS on-time mark is <10 ns

Thus the offset between the 1 PPS output of the DUT and **the 1 PPS output of the Reference** is -6 ns with a random uncertainty of 0.6ns and a systematic uncertainty of 0.5 ns

The offset between the 1 PPS output of the DUT and **the Simulated GPS-time** is -6 ns with a random uncertainty of 0.6 ns and a systematic uncertainty of 10 ns.

This is the same offset of the DUT that can be expected to the GPS on-time mark, when connected to a live GPS-antenna signal, and compensated for antenna cable delay.

NOTE that the uncertainty of the 1 PPS pulse of the Reference relative simulated GPS-time can be reduced to <1 ns by a special calibration method, described in reference 3.

SUMMARY

The combination of a GNSS-simulator, and a Timer/ Counter/Analyzer, can be used to evaluate the 1 PPS performance of GNSS-disciplined oscillators in terms of settling time, offset and stability **of the 1 PPS timing output.**

Furthermore the Pendulum CNT-91 in combination with SpectraTime's PicoTime Pico Second Resolution Test Set can characterize the stability **of the frequency output** of a GPSDO. See the application note described in reference 4.

Other useful tests that a GSG series GNSS simulator can perform on any GPSDO include:

- Connectivity test in production (verify that the GPS-receiver detects a GPS satellite)
- Stress test – simulation of received multipath signals and the effect on the receiver
- Stress test – simulation of noise and interference
- Stress test – simulation of satellite drop-outs and/or reduced power
- Preventive test – the effect of a Leap second on the GPS-receiver

REFERENCES

All references from Spectracom unless noted

[1] *GSG-62 User Manual*

[2] *Pendulum CNT-90/90XL/91 User Manual*

[3] "A Calibrated Precision GNSS Simulator for Timing Applications" (John Fischer & Lisa Perdue

[4] "Application note: Improvement of frequency measurement resolution using PicoTime along with the CNT-91"

[5] *Resolution-T User Guide*, Trimble

[6] *PRS-10 User Manual*, Stanford Research