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SYNCHRONIZATION

Atomic Clock Relative Phase Monitoring

How to Confirm Proper Phase Alignment & Stability in the Field

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1. Introduction

Synchronization test sets are intended to measure the accuracy and stability of frequency and timing sources or recovered clocks. But, out in the field without any other reference to compare its internal reference to, how do you know if the GPS-disciplined atomic oscillator in your test set has achieved the desired phase alignment accuracy and stability? Well, there is no absolute way to tell, unless you have access to another traceable reference to compare it to.

We all know that the quality of the disciplining process could be affected by the quality of the GPS radio signal reception. This is not just limited to having good power or signal-to-noise ratio. In urban "canyon" scenarios, the GPS radio signal can reflect or bounce off energy-efficient glass buildings creating multi-path effects. Tall buildings can also obscure and narrow the receiver's sky visibility, limiting the quality of the signal and affecting the recovery of the UTC-aligned 1PPS timing signal.

It is very important to have as much information as possible about the quality of the GPS reception, such as number of satellites in view and their respective carrier to noise densities. They provide a good idea of the GPS receiver's RF signal quality and satellite visibility. We usually recommend seeing at least four[1] satellites with carrier-to-noise densities greater than 33 dB-Hz. But RF quality alone may not always be enough.

The precision oscillator being disciplined by the resulting GPS receiver's 1PPS output has to go through a process of tracking the GPS 1PPS and adjusting (steering) its own frequency to align its phase and provide accurate frequency. The time required to achieve accurate frequency and timing can vary depending on the settings and conditions. So, how do you know when the time is right to trust the accuracy and stability of the disciplined oscillator's output?

This document introduces the Relative Phase Measurements as that extra tool to provide a bit more visibility into the disciplining process. VeEX test sets equipped with GPS receiver and Chip Scale Atomic Clock options include a relative phase monitoring tool that can be used for this purpose.

2. Relative Phase Measurements

In the absence of another traceable frequency source or timing reference, users have to rely on relative phase measurements. It is a direct comparison between the GPS receiver's "raw" 1PPS signal being fed to the high-precision oscillator (CSAC) and the filtered (stabilized) 1PPS output from the oscillator, which ultimately would be the reference signal to be used by the test set for Wander, Absolute Time Error (Phase) and One-Way Delay (link symmetry) measurements. Since the disciplined output combines the short-term stability of the precision oscillator and the long-term accuracy of the GPS it provides the best of both worlds, so it can be used to measure the internal GPS receiver output to verify they are in agreement.

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[1] A minimum of four satellites are required to establish the tridimensional geographical position during the initial location survey. Having the correct elevation information plays a significant role in determining accurate time.

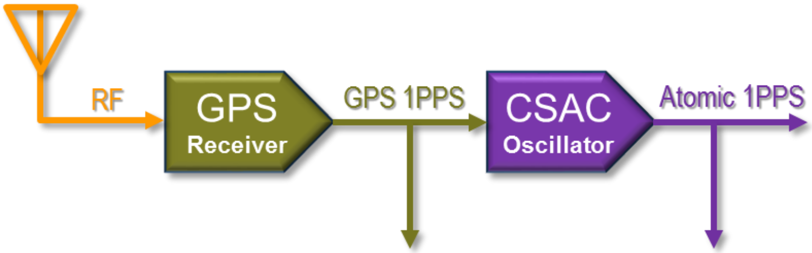
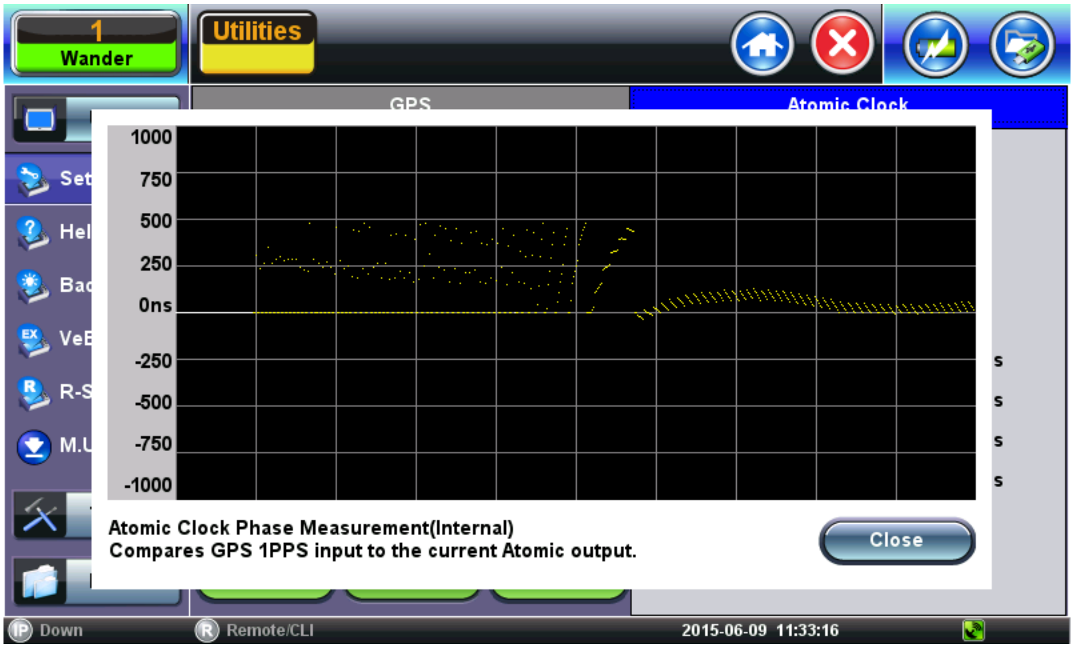


Figure 1. Relative phase compares disciplined Atomic 1PPS vs. GPS 1PPS

Relative phase measurements are more useful when monitored at the beginning of the disciplining process, to track the phase alignment between the oscillator's output (Atomic 1PPS) and its input (GPS 1PPS). Since the oscillator filters the raw 1PPS noise and fine tunes its frequency to align its own 1PPS to true time, the input vs output differential graph can become a very useful tool to monitor and verify that the convergence process is going as expected.

Phase Graph The Atomic Phase Graph can be found in the Atomic Clock settings and status screen at >Utilities >Settings >More >High Precision Clock Source >Atomic Clock



Atomic Clock Phase Measurement(Internal)
Compares GPS 1PPS input to the current Atomic output.

Figure 2. Example of GPS-disciplined Atomic relative phase convergence graph

- Yellow dots indicate valid relative phase measurements (output - input).
- Scattered yellow dots could indicate bad GPS signal, which in turn provides bad timing accuracy, or that the oscillator trying to compensate for large phase differences.
- White dots (line) at zero indicates loss of GPS 1PPS. It basically indicates holdover periods.

What you want to see in this graph is a tight bundle of differential phase measurements forming a line converging to zero and staying at zero. Since the Atomic Clock output is very stable, it will slowly try to infer the true (accurate) time alignment out of the GPS 1PPS output and maintain it. The less disperse the individual measurements (dots) are, the better the GPS timing signal is. So, you want to see a straight line formed by not-so dispersed group of dots.

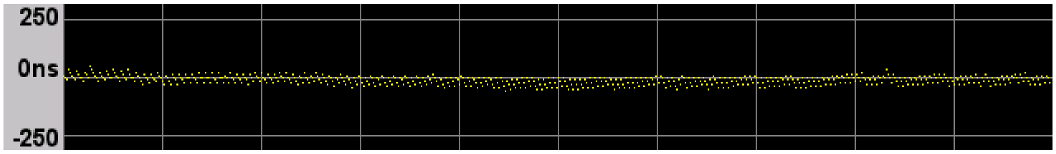


Figure 3. Example of proper (converged and stable) phase alignment

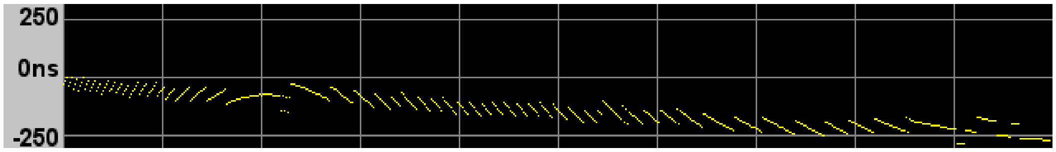


Figure 4. Not so good phase alignment

The chip scale atomic clock oscillator uses its 10 MHz frequency source for the disciplining process. Its 1PPS phase is initially aligned to the 10 MHz phase, so it should be within ±100 ns (one 10 MHz cycle). Then the CSAC would start steering its frequency to finely align its 1PPS output within a few nanoseconds to the "average" 1PPS input coming from the GPS receiver[2].

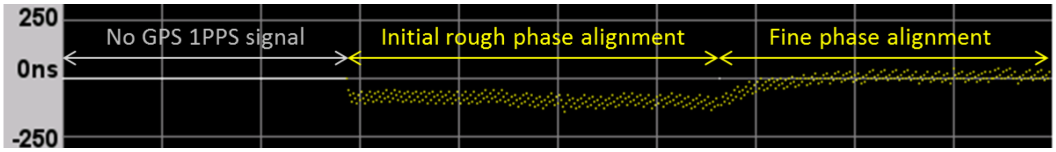


Figure 5. Example of initial phase alignment

Although the relative phase alignment may converge rather fast in many occasions, users must still observe the minimum recommended disciplining time.

Tip: If the disciplining time constant (TC) is changed in the middle of the process, from one long value to another, the phase may take long time to converge to zero or could display a somewhat erratic behavior for a while. In this scenario, if users need to change the TC, it may be worth temporarily changing it to a short TC (e.g. 60s) for faster steering and then change it to the desired value. (Note that although the Sync 1PPS button could also be used to force alignment of the Atomic 1PPS output, it does not adjusts the required disciplining or steering parameters.)

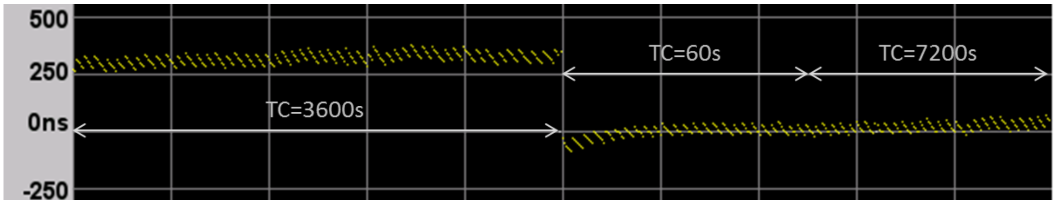


Figure 6. Using short TC to force quicker phase convergence to zero

3. Phase Alignment and Holdover

Knowing whether the oscillator is still steering (changing) its frequency to correct the 1PPS output's phase has a big impact in deciding when to force the test set into holdover for indoors testing. The Phase Graph can help in identifying when the disciplining process has stabilized.

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[2] In the context of this document the term "GPS Receiver" is not considered a synonym of "GPS Clock" or "GPS-disciplined Clock". A GPS Clock is considered a combination of a GPS receiver and a highly stable precision oscillator.

A disciplined oscillator will continuously adjust its frequency to keep the 1PPS aligned to the standard second, but those offset adjustments are usually small fractions of ppb when proper disciplining has been achieved.

Upon the loss of the GPS 1PPS reference, the oscillator enters holdover mode. This means that the precision oscillator will hold its last frequency and the phase error will continue its trend. That means, you want the instantaneous frequency to be as accurate as possible at the moment when the GPS receiver is turned off. Keep in mind that any ±X.XXX ppb frequency offset would result in a cumulative time error of ±X.XXX ns per second and that would impact the resulting usable holdover time, by reaching the defined error tolerance faster or slower.

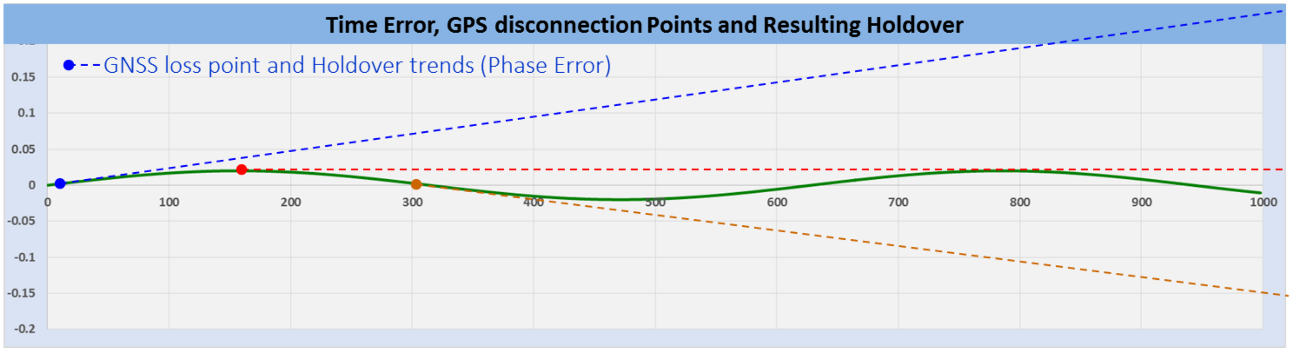

Figure 7. Illustrative examples of what would happen if GPS 1PPS is lost during different steering stages

It is not possible to know the absolute frequency accuracy in the field (without the help of a traceable reference), nonetheless, being able to identify when a disciplined oscillator has reached stability and is no longer steering too much should help a lot.

4. Limitations

This method of determining proper 1PPS phase disciplining convergence would only work at the beginning of the disciplining process, which is what would be needed in the field.

Long-term, especially when long time constants are used, the oscillator will become hard to steer as it would be trying to hold what it “believes” is true time alignment, based on a long learning process. In this case, if the GPS receiver starts to wander and becomes somewhat inaccurate, the graph would show such discrepancy, but the oscillator’s 1PPS output would still be stable and accurate.

GPS instant accuracy could change within ±150ns during the course of a day depending on atmospheric conditions and satellites visibility. The job of the atomic clock is to filter those slow variations, so in the long term it is normal to see the GPS and CSAC phases temporarily disagree (relative phase ≠ zero).

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