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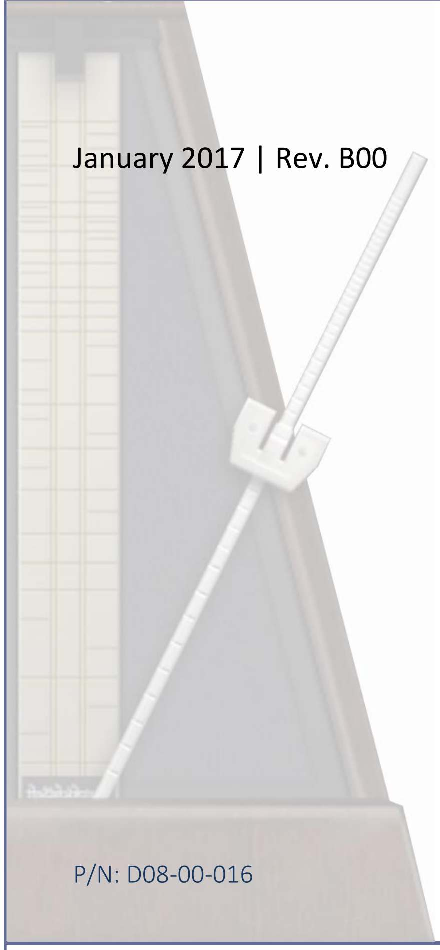
SYNC SERIES

Atomic Clock Relative Phase Monitoring

How to Confirm Proper Phase Alignment & Stability in the Field



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Atomic Clock Relative Phase Monitoring

How to Confirm Proper Phase Alignment & Stability in the Field

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 GNSS-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 GNSS radio signal reception. This is not just limited to having good power or signal-to-noise ratio. In urban “canyon” scenarios, the GNSS 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 GNSS reception, such as number of satellites in view and their respective carrier to noise densities. They provide a good idea of the GNSS 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 GNSS receiver’s 1PPS output must go through a process of tracking the GNSS 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 or GNSS receivers and chip-scale Atomic Clock options include a relative phase monitoring tool that can be used for this purpose. (The terms GPS and GNSS may sometimes be used interchangeably in this document, in general both refer to the generic GNSS.)

2. Relative Phase Measurements

In the absence of any other traceable frequency source or timing reference, users have to rely on relative phase measurements to assess test equipment readiness. It is a direct comparison between the GNSS receiver’s “raw” 1PPS signal being fed to the high-precision oscillator (Cs) 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 GNSS it provides the best of both worlds, so it can be used to measure the internal GNSS 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.

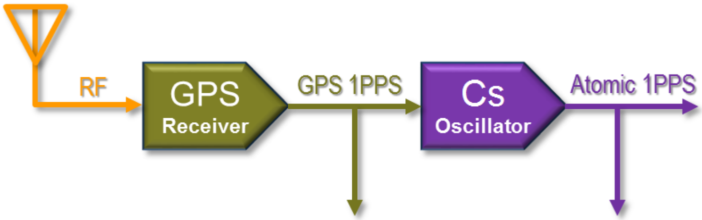
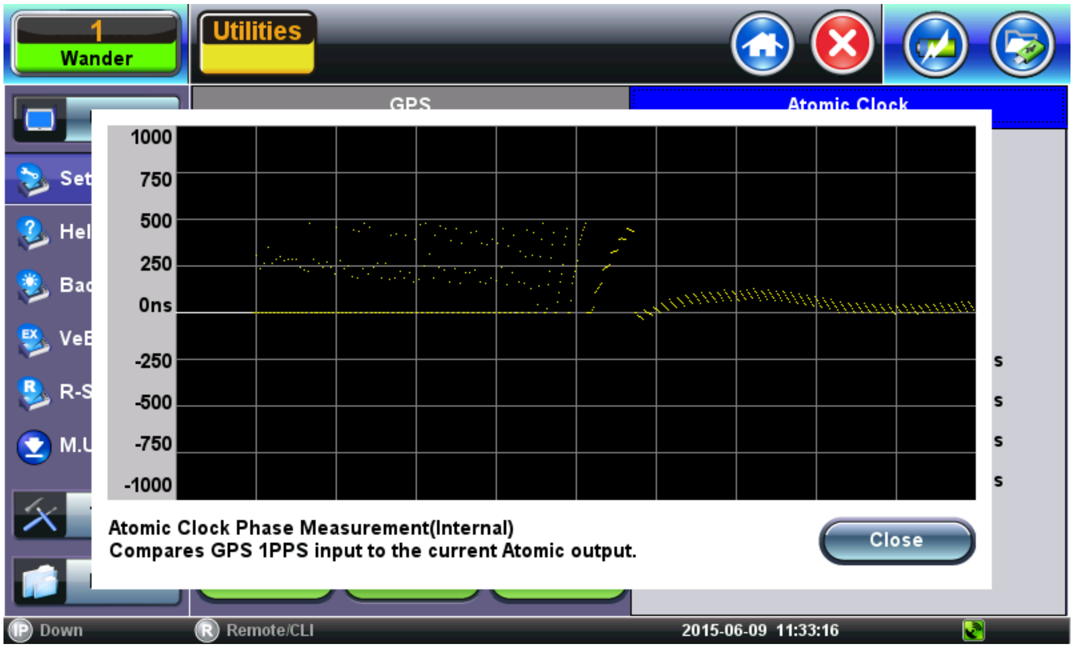


Figure 1. Relative phase compares disciplined Atomic 1PPS vs. GNSS 1PPS

Relative phase measurements are more useful when monitored from the beginning of the disciplining process, to track the phase alignment between the oscillator's output (Atomic 1PPS) and its input (GNSS 1PPS). Since the oscillator filters the raw 1PPS noise and fine tunes its frequency to align its own 1PPS to the resulting 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 >High Precision Clock Source >Atomic Clock



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

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

- Yellow dots indicate individual valid relative phase measurements (output - input).
- Scattered yellow dots could indicate bad GNSS signal, which in turn provides bad timing accuracy, or that the oscillator is trying to compensate for large phase or frequency differences.
- White dots (line) at zero indicates loss of GNSS 1PPS reference. 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 GNSS 1PPS output and maintain it. The less disperse the individual measurements (dots) are, the better the GNSS timing signal is. So, you want to see a straight line formed by not very scattered group of dots.

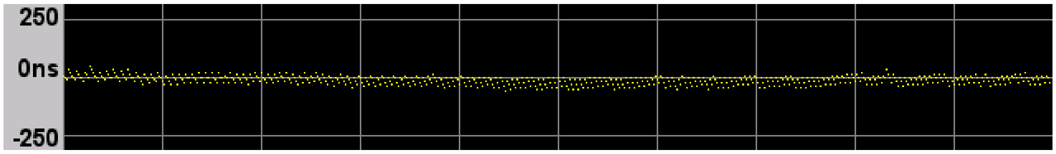


Figure 3. Example of proper (converged and stable) phase alignment

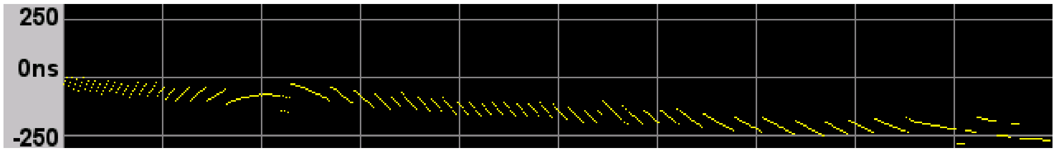


Figure 4. Not so good phase alignment

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

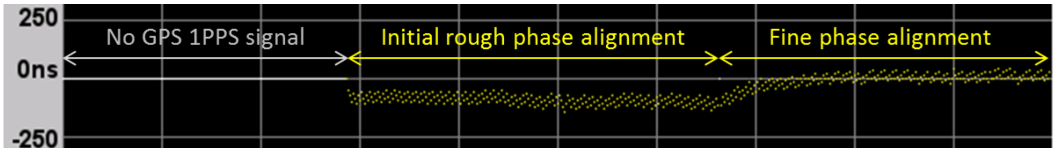


Figure 5. Example of initial phase alignment

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.)

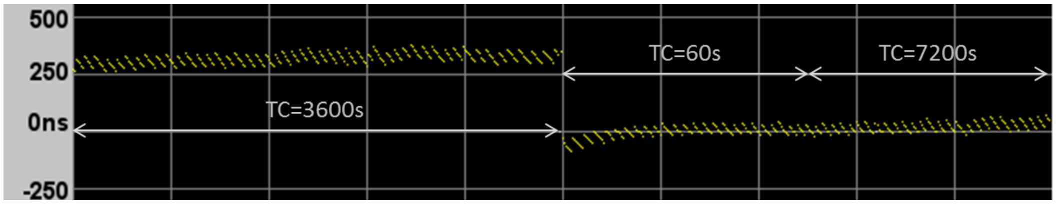


Figure 6. Using short TC to force quicker phase convergence to zero

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 start a long-term measurement or 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 "GNSS or GPS Receiver" is not considered a synonym of "GPS Clock" or "GPS-disciplined Clock". A GNSS Clock is considered a combination of a GNSS 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 (parts per billion, 1E-9) when proper disciplining has been achieved.

Upon the loss of the GNSS 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 GNSS 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.

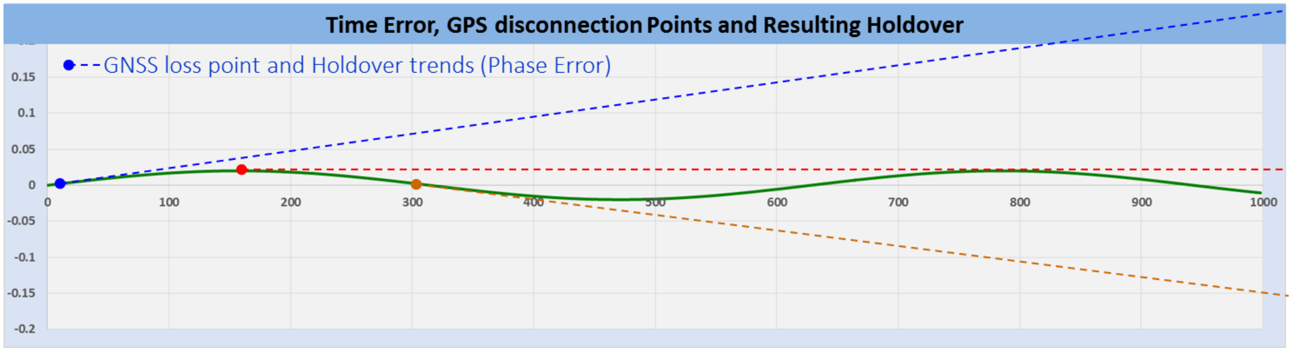

Figure 7. Illustrative examples of what would happen if GNSS 1PPS is lost during different steering stages

It is not possible (or practical) to know the instantaneous absolute frequency accuracy in the field (without the help of another 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 in achieving the longest holdover possible.

The example above shows three possible disconnection points with three different holdover outcomes. If the disciplining system was correcting the phase by using a slightly higher frequency, when disconnected (blue dot), then the phase error will continue to follow that trend. Ideally, for the longest holdover, the GNSS 1PPS should be removed when the TIE graph is flat (red dot). You can use the Phase Graph to help you find that ideal point.

4. Limitations

This method of determining proper 1PPS phase disciplining convergence works better when the disciplining process is monitored from the beginning 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 GNSS receiver starts to wander and becomes somewhat inaccurate (e.g. due to whether), the graph may show such discrepancy, but the oscillator’s 1PPS output should still be stable and accurate.

GNSS instant accuracy could change as much as ±100ns during a day, depending on atmospheric or ionospheric 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 GNSS and Atomic Clock phases temporarily disagree (relative phase ≠ zero).

Users must keep in mind that this relative measurement is just an indication of the internal disciplining and phase alignment process, so it assumes that the GNSS input is always accurate. Users have to make sure they have the best GNSS antenna setting possible on site and that enough time is given to the GNSS receiver to survey its current position in order to provide accurate time.

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About VeEX®

Founded in 2006 by test and measurement industry veterans and strategically headquartered in the heart of Silicon Valley, VeEX Inc. provides innovative Test and Measurement solutions for next generation networks, services and communication equipment.

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