# Analysis of NTS-3 Satellite Clock Stability using Ground-Based Measurements

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Navigation Technology Satellite 3 (NTS-3) is a Vanguard program that will test flexible signals to improve robustness and resilience from a geosynchronous orbit and will strive to increase the accuracy and integrity of GPS measurements. The accuracy achievable from GNSS systems is highly dependent on the accuracy of the on-board clocks. Even very small errors in satellite clocks can cause significant miscalculations of the position solution. With NTS-3's launch date approaching in late 2023, it is imperative to characterize its clock stability as accurately as possible. The measurement of the performance of the clocks is limited to the quality of the best clock on-board the satellite. It is not possible to measure the absolute stability of the clock without external timing references, such as a better clock on the ground.

Previous works have established techniques to characterize GPS satellite clocks by relating them to clocks on the ground through differences of carrier phase measurements. The One-Way Carrier Phase (1WCP) method uses the first derivative of the measurements to estimate the short-term stability of the clock [1]. The second method is the Three-Way Carrier Phase (3WCP), which uses measurements from a second satellite and a receiver at a ground station seen by the first satellite [2]. These methods are relevant in cases where the clock on the observed satellite is not very stable. Using the difference between single-frequency carrier phase measurements for two satellites, eliminates the satellite clock errors, and relates the satellite to a receiver that could have a higher-quality clock such as a Hydrogen maser.

As a stepping stone to being able to test NTS-3 clocks, a code was developed to test these methods with GPS data. The data tested using the 1WCP method was from three different ground stations, broadcast by three different satellites. The ground stations and satellites were chosen according to their clocks. The GPS satellites use cesium and rubidium Atomic Frequency Standard clocks, which are not as accurate as an active hydrogen maser, present at some ground stations. For this analysis data from GPS satellites from Blocks IIR, IIM and IIF were tested. They all contain rubidium clocks; however, the block II-F satellites contain higher performing clocks. The 3WCP method was also applied, using two satellites, and two receivers, but relating one satellite to one ground station. A polynomial fit was applied to the GPS data to remove errors due to tropospheric and ionospheric effects, biases, and measurement errors. The Overlapping Allan deviation was calculated from the residuals to determine the stability of the satellite clock. There was a good agreement between the results of this test and previously published results.

The software tool developed in this project will be used in future NTS-3 tests to evaluate the stability and capability of its clocks after the launch. There are additional tests being designed to characterize the NTS-3 clock stability before the launch, in order to compare the behavior of the clocks on the ground to their behavior in space. These tests will take place at the Kirtland AFB during the 2023 calendar year. The results of the NTS-3 experiment will be used to advance GPS technology and improve navigation accuracy for both civilian and military users.

References:
[1] Gonzalez, F., Waller, P., (2007). *Short term GNSS clock characterization using One-Way carrier phase*. 517-522. 10.1109/FREQ.2007.4319127.
[2] Hauschild, A., Montenbruck, O., & Steigenberger, P. (2013). *Short-term analysis of GNSS clocks*. GPS Solutions, 17, 295-307.