CAST

— Center for Alternative —
Synchronization and Timing

Technical Bulletin #003

Summary: This CAST technical bulletin highlights the importance of GPS connectivity for Remote Timing Units. This bulletin will describe how GPS is currently used in a timing and synchronization architecture to validate the accuracy of a PTP signal. GPS provides an important link to an authoritative timing source and enables the calibration and validation of terrestrial timing systems for meeting power grid accuracy requirements. Absent GPS, a well-calibrated grandmaster clock will maintain a highly stable PTP timing distribution using a reference atomic clock, such as a Cesium reference.

Terrestrial timing solutions, such as atomic clocks, are designed to service as a precision time and synchronization source for components over a network. These solutions can both benefit from, and provide resilience to, time received from Global Navigation Satellite Systems (GNSS). This paper will explain the role of GNSS, and specifically the US global positioning system (GPS) in terrestrial timing solutions.

Timing systems are deployed in a hierarchical manner, where a Grandmaster clock (often called a stratum 0 clock) distributes time to downstream devices that are synchronized to that clock. In many implementations, additional clocks, called boundary or slave clocks, are synchronized to the grandmaster clock and further distribute time to sets of devices. Terrestrial timing solutions can have many tiers (or stratums) in their timing hierarchy. Remote Timing Units (RTUs), or Remote Synchronization Units (RSUs), are boundary clocks for the purpose of wide-area synchronization of devices on the power grid. The timing signal from the grandmaster clock to the RTU is precision time protocol (PTP).

When connecting a RTU over a network, GPS connectivity has an important role for validating the timing signal coming from the grandmaster clock. The RTU is synchronized to the grandmaster using PTP time and sync from a Grand Master Clock over the network, while GPS serves as a reference for measuring and validating the performance of the PTP signal over the network, GPS is not needed to calibrate or steer the internal oscillator of the RTU. This validation is crucial during new installations, as it can identify potential issues with the clock, configuration, or network.

Once the PTP signal is calibrated and validated, the GPS reference can reasonably be disconnected from the RTU. However, GPS can also continue to play an important role in assessing system health. Through analysis of the PTP signal against the GPS signal, issues such as temperature changes or network routing changes can be highlighted, as they will manifest as deviations from a trusted value. If GPS connectivity is unavailable, an alternative local time source, comparable or superior to GPS, would be necessary to validate the timing signal.

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

It is important to note that the RTU does not use GPS as a source to steer the internal oscillator. Consequently, a GPS outage would not impact the time or synchronization provided by the RTU to its clients, once the PTP signal has been established and validated. Using GPS as a reference for any clock within a terrestrial timing system can also help identify local or widespread problems with the GPS system. In a network scenario where there is one grandmaster clock and multiple boundary clocks spread across a large area, disturbances in the measured timing signal at one location could indicate jamming or spoofing of the GPS signal.

Figure 1 below shows an example of the locations and functionality of GPS within the terrestrial timing system along with the PTP signal which is being utilized for terrestrial timing in order to support accurate time distribution to grid edge devices. Within this diagram, GPS is an input signal to the Grandmaster clocks and any boundary clocks solely for calibration/validation analytics. Of note is the calibration is done initially to confirm the operations of the terrestrial link.

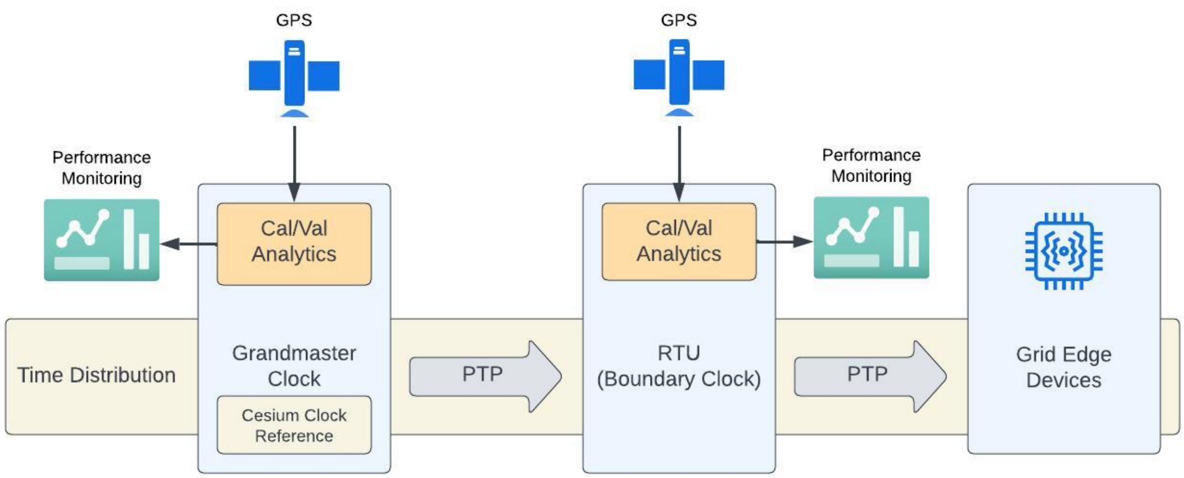

Figure 1: Example overview of GPS's role in terrestrial timing systems.

Figure 2 illustrates the configuration of a clock probe on a Grandmaster, Boundary, or Slave clock. A clock probe is utilized to gauge the accuracy of the internal oscillator or "clock." During a clock probe, the internal oscillator is compared to a reliable reference. In this instance, the source is set to "Time Clock 1-1-1-1", representing the internal oscillator of the clock. The internal oscillator typically consists of a small amount of Quartz or Rubidium, which is subjected to precise and steady voltage and temperature to generate a highly accurate and stable frequency. This internal oscillator's accuracy is further enhanced by continuous adjustment or conditioning over time. In the case of a grandmaster clock, it is steered by a 10MHz frequency from a Cesium clock and a one pulse per second (1pps) signal from GPS; for a boundary or slave clock, it is synchronized via a PTP signal from a grandmaster clock over a network link. Once the Time Clock, or internal oscillator, is synchronized with its clock source, it undergoes testing against a trusted reference, such as GPS. As depicted in Figure 2, GPS is selected as the reference to validate Time Clock 1-1-1-1.

Identification

Entity ID: CLOCK PROBE-1-1 **Name:** ClockProbe1

State	: Running	**Mask Failure**	: No
Running Failed Count	: 0	**Mask Crossed Time**	: 0
Actual Test Start Time	: 2024-03-05 15:50:53	**Mask Margin Failure**	: No
Actual Test Duration (s)	: 2585095	**Mask Margin Crossed Time**	: 0
Reference	: GPS-1-1-1-1	**Measurement Rate, measurements/s**	: 1
Reference Expected QL	: QL-NONE	**Last TIE Result (ns)**	: 138
Source	: TIME CLOCK-1-1-1-1	**Time Of Last TIE Result**	: 2024-04-04 13:55:42
Source Type	: Phase	**Raw Data Collection**	: Enabled
MTIE Mask	: G823 Pdh	**MTIE Restart**	: Disabled
Mask Margin (%)	: 0	**Measurement Type**	: Phase
Scheduler	: SYNCJACK SCHEDULE-1-1-1-1		
Source Failure	: No		
Reference Failure	: No		

Figure 2: This image shows the configuration of a clock probe on an RTU.

Figure 3 illustrates the results of a clock probe. The graph presents the time error (TE) measured in nanoseconds over elapsed time in seconds. The time error reflects the variance of the internal oscillator from the GPS reference. This graph showcases an outstanding clock performance, with only a slight deviation of a few nanoseconds compared to GPS. Specifically, over an elapsed time of 2,000 seconds, the Time Error fluctuates within one nanosecond above and below the GPS reference signal.

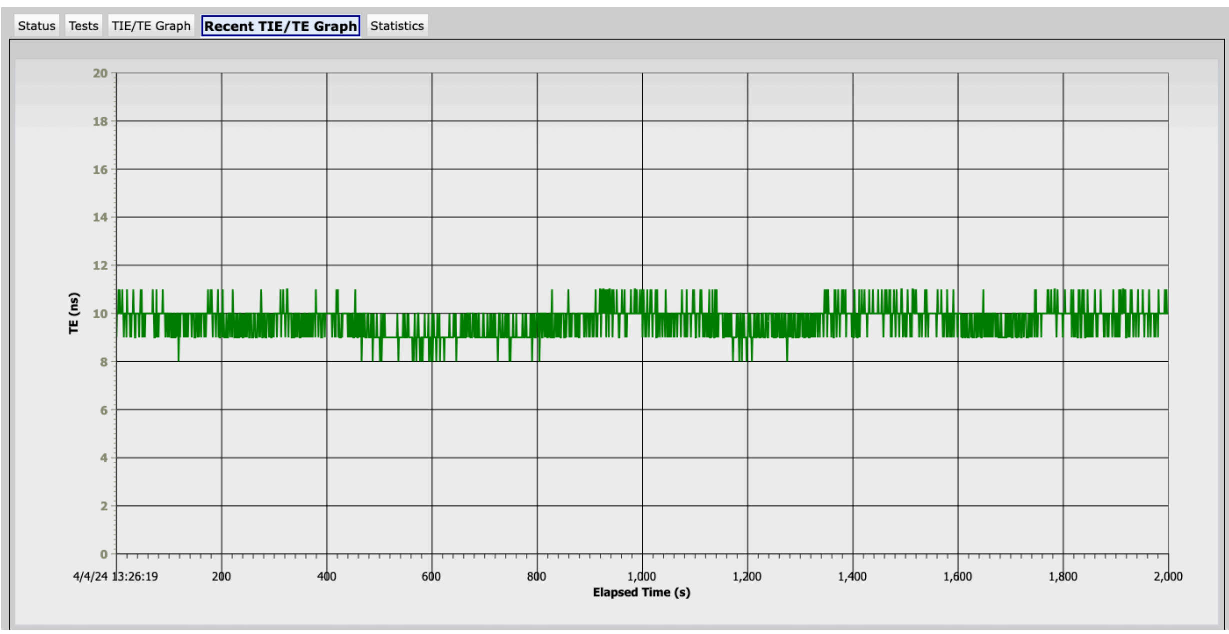

Figure 3: This graph shows the result of using GPS as the reference to validate the accuracy of the internal clock on the RTU. This graph shows the Time Error of the internal oscillator or Time Clock compared to GPS over time.

In conclusion, while GPS serves as a crucial element in the deployment of terrestrial timing solutions, the CAST team designs these systems to be robust even in the face of GPS outages. GPS remains a trustworthy and important component for validation of the system calibration, configuration, and performance. Analyzing data from grandmaster clock PTP and GPS signals can help determine issues across a network and may provide indications of GPS jamming or other anomalies that reinforce the need for resilient terrestrial solutions. While GPS is currently a reliable part of a timing architecture, its reliability might not always be guaranteed. Hence, the CAST team is working to identify and implement alternatives to GPS, with the goal of enhancing security and reliability in the foreseeable future.

The Center for Alternative Synchronization and Timing (CAST) at Oak Ridge National Laboratory (ORNL) performs research, development, testing, evaluation, and technical assistance to enable resilient timing and synchronization for the power grid. Working closely with power utilities, timing hardware and software vendors, network operators, and federal stakeholders, CAST helps develop and validate alternative timing architectures to augment GPS time. CAST also translates and transfers ORNL's research and development (R&D) advances in secure timing and grid communications to power sector applications, and engages across the broader timing community to develop best practices to ensure the resilience of US critical infrastructure. CAST is sponsored by DOE's Office of Electricity. Visit https://cast.ornl.gov for more information.