Quartzlock

GPS Time and Frequency Transfer Techniques a brief overview.

GPS time and frequency transfer is a method of enabling multiple sites share a precise reference time. GPS time and frequency transfer solves problems such as astronomical observatories correlating observed flashes or other phenomena with each other.

Multiple techniques have been developed, often transferring reference clock synchronization from one point to another, often over long distances. Accuracy approaching one nanosecond worldwide is economically practical for many applications. Radio-based navigation systems are frequently used as time and frequency transfer systems.

In some cases, multiple measurements are made over a period of time, and exact time synchronization is determined retrospectively.

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One Way

The one way GPS technique uses the signals obtained from a GPS receiver as the reference for a calibration. The GPS signals are used in real time to synchronize the local clock and GPS or UTC time. The purpose of the measurement is usually either to synchronize an on-time pulse, or to calibrate a frequency source. Before a receiver is used for measurements, it must complete its signal acquisition process. Part of the acquisition process is the antenna position survey. Unlike GPS navigation receivers (SAT NAVs), which compute position fixes while moving (often at a rate faster than one position fix per second), GPS time and frequency receivers normally do not move and therefore do not need to compute position fixes once the survey is completed.

Therefore, time and frequency receivers generally store a single position fix, and use that same position from then on. Many receivers automatically start a survey when they are turned on.

Once the signal acquisition is completed, an output signal from the receiver is connected to a measurement system. For time synchronization measurements, a 1 PPS signal from the receiver is generally used as an input to a time interval counter. For frequency measurements, a 10MHz frequency output from a GPSDO is used as an input to a phase comparator, or used as the external time base for test equipment such as frequency counters and signal generators.

Since the GPS satellites transmit signals that are steered to UTC, the long-term accuracy of a GPS receiver has always been excellent.

The time pulse accuracy (1PPS) is affected by delay in the antenna cable. This is about 4ns/m and can be allowed for by offsetting the 1PPS output. There is also a constellation dependant error between UTC and GPS time of up to ±15ns. A time receiver will typically have an accuracy of ±15ns (1sigma) to GPS time. A final accuracy of about ± 30ns to UTC can be achieved.

Common View

The common view method is a simple but elegant way to compare two clocks or oscillators located in different places. Unlike one-way measurements that compare a clock or oscillator to GPS, a common-view measurement compares two clocks or oscillators to each other.

The GPS satellite (S) serves as a single reference transmitter. The two clocks or oscillators being compared and are measured against two GPS receivers. The satellite is in common view of both receivers, and both simultaneously receive its signals. Each receiver compares the received signal to its local clock and records the data. The two receivers then exchange the data.

Common view directly compares two time and frequency standards. Errors from the two paths, that are common to the reference, cancel out, including the performance of the satellite clock.

The advantage of this technique is that it minimizes certain errors that might be present. The satellite clock errors are completely eliminated since they are common in both receivers. Ephemerides errors in the transmitted data and affecting to the computation of the paths are minimized. However, the main disadvantaged with respect to the one-way mode is that data between the receivers must be exchanged.

Common view requires a GPS receiver that can read a tracking schedule. This schedule tells the receiver when to start making measurements and which satellite to track. A receiver at another location makes measurements from the same satellite at the same time. The data collected at both sites are then exchanged and compared.

All in View

The All in view mode, can be used to synchronize clocks over widely separated distances. Unlike the Common view mode, the all in view mode does not require simultaneous observations by both stations; it only requires that each station observe as many satellites as possible during the day that its receiver can track.

The individual GPS time versus the local standard's time comparisons are put together over a period of time. The linear fit solution of these points is considered the offset of the GPS time from the local standard's time. Subtracting one local standard's offset time from the other yields the time difference between the two locations.

This method is more robust than the Common View Mode, because it observes significantly more satellites during the day. Therefore, it is more suitable for unattended synchronization systems because the offset values are more stable and the system is more robust to occasional data gaps since the offset is computed from several measurements.

The disadvantage is that post processing is required, and the time difference is not available in real time.

Carrier Phase

This technique uses both the L1 and L2 carrier frequencies instead of the codes transmitted by the satellites. It is important to note that carrier phase measurements can be one way measurements made in real time or post processed common view measurements.

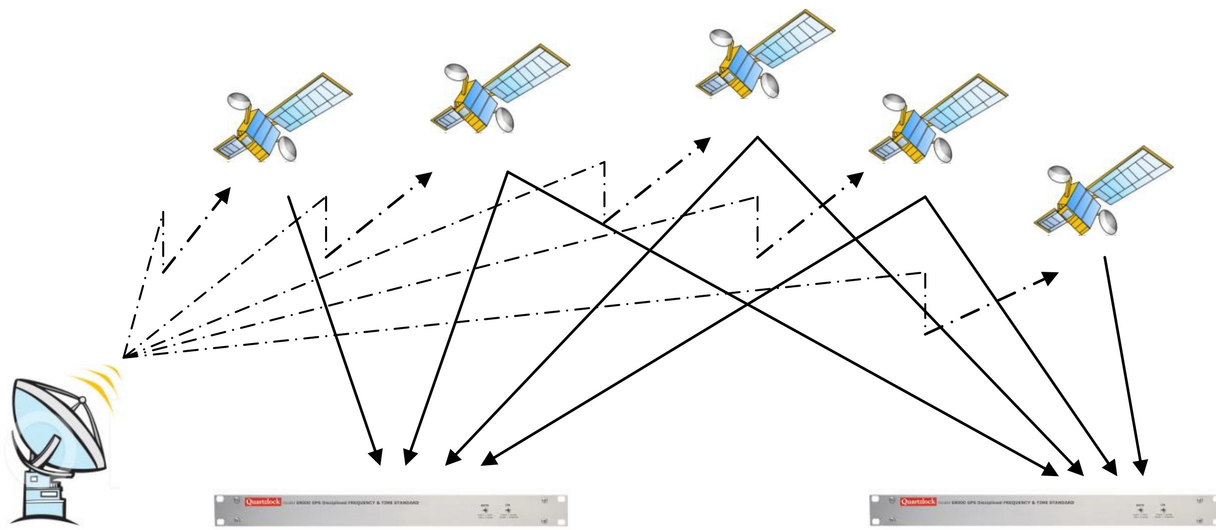
The phase difference between the satellite oscillator and the receiver’s local oscillator is calculated. However, the phase observable is an ambiguous observable, the phase is measured modulo 2π and only the fractional phase can be measured, whereas the pseudo range is an absolute observable. The absolute offset between the remote clocks is then only determined by the code information, while the carrier phases give a precise signal evolution. The use of the pseudo range information together with the carrier phase information increases the accuracy up to a factor 1000.

Since the carrier phase GPS technique requires geodetic GPS receivers as well as making corrections of the collected data using orbital, ionosphere and troposphere models and extensive post-processing, it is not practical to use for everyday measurements. However, the technique is used for experimental purposes and for international comparisons between primary frequency standards when the goal is to reduce the measurement uncertainty as much as possible.

Time Transfer Using the Quartzlock E8000-TT

Quartzlock has just enhanced its range of GPS Time and Frequency References with a new economical GPS All in View One Way Satellite Time and Frequency Transfer instrument the E8000-TT a GPS time and frequency reference with a smoothed 1PPS output synchronized to UTC.

Quartzlock are using the one way all in view mode, where each site is compared to an average of GPS time, derived by letting the receiver generate an average of all the satellites tracked. If the constellation is nearly the same at each site, then the result of the average is likely to be very close at each site.



E8000-TT Location A   E8000-TT Location B

Two or more E8000-TT units will provide remarkably accurate time transfer over medium baselines, up to several hundred kilometres.

E8000 design

The E8000 uses a commercial GPS timing receiver. This performs a self survey when moved to a new location, and stores the averaged position. The stored position is used when the unit is reset, and remains valid provided the unit is not moved.

With a valid stored position, the GPS receiver switches into over determined clock mode, and uses all satellites in view to provide the best possible estimate of GPS time, output as the rising edge of a pulse every second (1PPS).

The 1PPS output from the GPS receiver is phase modulated with a saw tooth with a peak amplitude of about 12ns. This is due to the finite clock resolution used in the GPS receiver.

The E8000 uses a Kalman filter to a) correct the local clock, which is an OCXO, and b) to smooth the 1PPS and remove the saw tooth modulation. The eventual 1PPS output from the E8000-TT has short term phase jitter of less than 1ns RMS.

GPS time can differ from UTC by up to ±15ns (1 hour averages), with occasional peaks at ±20ns (see NIST archived data). However when using short or medium baseline time transfer, both receivers will largely share the same constellation, and will therefore see the same offset from UTC.

Measurements on two E8000-TT receivers with co-sited antennas (zero baseline) have shown typical time differences (1 hour averages) of ±3ns, with occasional peaks at ±5ns. There is usually a fixed time difference of up to 30ns which can be removed after a calibration run. The 1PPS output from the E8000-TT receiver can be offset by up to ±500ms in 1ns steps.

Specification (typical results)

Using 2 Quartzlock E8000-TT receivers with identical co-sited antennas and cable lengths.

Fixed time difference before calibration:	±50ns maximum
Fixed time difference after calibration:	±5ns
Time difference variation (10 minute average):	±10ns
Time difference variation (1 hour average)	±6ns

Analysis of 1PPS difference between 2 Quartzlock E8000A-TT

Smoothed version of data 1 hour moving average