GNSS Timing Application Note

GNSS Products

Version: 1.0

Date: 2025-09-10

Status: Released

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About the Document

Document Information	
Title	**GNSS Timing Application Guide**
Subtitle	GNSS Products
Document Type	Application Note
Document Status	Released

Revision History

Version	Date	Description
-	2025-04-15	Creation of the document
1.0	2025-09-10	First official release

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1 Introduction

High-precision timing module is a clock synchronization device characterized by high accuracy, exceptional stability, and superior reliability. It provides high-precision time synchronization support for various real-time applications.

This document focuses on how to utilize the timing functionality of Quectel's high-precision timing modules.

Table 1: Applicable Modules

Module Series	Model
L26-T	L26-T
	L26-T (B)
	L26-T (D)
LC98S	LC98S (IB)
LC29T	LC29T (AA)
LC99T	LC99T (IA)

1.1. Overview

In addition to navigation and positioning functions, GNSS systems (such as GPS, GLONASS, Galileo, and BDS) provide timing services using the high-precision atomic clocks onboard navigation satellites, synchronizing various clocks on Earth through precise time information.

It is widely used in time-critical applications such as communications, financial transactions, and power distribution.

1.1.1. Timing Working Principle

GNSS timing achieves precise time synchronization through the coordinated work of satellite atomic clocks and ground-based receiver modules. The main process is as follows:

1. **Atomic clock signal transmission**
   Each GNSS satellite carries a high-precision atomic clock and continuously broadcasts navigation signals containing precise timestamps.

2. **Multi-satellite signal reception**
   The GNSS timing module can synchronously receive signals from at least four satellites to obtain the precise transmission time of each satellite.

3. **Pseudorange calculation**
   The pseudorange between the module and each satellite is calculated by the signal propagation delay.

4. **Time-space deviation calibration**
   By calculating the pseudorange, the following data are obtained:
   - The three-dimensional position coordinate (longitude/latitude/altitude) of the module
   - The deviation of the local clock relative to the satellite atomic clock

Accuracy enhancement mechanisms:

- PPS output
  The module outputs PPS (Pulse Per Second) signal, which generates synchronization pulses with nanosecond-level precision at UTC whole-second boundaries
- Propagation error compensation:
  Real-time correction of ionospheric delay, tropospheric delay, etc.

1.1.2. Typical Application Scenarios

1.1.2.1.Power Systems

Figure 1: Power Systems

The GNSS timing module provides high-precision time synchronization service for power systems, ensuring the stable operation of power grid, optimizing power transmission and improving fault detection capability.

Table 2: GNSS Timing Applications in Power Systems

Application Scenario	Description
Phasor measurement unit (PMU) Synchronization	Provide a unified time reference for PMUs distributed globally, enabling accurate cross-regional measurement of phase angles, thereby realizing real-time monitoring and analysis of power systems.
Relay protection device coordination	High-precision time synchronization can ensure the consistency of timestamps recorded by relay protection devices in different locations, which is convenient for post-analysis and fault diagnosis.
Distributed energy management	The various components in the distributed energy resource management system (such as inverters and energy storage systems) maintain time synchronization, which can optimize energy scheduling and control strategies.

Application Scenario	Description
Fault recorder	Precise nanosecond time synchronization can ensure the accuracy of the recorded data.
Automated switch station	The equipment in the switch station must be strictly synchronized and all related equipment operates within the same time frame, ensure fast and accurate execution of circuit breaker operations.
Frequency synchronization	By locking the local oscillator to the PPS signal provided by the GNSS module, extremely high-precision frequency synchronization can be achieved, which helps maintain the stability of the power grid frequency.

1.1.2.2.Communication Base Stations

Figure 2: Communication Base Stations

The GNSS timing modules provides high-precision time synchronization services for communication base stations, ensuring stable operation of communication networks, improving data transmission efficiency, and enhancing service quality.

Table 3: GNSS Timing Applications in Communication Base Stations

Application Scenario	Description
Time Synchronization	The nanosecond-level time synchronization service provided by the GNSS timing module can meet the extremely high time synchronization accuracy requirements of 4G and 5G networks:

Application Scenario	Description
	● Support advanced features such as MIMO technology and carrier aggregation ● Reduce interference between base stations and improve spectrum utilization ● Ensure the accuracy of base station coordination
Frequency synchronization	Achieve extremely high-precision frequency synchronization by locking the local oscillator to the PPS signal provided by the GNSS timing module.
Network Time Protocol (NTP) and Precision Time Protocol (PTP) support	NTP and PTP can synchronize time within the network, but they rely on a high-precision time source--the GNSS timing module, which ensures accurate time synchronization even in the event of network interruptions or failures.
Roaming continuity	The GNSS timing module provides accurate time synchronization service to ensure time consistency between base stations, enabling seamless switching between different base stations for mobile devices and improving user experience and service quality.
Positioning service	Communication base stations rely on high-precision time information to calculate the location of user equipments. The high-precision timestamp provided by the GNSS timing module can significantly improve positioning accuracy.

2 Timing Related Concepts

2.1. PPS

PPS signal is a high-precision time synchronization signal generated by GNSS satellite time reference.

Generation Principle:
The GNSS timing module receives time information transmitted by GNSS satellites and calculates the UTC time, generating electrical pulse signals at each UTC whole-second boundary.

Technical features:
- The pulse width and polarity of the output PPS signal is adjustable.
- PPS signal is synchronized with the GNSS or UTC time

The waveform of the output PPS signal can be viewed through an oscilloscope, as shown below:

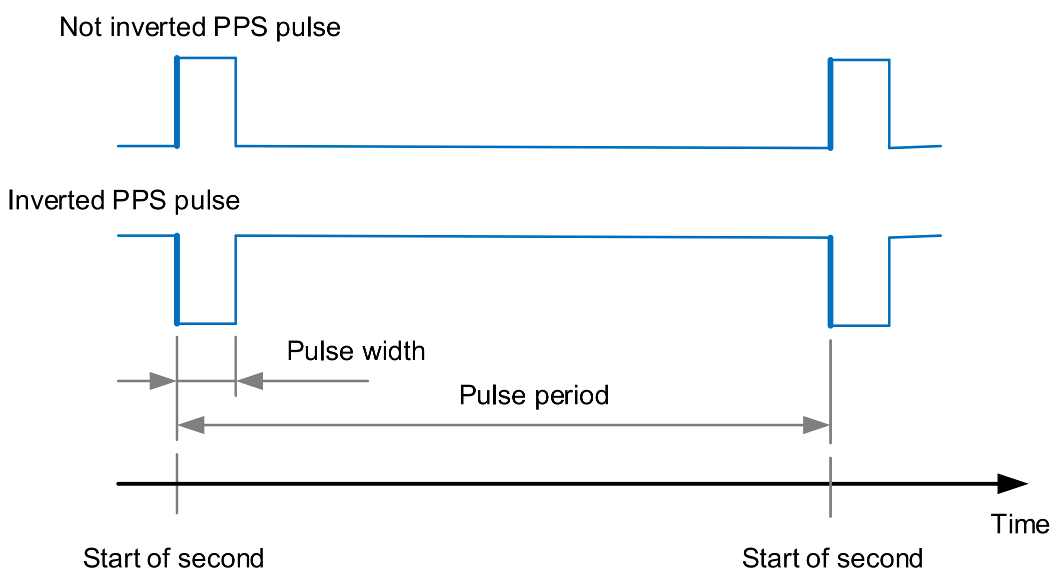

Figure 3:Time Pulse Signal

2.2. Timing Mode

The GNSS timing module supports two working modes in static scenarios: Fixed-position mode and Automatic Position Hold mode, meeting the time synchronization application requirements of different accuracy levels.

2.2.1. Basis for Mode Selection

The appropriate mode should be selected based on the applicable scenario:

Table 4: Applicable Scenarios for Timing Mode

Timing Mode	Applicable Condition
Fixed-position	Suitable for static scenes where the antenna position coordinates and antenna position are fixed.
Automatic Position-hold	Suitable for static scenes where the initial position of the antenna is unknown or the antenna position may change.

2.2.2. Fixed-position

Suitable for timing applications in static scenarios with known antenna positions, this mode allows the module to quickly synchronize time based on known location information. In environments with limited GNSS signals (such as urban canyons and areas with severe obstruction), the module only needs to receive signals from a single satellite to calculate the deviation between the local clock and the satellite's atomic clock, thus achieving high-precision timing. This is known as "single-satellite timing."

Workflow:

1. User enters accurate location information: Enter the exact center position of the receiver antenna in WGS-84 geodetic coordinate system (parameter format: latitude, longitude and altitude);
2. The module calculates the precise time based on preset location information and satellite observation data;
3. The module enters position hold status and updates the PPS status based on the calculation results;
4. The module can be used for precise timing applications.

2.2.3. Automatic Position Hold

This mode is suitable for timing applications in static scenarios where the antenna position is unknown or may change. In this mode, it is necessary to ensure that the module has sufficient observation time and avoid moving the antenna during convergence. After the module enters the position hold status, the quality of the GNSS signal deteriorates, and even the module can only resolve a single satellite. The module can still provide accurate timing using information from a single satellite, same as the "single-satellite timing" in *Chapter 2.2.2 Fixed-position*.

Workflow:
1. Position acquisition and calculation: The receiver continuously collects a certain amount of positioning data (observation time) and calculates the exact position of the antenna;
2. The module calculates the precise time based on the converged accurate position information and satellite observations;
3. The module enters position hold status and updates the PPS status based on the calculation results;
4. The module can be used for precise timing applications.

NOTE

1. In Automatic Position Hold timing mode, the calculated position data is not saved when voltage drop. The position acquisition and calculation will be repeated after the next startup.
2. In any case, after changing the antenna position of the receiver, the receiver must be restarted and the timing mode back set to Automatic Position Hold timing mode to recalibrate the antenna position.
3. In Automatic Position Hold timing mode, to ensure the module's timing accuracy, it is necessary to perform position convergence with a good GNSS signal.

2.3. GNSS System Time Reference

The GNSS system uses a unified time scale to synchronize time between devices, providing a foundation for high-precision positioning, navigation and timing service.

2.3.1. GNSS System Time and Traceability

Each GNSS system maintains an independent and stable system time, which is traced back to UTC time.

Table 5: GNSS System Traceability

GNSS System	GNSS System Time	Traceability Benchmark
GPS	GPST	UTC (USNO)
GLONASS	GLONASST	UTC (SU)
BDS	BDT	UTC (NTSC)
Galileo	GST	UTC (GST)

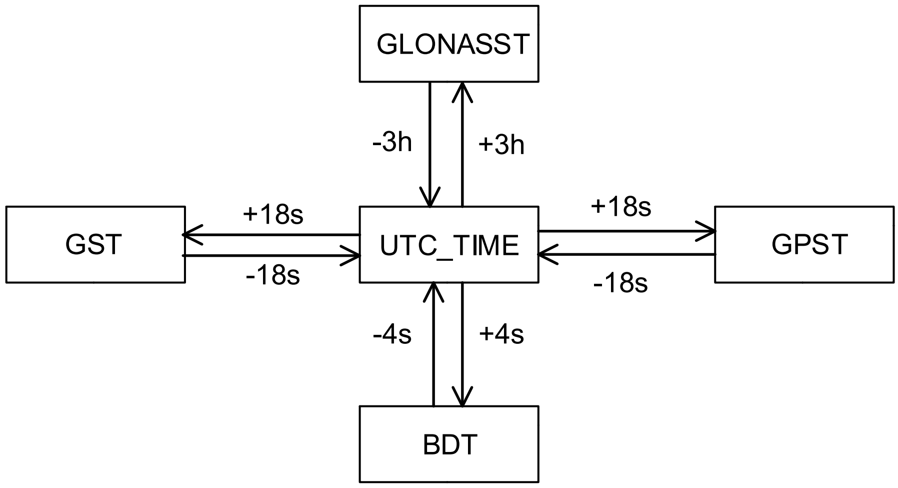

Figure 4: GNSS System Time Base Difference

2.3.2. GNSS System Time Reference

Table 6: Time Base List

Time Base	Abbreviation	Definition and Features
UTC	UTC	Coordinated Universal Time (UTC), maintained by the United States Naval Observatory (USNO), is the international standard time scale.
GPS Time	GPST	**Definition:** GPS Time (GPST) is a composite time scale based on the frequency standards of GPS monitoring stations and satellite clocks. Its calculation process is part of the overall estimation of satellite clocks and orbital parameters. **Monitoring Station System:** The GPS system uses multiple monitoring stations distributed around the world: ● Includes six monitoring stations operated by the US National Geospatial-Intelligence Agency (NGA). ● Six additional monitoring stations are distributed around the world. ● All monitoring stations use cesium atomic clocks as time and frequency references; two of the monitoring stations also use hydrogen atomic clocks. **Time Tracing and Maintenance:**

Time Base	Abbreviation	Definition and Features
		● **Traceability Relationship:** GPS time is established by the GPS ground control segment and traced back to the UTC time maintained by the United States Naval Observatory (USNO). ● **Time Accuracy:** The deviation target between GPST and UTC (USNO) is maintained within 1 μs, with a correction accuracy of 40 ns (95 % probability). ● **Update Mechanism:** The clock parameters of each satellite are theoretically updated at least once a day. **Leap second rules:** ● GPST is not corrected by whole seconds with UTC leap seconds. ● Since January 2017, GPST has been 18 s ahead of UTC time.
GLONASS Time	GLONASST	**Definition:** GLONASS time (GLONASST) is generated based on the GLONASS Central Synchronizer (CS). The central synchronizers are deployed in two GLONASS ground control segments, each synchronizer containing a set of hydrogen clocks with daily stability better than 2×10^{-15}. **Central Synchronizer System:** ● The central synchronizer system consists of a main central synchronizer and a backup central synchronizer. ● The main central synchronizer is responsible for generating the GLONASS time reference. ● The backup central synchronizer synchronizes its time scale with the main central synchronizer through a satellite signal full view algorithm. **Time Tracing and Accuracy Control:** ● **Traceability Relationship:** GLONASST is traceable to UTC (SU) maintained by the National Standard Time and Frequency Reference (STFR). ● **Accuracy Control:** The deviation of GLONASS time from UTC (SU) is kept within 1 ms, and its correction parameters are calculated and uploaded once a day with a correction accuracy of 1 μs. **Leap second rules:** ● GLONASST uses the same leap second correction

Time Base	Abbreviation	Definition and Features
		mechanism as UTC, so there is no time deviation of whole seconds between GLONASS time and UTC (SU). ● Due to the operating rules of the GLONASS ground control segment, there is a constant offset of 3 h between GLONASS time and UTC.
UTC (SU)	UTC (SU)	Coordinated Universal Time maintained by the Russian Institute of Time and Space Metrology (SU).
GPS time (from GLONASS time reference)	GPS time from GLONASS	GPS_UTC_FROM_GLONASS is the GPS time derived from the GLONASS satellite system. Its core logic is to use the GPS time broadcast by GLONASS satellites to correct parameters and convert the GLONASS system time to the corresponding GPS time.
BDS Time	BDT	**Definition:** Beidou Satellite Navigation System Time (BDT) is a composite time scale generated and maintained by the master control station, which is calculated based on the hydrogen clocks of the master control station and the monitoring station. ● Master Clock: BDT uses a high-precision hydrogen clock as its master clock to provide a time reference for the BDST and other subsystems. ● Stability: daily stability: 2×10^{-14}; weekly stability: 1×10^{-14}. **Time Tracing and Accuracy Control:** ● **Traceability Relationship:** BDT traces back to international UTC through the National Time Service Center (NTSC) of the Chinese Academy of Sciences. ● **Time Accuracy:** The time deviation between BDST and the reference time UTC (NTSC) is better than 100 ns, with a correction accuracy of 5 ns (95 %). ● **Update Mechanism:** The time deviation parameters are updated every hour through satellite navigation broadcast messages. **The starting epoch and leap second rule:** ● **Starting Epoch:** UTC time 00:00:00 on January 1, 2006. ● **Leap Second Rule:** Without leap second correction. ● **Time Difference Result:** Since January 2017, BDT has been 4 s ahead of UTC time.

Time Base	Abbreviation	Definition and Features
UTC (NTSC)	UTC (NTSC)	**Definition:** UTC (NTSC) is the Chinese national standard time established and maintained by the National Time Service Center (NTSC) of the Chinese Academy of Sciences. It is the result of the comprehensive coordination of highly stable atomic clocks and world time based on the measurement of the Earth's rotation. **Time tracing and generation process:** 1. Local atomic time calculation: NTSC calculates local atomic time based on the clock difference measurement results of the atomic clock. 2. International collaborative traceability: ● NTSC sends local atomic clock data to the International Bureau of Weights and Measures (BIPM) in Paris, France. ● BIPM comprehensively processes atomic clock and atomic time data submitted by countries around the world, calculates international standard time, and publishes it regularly. 3. Time Steering Generation: NTSC steers the atomic clock based on its own calculated local atomic time and the calculation results of BIPM to generate China's standard time UTC (NTSC), that is, Beijing time.
Galileo Time	GST	**Definition:** Galileo Time (GST) is an atomic time scale generated by the primary clock of the Galileo System's Precision Time Facility (PTF). ● **PTF geographical distribution:** The two PTF systems of Galileo are located in the Galileo control centers in Italy and Germany respectively. ● **PTF clock configuration:** Each PTF is equipped with a hydrogen clock (master clock) and a cesium clock (backup clock). ● **GST generation mechanism:** The PTF clock, other ground station clocks and satellite clocks work together to generate GST based on the PTF master clock. **Time Tracing and Accuracy Control:** ● **Traceability Relationship:** GST is a UTC forecast time obtained by the Galileo Time Service Provider from

Time Base	Abbreviation	Definition and Features
		multiple European UTC laboratories. ● **Time deviation control mechanism:** The Galileo Time Service Provider calculates the deviation between GST and UTC by calculating the GST-UTC time deviation and the GST-UTC conversion parameters. ● **Time Accuracy:** GST is aligned modulo 1 s, with a deviation from UTC of less than 50 ns (95 %), and a correction accuracy of 28 ns (95 %). The correction parameters for GST and UTC are updated once a day. **Leap Second Rules:** ● GST is not corrected by whole seconds with UTC leap seconds. ● Since January 2017, Galileo time has been 18 s ahead of UTC.
UTC (GST)	UTC (GST)	UTC (GST) is European UTC, which is derived from Galileo time, applying the UTC delta time downloaded from the Galileo satellite.
GPS time (from the Galileo time reference)	GPS time from GST	GPS_UTC_FROM_GST is the GPS time derived from Galileo, applying the GPS correction parameters downloaded from the Galileo satellite.

2.3.3. GNSS System Time Base Configuration

For the output second pulse signal, the time pulse can be aligned with the following two time bases:

- **GNSS System Time:** GPST, BDT, GLONASST and GST;
- **UTC time:** The receiver calculates the time based on the GNSS system time, using the coordinated universal time offset (UTCO) parameters and leap second information broadcast by the navigation satellites.

Standard configuration process and recommendations:

- In general, the receiver allows the user to use commands to select between GNSS system time and UTC time;
- The user needs to select a suitable time base according to the needs;
- It is strongly recommended that the time base selection is aligned with the available GNSS signal. For example, if you choose GPS time and UTC, make sure that GPS signals are present; if you choose GLONASS time or UTC (SU), make sure that GLONASS signals are present.

UTC synchronization delay risk warning:

Each GNSS system periodically transmits information about its system time converted to the relevant UTC time at relatively long intervals. For example, GPS transmits UTC (USNO) information every 12.5 minutes. Therefore, if the time pulse is configured to using UTC, the time pulse may be delayed significantly after a cold start before the receiver obtains enough information.

2.4. Leap Second

The principles of leap second generation:

- Because the Earth's rotation is not uniform, UTC is out of alignment with mean solar time (i.e., the sun no longer appears directly above 0 degrees longitude at noon), and the International Timekeeping Organization uses "leap seconds" to readjust UTC to bring it into close alignment with mean solar time.
- This is usually done by adding or subtracting a second in the last minute of the year, but can also occur on June 30.
- When this happens, UTC is expected to go from 23:59:59 to 23:59:60 before going to 00:00:00. Negative leap seconds are theoretically possible, in which case a minute would only have 59 seconds, and 23:59:58 would be followed by 00:00:00.

Receiver processing mechanism:

The receiver performs leap second adjustments in UTC output, so users who process UTC time from NMEA messages should note that the minute length may contain 59 or 61 seconds.

2.5. True Value Device

The accuracy of the time pulse can be measured by the time difference between the device under test and the reference device. The time of the reference device should be as accurate as possible. Usually, a GPS receiver equipped with a high-precision atomic clock is used as a reference device. The following are two common devices that can be used as the true value of time.

2.5.1. FS740 (Rubidium Atomic Clock)

PPS accuracy specification: peak-to-peak value ≤ ±50 ns, that is, the difference between the maximum deviation and the minimum deviation compared with the true value does not exceed ±50 ns.

2.5.2. VCH-1008 (Hydrogen Atomic Clock)

PPS accuracy specification: peak-to-peak value ≤ ±50 ns, that is, the difference between the maximum deviation and the minimum deviation compared with the true value does not exceed ±50 ns.

NOTE

Both FS740 and VCH-1008 use standard GNSS disciplining for atomic clock calibration, thus their PPS accuracy is basically the same. The difference is that one is a hydrogen atomic clock and the other is a rubidium atomic clock. In the event of loss of external GNSS signals, the hydrogen clock exhibits significantly higher holdover performance.

2.6. PPS Statistical Metrics

2.6.1. PPS Accuracy Index–Standard Deviation (σ)

2.6.1.1.Definition

Standard Deviation quantifies the dispersion of a dataset, represented by σ. In essence, it measures how spread out the values are around the mean. A larger σ indicates greater variation from the mean, while a smaller σ denotes closer clustering to the average. It is expressed as PPS accuracy < N ns @ 1σ, such as LC99T (IA) PPS accuracy: < 13.6 (±6.8) ns @ 1σ.

2.6.1.2.Calculation

For a dataset of deviations (X_1, X_2, X_3, X_4, X_5) representing differences between module PPS output and the true value, and the standard deviation σ is calculated as:

$$\sigma = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + (X_3 - \overline{X})^2 + (X_4 - \overline{X})^2 + (X_5 - \overline{X})^2}{5}}$$

As derived from the formula, a smaller σ value indicates reduced dispersion of individual differences between module PPS and the true value around the mean deviation. That is, lower fluctuation between module PPS and true value indicates higher PPS stability.

The fixed bias from cable delay does not affect the PPS stability, so the above calculation method does not take cable delay into consideration.

2.6.2. PPS Stability Index–Jitter

2.6.2.1. Definition

PPS jitter reflects the stability of the difference between the module PPS and the true value, expressed as ± N ns (Jitter). For example, the PPS jitter of LC99T (IA) is: ±6.5 ns (Jitter).

2.6.2.2. Calculation

Taking a set of data X_1, X_2, X_3, X_4, X_5 representing the difference between the module PPS and the true value as an example. The calculation formula for Jitter is as follows:

1. First calculate the difference between adjacent data to obtain a new set of data:

$$Y_1 = X_2 - X_1,\ Y_2 = X_3 - X_2,\ Y_3 = X_4 - X_3,\ Y_4 = X_5 - X_4$$

2. Calculate the Jitter value for the new set of data:

$$\text{Jitter} = \sqrt{\frac{{Y_1}^2 + {Y_2}^2 + {Y_3}^2 + {Y_4}^2}{4}}$$

It can be seen from the calculation formula, the smaller the Jitter value is, the smaller the difference between adjacent data will be. That is, the fluctuation of the difference between the module PPS and the true value will be smaller.

3 Timing Operation Guide

3.1. PPS Status Introduction

The timing receiver provides a PPS signal with output pulse width and adjustable polarity. The output PPS signal is synchronized with GNSS or UTC time and can be configured and queried through the **PSTMPPS** command (for details about the **PSTMPPS** command to configure the PPS signal, see *documents [1]* and *[2] protocol specifications*). The **PSTMPPSDATA** message is used to describe the corresponding PPS information, including the corresponding time and time accuracy indication; the **PSTMPOSHOLD** message is used to describe the position hold status and position.

The **<PPS_Valid>** parameter in the **PSTMPPSDATA** message can be used to determine whether the PPS signal is valid and available for use.

PPS performance when the device is powered on but not positioned:

```
$PSTMPPSDATA,1,0,0,0,1,0,0.500000,0,350,305,357,841,0,0,0,10,89231,50,1,0,18,0,0,0,1.384e-08,65473975.61,26000006.86,4*14
```

Unlocked PPS performance:

```
$PSTMPPSDATA,1,0,1,0,1,0,0.500000,0,350,305,357,841,0,0,0,10,89231,38,1,0,18,0,0,0,8.472e-09,65473975.33,26000006.75,4*16
```

Before holding position:

```
$PSTMPOSHOLD,0,3149.303678,N,11706.919399,E,094.45*45
```

After holding position:

```
$PSTMPOSHOLD,1,3149.303676,N,11706.919399,E,094.45*4A
```

PPS valid:

```
$PSTMPPSDATA,1,1,1,0,1,0,0.500000,0,350,305,357,841,0,0,0,10,89231,58,3,35,18,0,0,0,1.181e-08,65473974.09,26000006.26,4*2A
```

NOTE

When the PPS accuracy exceeds the set accuracy threshold, it will be displayed that PPS is invalid.

3.2. PPS Signal Configuration

This chapter takes the L26-T as an example to explain how to configure the PPS signal when the module is set to GPS only. When adjusting the timing pulse, the propagation delay caused by the cable length between the antenna and the GPS receiver must be taken into account.

3.2.1. Pulse Waveform Configuration Example

1. Set the pulse output mode:

Set the output PPS per second:
$PSTMPPS,2,2,0*55

2. Set the pulse width:

To set the pulse width to 500 ms:
$PSTMPPS,2,5,0.5*49

3. Set pulse polarity: polarity inversion, polarity non-inversion:

Set the polarity of PPS not to be reversed:
$PSTMPPS,2,6,0*51

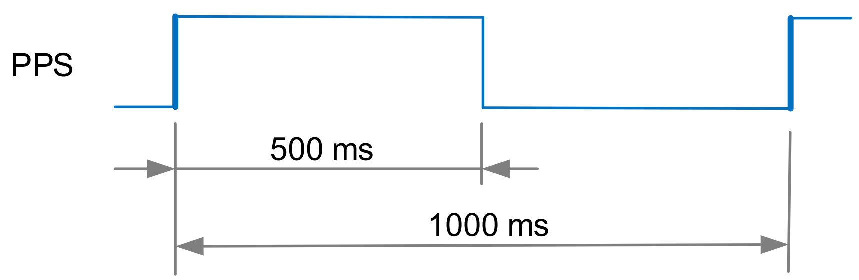

Figure 5: Configure the PPS Signal

3.2.2. Other Configuration Examples of Pulse

1. Set the reference time for synchronizing PPS:

Set the reference time of PPS to GPS time:
$PSTMPPS,2,19,1*6E

2. Set a time correction to compensate any delay on the PPS signal caused by cables and/or RF chain:

Output the PPS signal 10 ns earlier:
$PSTMPPS,2,4,10*62

3. Set the GNSS positioning conditions for generating PPS signals:

PPS can also be output when no positioning is set:

$PSTMPPS,2,8,1*5E

4. Set the minimum number of satellites to generate PPS signals:

Set the minimum number of satellites to generate a PPS signal to 0:
$PSTMPPS,2,9,0*5E

5. Set the minimum elevation of a satellite when it is used in timing filtering:

Set the satellites with elevation angle lower than 10° not to participate in timing:
$PSTMPPS,2,10,10*57

6. Set the satellite constellation to be used in timing filtering:

Set the satellite constellation to be used in timing filtering to GPS satellites:
$PSTMPPS,2,11,1*66

7. Set the number of position samples for automatic position keeping:

Set the number of position samples for automatic position keeping to 3600:
$PSTMPPS,2,14,3600*57

8. Set the time error threshold for satellites removal in the TRAIM algorithm:

Set the satellites whose time correction error calculated by the TRAIM algorithm is greater than 15 ns to not be used for timing:
$PSTMPPS,2,15,1,15E-9*1B

9. Set the information of the fixed-position.

Set the longitude, latitude, and altitude information of a static fixed point:
$PSTMPPS,2,13,1,3149.339242,N,11706.952207,E,004.01*60

3.3. Testing PPS Accuracy

3.3.1. Testing PPS Accuracy Using Instrument

The device connection diagram for timing test with instruments is as follow:

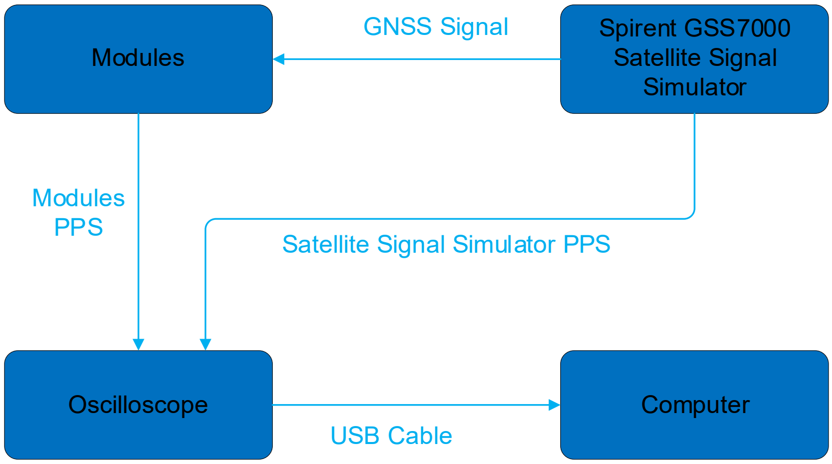

Figure 6: Device Connection Diagram

3.3.1.1. Testing PPS Accuracy in Automatic Position Hold Mode

1. Connect the Spirent GSS7000 dedicated RF output line to the antenna interface of the module.
2. If the test requires specific ambient temperature conditions, place the module in a thermal chamber and set it to the target temperature. Skip this step if no temperature control is required.
3. Turn on the module, perform relevant configurations, and wait for the module to enter the Automatic Position Hold mode. The position hold status and fixed position information can be viewed through the **PSTMPOSHOLD** message.
4. After the module enters the position hold status, measure the PPS waveforms of the module and GSS7000 using an oscilloscope.
5. Use an oscilloscope to record the time difference between the PPS signal of the module and that of the GSS7000 per second.
6. Calculate the PPS accuracy based on the recorded time differences.

3.3.1.2. Testing PPS Accuracy in Fixed-position Mode for Single-satellite Timing

1. Connect the Spirent GSS7000 dedicated RF output line to the antenna interface of the module.
2. Set the Spirent GSS7000 to broadcast only one satellite, and require that this satellite is always visible during the test duration.
3. Turn on the module, inject the current latitude, longitude and altitude of the Spirent GSS7000 into the module through the following command:
   $PSTMPPS,2,13,1,<Lat>,<N/S>,<Lon>,<E/W>,<H_Msl>*<Checksum><CR><LF>.
   The position hold status and fixed position information can be viewed through the **PSTMPOSHOLD** message.
4. Use an oscilloscope to measure the PPS waveform of the module and GSS7000.
5. Use an oscilloscope to record the time difference between PPS signal of the module and that of the

GSS7000 per second.
6. Calculate the PPS accuracy based on the recorded time differences.

3.3.1.3. Testing PPS Accuracy in Automatic Position Hold Mode for Single-satellite Timing

1. Connect the Spirent GSS7000 dedicated RF output line to the antenna interface of the module.
2. Turn on and configure the module, and then wait for the module to enter the Automatic Position Hold mode. The position hold status and fixed position information can be viewed through the **PSTMPOSHOLD** message.
3. After the module enters the position hold status, reduce the number of satellites broadcast by GSS7000 to 1 visible satellite, and measure the PPS waveforms of the module and GSS7000 using an oscilloscope.
4. Use an oscilloscope to record the time difference between the PPS signal of the module and that of the GSS7000 per second.
5. Calculate the PPS accuracy based on the recorded time differences.

3.3.2. PPS Accuracy Test under Real Network

The device connection diagram for timing test under the real network is as follow:

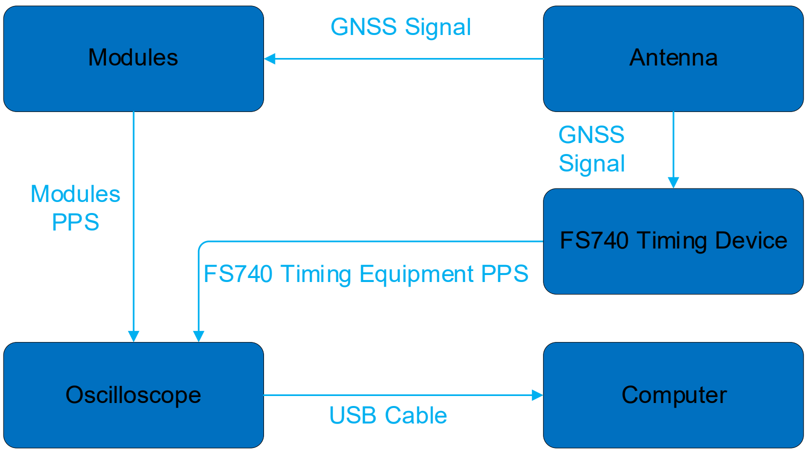

Figure 7: Device Connection Diagram

The test steps are as follows:

1. Place the antenna on the rooftop in an open sky environment, and connect the module and FS740 (rubidium clock) timing true value device to the antenna.
2. If the test requires specific ambient temperature conditions, place the module in a t thermal chamber and set it to the target temperature. Skip this step if no temperature control is required.
3. Turn on the module, perform relevant configurations, and wait for the module to enter the Automatic

Position Hold mode. The position hold status and fixed position information can be viewed through the **PSTMPOSHOLD** message.
4. After the module enters the position hold status, measure the PPS waveforms of the module and FS740 using an oscilloscope.
5. Use an oscilloscope to record the time difference between the PPS signal of the module and that of the FS740 per second.
6. Calculate the PPS accuracy based on the recorded time differences.

3.4. PPS Accuracy Calculation Example

Using the following set of PPS time difference data between the module and true value device as an example:

Table 7: PPS Accuracy Calculation Example

Local Time	PPS Error Statistics	Unit
3:27:53	4	ns
3:27:54	1	ns
3:27:55	-6	ns
3:27:56	5	ns
3:27:57	3	ns
3:27:58	1	ns
3:27:59	8	ns
3:28:00	2	ns
3:28:01	-5	ns
3:28:02	-3	ns

3.4.1. Calculate the Standard Deviation (σ)

1. First, calculate the average value of the dataset:

$$\overline{X} = \frac{4 + 1 - 6 + 5 + 3 + 1 + 8 + 2 - 5 - 3}{10} = 1$$

2. Then calculate the standard deviation of the dataset:

$$\sigma = \sqrt{\frac{(4-1)^2 + (1-1)^2 + (-6-1)^2 + (5-1)^2 + (3-1)^2 + (1-1)^2 + (8-1)^2 + (2-1)^2 + (-5-1)^2 + (-3-1)^2}{10}} = \sqrt{18} \approx \pm 4.24$$

3.4.2. Calculate Jitter

1. First, calculate the difference between adjacent data:

   1 - 4 = -3
   -6 - 1 = -7
   5 - (-6) = 11
   3 - 5 = -2
   1 - 3 = -2
   8 - 1 = 7
   2 - 8 = -6
   -5 - 2 = -7
   -3 - (-5) = 2

2. Then, calculate Jitter:

$$\text{Jitter} = \sqrt{\frac{3^2 + (-7)^2 + 11^2 + (-2)^2 + (-2)^2 + 7^2 + (-6)^2 + (-7)^2 + (2)^2}{9}} = \sqrt{\frac{325}{9}} \approx \pm 6.01$$

4 FAQ

Troubleshooting directions when PPS accuracy does not meet expectations:

- Check the module's satellite tracking count and C/N_0 values. Avoid testing PPS accuracy under weak signals.
- Verify whether the module has entered the position hold status.
- Inspect the test environment (including module operating temperature, operational procedures, and device connection method).
- Confirm whether the true value reference device itself introduces errors.

5 Appendix Reference

Table 8: Related Documents

File Name
[1] Quectel_LC29T(AA)&LC99T(IA)_GNSS_Protocol_Specification
[2] Quectel_L26-DR&L26-P&L26-T&LC98S_Series_GNSS_Protocol_Specification

Table 9: Terms and Abbreviations

Abbreviation	Description
BDS	Beidou Navigation Satellite System
BDT	BDS Time
BIPM	The International Bureau of Weights and Measures
CS	Central Synchronizer
GLONASS	Global Navigation Satellite System (Russia)
GLONASST	GLONASS Time
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPST	GPS Time
GST	Galileo Time
NGA	National Geospatial-Intelligence Agency
NMEA	NMEA (National Marine Electronics Association) 0183 Interface Standard
NTSC	National Time Service Center
STFR	Standard Time and Frequency Reference

Abbreviation	Description
PPS	Pulse Per Second
PTF	Precision Time Facility
TRAIM	Time-Receiver Autonomous Integrity Monitoring
USNO	United States Naval Observatory
UTC	Coordinated Universal Time
σ	Sigma