Chapter 35
Title Research on Key Technology of Testing and Verification Multi GNSS Simulator

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Abstract Multi GNSS Simulator provides the technical means and environments in those areas as the framework designing for navigation systems, study of effects of signal propagation environments, ground testing and verification of Compass navigation system. As a satellite navigation testing device, high-performance multi-mode satellite navigation signal generators includes many essential technologies as multi-system constellation simulation, signal propagation environment effects simulation, user movement characteristic simulation, antenna characteristic simulation, high-precision navigation signal simulation, thus brings the challenges for the high-precision, accurate, objective and just assessment and testing. The article based on the generator project, studies the testing and assessment system for the generators and preliminarily determines complete assessment means and testing guidelines, particularly in the study of processing and analysis method of applying standard equipments such as high-speed signal sampler. The generator has gone through the testing of the control resolution of generator's pseudo ranges and passed the actual testing and verifications.

Keywords GNSS · GNSS simulator · Testing and assessment · High-speed signal sampler

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35.1 Introduction

As a signal framework verification means that is the most close to practical considerations, multi-mode GNSS simulator is used to help with the verification of the design rationality of navigation signal system, the assessment of navigation signal stream, the rationality verification of information stream and other specification verification in addition to supporting the development of ground receiver terminal and other related application products.

As test equipment particularly for navigation equipment, GNSS simulator is required to have high accuracy, good measurability and calibration capability. Its navigation test capability is based on overall testing and assessment to itself. However, GNSS simulator is classified as high-end test equipment and involved in many sensitive applications and technologies, and almost no open literature is available internationally about the testing and assessment methods. In China, along with the construction of navigation system, some navigation simulators were developed, of which the testing and assessment is still in exploratory experiment stage. In a simulator development project we undertook, an in-depth research and analysis and verification test were given to the testing and assessment methods for simulator, so as to assure the testing accuracy and objectivity.

35.2 Test and Assessment of GNSS Simulator

35.2.1 Key Test Items of Simulator

Considering the characteristics of GNSS simulator, the tests are divided into functional and performance tests to mathematic simulation software and hardware performance test of simulator. The simulator hardware tests are performance tests particular for high-accuracy signal, which is quite different from the ones for general signal simulator.

1. Mathematic simulation test.

   - In terms of navigation constellation and orbit simulation function, the simulated orbital data should be in agreement with the Ephemeris data that are used to generate navigation message.
   - In terms of satellite clock error simulation function, the simulated satellite clock error should be in agreement with the clock error model set by user and the satellite clock parameters in the generated navigation message.
   - In terms of ionospheric delay simulation function, the simulated ionospheric delay should be in agreement with the ionospheric model set by user and the ionospheric parameters in the navigation message.

- In terms of tropospheric delay simulation function, the simulated tropospheric delay should be in agreement with the tropospheric model set by user and the tropospheric parameters.

2. Key test items for signal simulation precision.

- RF signal precision.

– Pseudo range zero value and its stability.
– Pseudo range precision.
– Pseudo-range control resolution.
– Pseudo-range rate precision.
– Carrier-phase change precision.
– Intersignal code phase consistence.
– Code-phase interchannel consistence.
– Carrier-phase interchannel consistence.
– Coherence between carrier and pseudo code.

- Dynamic control precision of RF signal.

– Speed resolution.
– Acceleration resolution and Jerk resolution.

35.2.2 Key Test Items of Simulator

Since the present requirement for pseudo-range control accuracy of simulator has reached centimeter level and the requirements for carrier control accuracy has reached millimeter level, it brings about challenges for the tests based on standard instrument, especially for the tests under dynamic signal conditions and the tests for modern navigation signals based on complicated modulation. The popular test proposals are mainly based on standard instrument or software receiver. Neither method is perfect. The standard instrument method is the easiest to be acceptable, but it requires corresponding research and strict test and assessment method. The software receiver method depends on signal acquisition and mathematical statistics of observed quantity; it is thereby applicable to the tests related to statistics.

35.2.2.1 Software Receiver Method

Signal simulator is mainly designed to give function verification and performance test to receiver. To complete specification and performance tests for multi-system signal simulator, the test instruments of higher resolution are required. If software receiver is to be used in testing signal simulator, then the software receiver must have excellent performance or accuracy to be qualified.

1. Pseudo-range zero value(accuracy) test

Pseudo-range zero value and stability test is mainly used to verify if the pseudo-range zero value and the stability of navigation signal simulation meet the requirements or not. Software receiver testing method uses the directly obtained pseudo range for assessment, which has the following weakness:

- Since software receiver has no reference 1PPS input, it is very difficult to acquire the time point information for synchronization with the simulator. It has no choice but to preestimate a local time after the receiver acquires and tracks the downlink signal and restores the emission time, and then acquire a pseudo-range value based on the time difference between the preestimated local time and the subsequently received emission time, which is used to compare with the theoretical value provided by the simulator and the value measured by the software receiver.
- After obtained the measurement pseudo range, software receiver may acquire the simulator error based on the difference between the measuring pseudo range and the real pseudo range. However, it is very difficult to eliminate the receiver error or to justify that the receiver error is much less than the simulator error; in other words, the challenge is no way to eliminate the system error.

2. Pseudo-range accuracy test

After the software receiver is given coarse alignment, if the alignment accuracy is inadequate, fine alignment should follow. In the process of fine alignment, it is required to shift the local sampled data to complete the test. If pseudo-range accuracy requirement is 0.01 m, then the resolution of data point after sampling must be higher than 0.01 m. To implement such a high accuracy, the sampling rate of receiver might have to be above 30 GHz and a series of design issues must be considered such as how to sample the receiver processing data, how to store and how to generate pseudo code and carrier of software receiver. In addition, even if post-processing mode is used, it needs a very long processing time to process the sampled data in unit time.

3. Pseudo-range rate accuracy test

In the measurement of pseudo-range rate, pseudo range is also used for being agreement with signal simulator, which is related to sampling rate as well. The more critical fact is that the assessment of pseudo-range rate accuracy is essentially the assessment of Doppler accuracy. The reference value provided by the signal simulator is an instant Doppler value, while receiver can only measure the average Doppler rather than the instant Doppler with the full-cycle carrier count traveled in unit time. When testing this specification, receiver is required to complete PVT solution to acquire local reference time accurately. The accuracy is required to be mill microsecond level at least. It is really difficult for a receiver to maintain mill microsecond-level accuracy.

4. Carrier Phase Modulation Orthogonality

In the testing process of carrier phase, to assure the same phase and the phase accuracy of orthogonality higher than 1 degree, the carrier loop accuracy must be much higher than 0.003 cycle. To reach such a high accuracy with software receiver or to assure the PLL to reach such a high accuracy, the requirements for the clock accuracy of the local AD capture card and for the local RF phase noise must be very high. In other words, it is very difficult to reach such a high accuracy with software receiver.

35.2.2.2 High-Speed Broadband Storage Oscilloscope Method

Along with the rapid development of high-speed broadband digital storage oscilloscope, it becomes possible to directly measure the high-accuracy signal characteristics in the delay test of BPSK modulator. It includes two types of test: modulation domain test and time domain test [1].

Essentially, modulation domain testing method is a method that integrates time domain and modulation domain together. It acquires baseband signal and RF signal simultaneously with oscilloscope, and then analyze the RF signal with vector analysis software and restore the baseband signal, which is finally compared with the original baseband signal in time domain to obtain the delay parameter. The major weakness of this method is that an inherent inconsistence exists between the acquired baseband signal and the finally modulated signal, which makes it impossible to precisely characterize the characteristics of the baseband signal finally modulated. Besides, vector analysis software is required to set such parameters as reference filter and testing filter. The setting accuracy of these parameters is directly related to the detail accuracy of the baseband signal waveform finally demodulated, and consequently affects the final test results [2]. In working practice, it is hard to obtain the accurate parameters of modulator, and the approximate value is usually used; therefore, it is not easy to evaluate the accuracy of this testing method. Besides, since digital down conversion is introduced for demodulation analysis, the time resolution might suffer from loss. Moreover, this method requires complicated operations, and changes take place twice in time domain and modulation domain. It will be extremely inefficient to work out the mean value by manual measurements for many times.

The theoretical basis of time-domain test is the assumption that the point of smallest amplitude on the signal envelope is the phase reversal point after modulation and filtering, for the frequency band of BPSK signal is the widest at the phase reversal point. For an ideal BPSK modulated signal, theoretically, the phase change of sinusoidal wave should take place at the change time of modulated signal, and the sinusoidal wave should be undamped before and after modulation. In actual measurement, however, there is no ideal waveform, but a point of minimum amplitude (envelope zero point) exists, because the frequency band is the widest at modulation time and the energy attenuation resulting from the finite

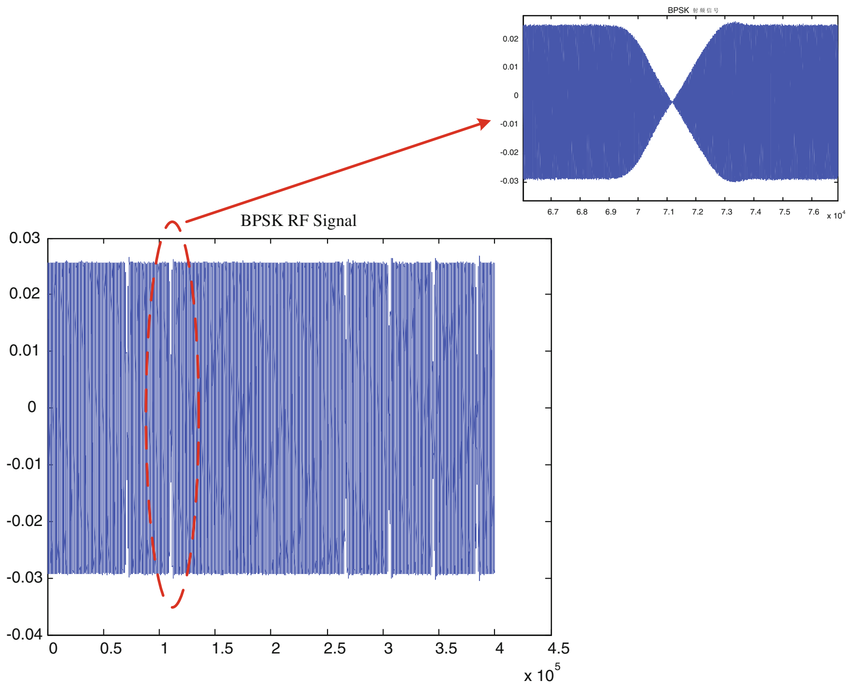

Fig. 35.1 Phase reversal point of BPSK signal

bandwidth of filter is the maximum [3]. The practice in the past was to directly measure the time difference between the signal edge and the phase reversal point with an oscilloscope. This measurement is generally taken with cursor manually. The weakness of this method is the difficulty to locate the phase reversal point. Besides, subjective factor of test operator is introduced in the test and the requirement for the output level of RF signal is definite to assure the observation with oscilloscope. Conclusively, it is difficult to guarantee the measuring accuracy and consistence in this method. In particular, it is really hard to directly observe and test the non-BPSK complex-modulated signals among the navigation signals (Fig. 35.1).

35.3 Research of Key Techniques

35.3.1 Test of BOC Signal

For BPSK, BOC and TMBOC signals, they have the same time domain characteristic as BPSK signal but subcarrier makes the chip width of BOC and TMBOC signals narrower. Currently, the oscilloscope testing method is based on the

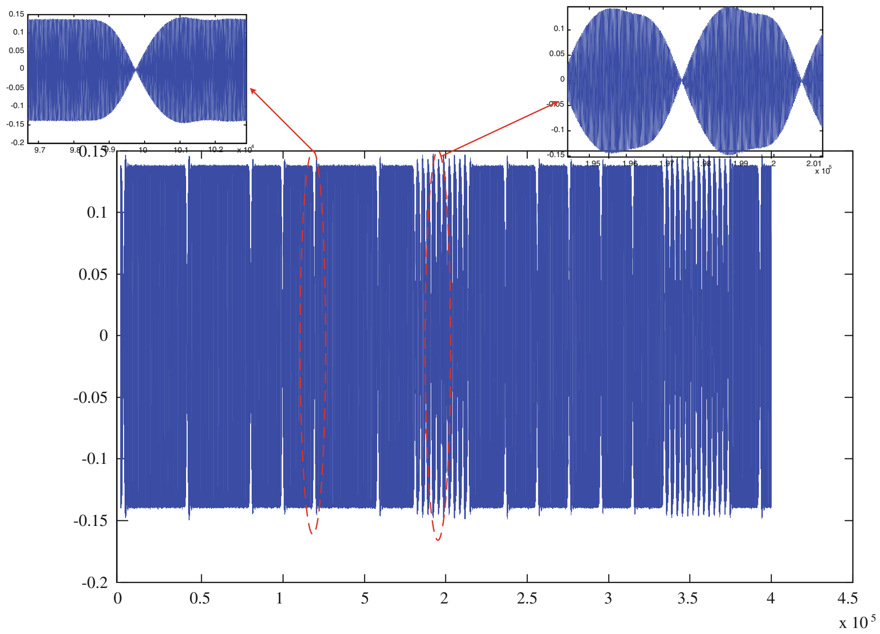

Fig. 35.2 Phase reversal point of MBOC signal

monitoring to the phase reversal point of chip variation. BPSK, BOC and TMBOC signals have the same phase reversal point of chip; therefore, they share the same testing basis (Fig. 35.2).

MBOC signal is based on the sum of one BOC(1,1) and one BOC(6,1). The power of BOC(6,1) is only 1/10 of that of BOC(1,1) and their subcarrier phases are aligned with each other; therefore, the oscilloscope testing method for BOC(1,1) is used when testing CBOC signal and BOC(6,1) is ignorable.

35.3.2 Dynamic Signal Tested with Oscilloscope

When testing the velocity related performance of simulator in response to dynamic signal, the frequency meter method is often used currently. In principle, velocity will generate Doppler that may cause frequency offset. It is allowed to measure the frequency offset to test the velocity related specifications. Specifically, it is implemented by setting the simulator under test to output single carrier plus the frequency offset generated by Doppler. However, since it is single-carrier signal directly generated by simulator, which has lost the intension of navigation signal as spread-spectrum signal to complete velocity measurement of user terminal, this method has certain limitation. Based on a research, Doppler will also pose offset of pseudo code

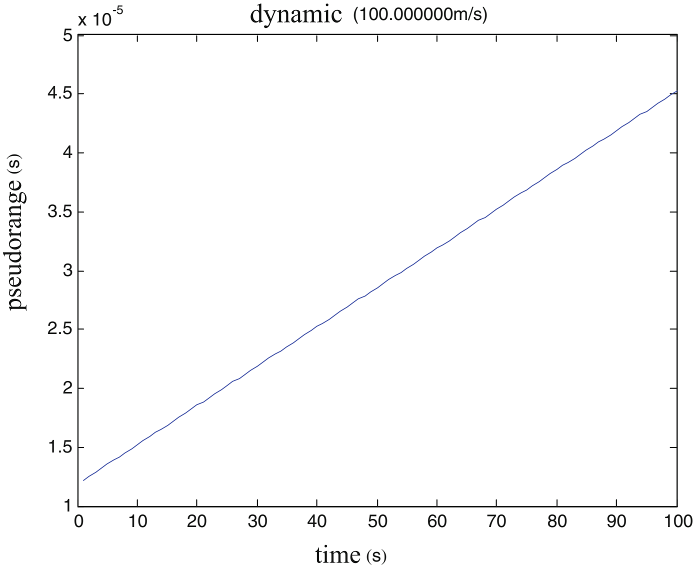

Fig. 35.3 100 m/s velocity test

and carrier relative to simulator reference signal; therefore, it is possible to carry out statistical test with oscilloscope method. The procedure is as follows:

Set the simulator under test to single satellite stationary state and the satellite and simulated user receiver keep overhead vertically (receiver antenna pointing at satellite transmitter antenna all the time). Couple the 10 MHz simulator output with the 10 MHz external synchronization of an oscilloscope. Regulate the reference frequency of the oscilloscope to external 10 MHz reference. Input the 1PPS simulator output and the RF signal from the simulator calibration port into the high-speed storage oscilloscope via two channels. 1PPS signal serves as trigger signal and RF signal as tested signal. Set the receiver to static state and set the initial pseudo range of satellite and receiver to P0; set the dynamic scenario of receiver to uniform rectilinear translation; set the direction towards or back on to the diametric connection direction(forward direction/backward direction); and set the velocity amplitude to the resolution of velocity. Test the first phase reversal point with oscilloscope and then estimate the velocity amplitude based on simulator setting and go on setting to measure the pseudo-range values at the subsequent 100 phase reversal points. Thereby, it is possible to acquire the relation between pseudo-range change and time, i.e., velocity.

The results of several typical velocity-control accuracies are as follows when the simulator under test outputs GPS-L1 signal (Fig. 35.3):

- Set velocity: 100.000000 m/s
- Test acquired velocity: 10.000057 m/s

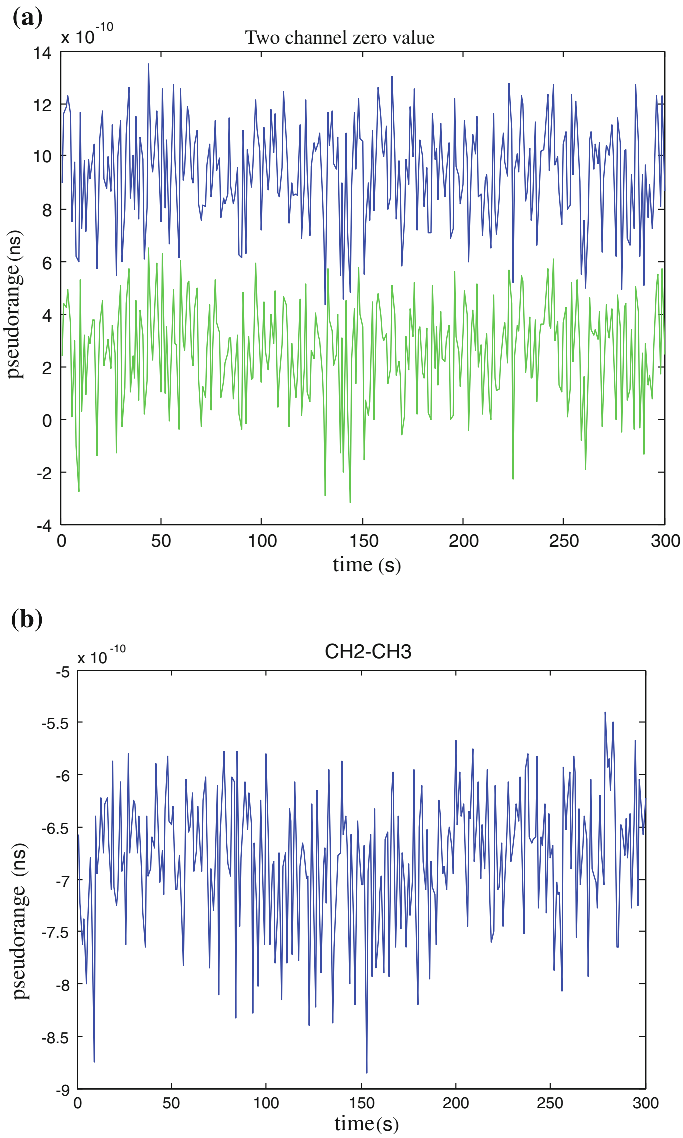

Fig. 35.4 Test results of pseudo-range control accuracy and interchannel deviation. **a** Two-channel zero value. **b** Interchannel deviation

As shown in the figures above, it is possible to measure the velocity control accuracy of simulator by measuring and summarizing the velocity at the reversal points of signal, which is applicable to testing dynamic signal accuracy.

Table 35.1 Test results of pseudo-range control accuracy and interchannel deviation

CH1 1PPS	CH2 GPS L1	CH3 B1	Interchannel deviation
Time calculating variance (ns)	0.188563	0.188243	0.062805
Time calculating variance after ten-point averaging (ns)	0.042881	0.044493	0.025107

Table 35.2 Test results with modified time frequency

CH1 1PPS	CH2 GPS L1	CH3 B1	Interchannel deviation
Time calculating variance (ns)	0.052826	0.055357	0.079713
Time calculating variance after ten-point averaging	0.010896	0.011469	0.013501
Time calculating variance after 60-point averaging	0.003581	0.005676	0.001717

35.3.3 Effect of Simulator Time–Frequency Signal to Measuring Accuracy

In the process of simulator specification test, it was found time–frequency signal had important effect to such specifications as pseudo-range control accuracy. Comparison tests were given for further analysis.

Test 1: 300 s test to two-channel data. Set oscilloscope CH1 to 1PPS, CH2 to GPS signal and CH3 to B1 signal (Fig. 35.4). The test results were as follows (Table 35.1).

The interchannel deviation satisfies the required specification of 0.02 m, but the single-channel deviation is poor, which might be related to the jitter of 1PPS signal. The good specification for 1PPS self jitter is 0.1 ns in China (a nominal performance index is higher than tens of ps abroad), it will introduce effect to signal accuracy test. It is concluded based on test that n-point data averaging is necessary to eliminate this effect. It is suggested to use external clock method (providing 10 M, 1PPS) when testing the accuracy specification, so as to eliminate the effect of 1PPS jitter.

Therefore, the following tests were conducted. Changed the time frequency and used Timetech Rb. oscillator and 10 MHz input instead of internal time frequency. The test results were as follows (Table 35.2):

As shown in the table above, after external time frequency was used, the jitter of self channel becomes smaller, which was in agreement with the result after 10-point averaging; conclusively, 1PPS jitter or internal time frequency affects the uncertainty of channel and deteriorates the jittering.

35.4 Conclusion

Based on the analyses and verification tests to simulator testing methods and the comparative analysis to the weakness of conventional methods, an exploratory research was given to the new navigation signal architecture and dynamic signal test with high-speed oscilloscope and by means of data statistic analysis. The proposed testing method was verified with tests that could improve the measurement accuracy significantly up to tens of ps. Comparing with the conventional methods, this method has the following features: directly testing in time domain, simple and easy to operate, direct output of results based on the characteristics of BPSK signal in time domain and the waveform sync calculation function, avoiding the factors that affect measuring accuracy by using digital down converter or filter in modulation domain test, and also avoiding the subjective uncertainty resulting from artificially reading the phase reversal points. On the basis of verification, this method may also be used to test such signals as BOC. It requires only to modify the test analysis program somewhat in working practice.

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