

# Calibrations of Satellite Navigation Signal Simulator channel-delay based on Hilbert Transform Envelope Detection Method

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**Abstract** – Satellite navigation signal simulators are widely used in validation of navigation system and test of navigation receivers, so the correctness and accuracy of the signal simulated are highly concerned in the field of satellite navigation. Channel-delay is one of the important parameters in Calibration for Satellite Navigation Signal Simulators. This paper designs an auto-test system of channel-delay based on Hilbert Transform Envelope Detection method, which can automatically complete multiple test of channel delay and calculate the uncertainty of measurement through high speed oscilloscope. In order to determine the exact location of the turning point, the system processes the signal by using the envelope detection method based on Hilbert Transform, and the minimum point of the signal level envelope is used as the turning point. Then, the channel delay of the simulator is finally obtained. The actual results show that the method can improve work efficiency, and is capable to raise the channel delay measurement accuracy up to 0.1ns. In conclusion, analysis of the test result implies that this method can be applied to test and calibration of the channel delay of the simulator. This methods also can be applied to high-precision calibration of GNSS simulator zero value and pseudo-range.

**Keywords** –Satellite Navigation Signal Simulator, channel-delay, Hilbert Transform

## I. INTRODUCTION

Satellite navigation signal simulator provides a simulation environment for testing navigation terminal, improve the efficiency of research and development. Each channel of the satellite navigation signal simulator simulates each working frequency point of visible satellite, and the satellite navigation receiver calculates the actual position of the receiver by measuring the

pseudo distance between the receiver and the visible satellite. Therefore, accurate measurement of channel-delay not only is one of the prerequisites for accurate positioning of the receiver, but also has important significance to assess the uncertainty of the test equipment[1][2].

## II. RELATED RESULTS IN THE LITERATURE

There are two methods to calibrate satellite navigation signal simulator channel-delay[3]-[8],one is measuring the delay between 1PPS(Pulse Per Second) and turning point in zero pseudo range and the other is estimating the delay of correlation peak. The first method is able to achieve the delay value in real-time, but the accuracy of testing results is decided on the oscilloscope sampling rate, and it is difficult to find the code turning point affected by noise. The second method cannot get the test results in real time ,which should be carried out on the signal postprocessing analysis, but it do not need to find the turning point and the test results are mainly determined by the accuracy of the pseudo code chip width. Taking into account the uncertainty of the test results, it is needed to measure and calculate the variance of the test results in real time, the above two methods can not realize the high-precision auto-test of channel delay. In order to achieve high-precision automated testing, this paper designs an auto-test system of channel-delay based on Hilbert Transform Envelope Detection method, which can automatically complete multiple test of channel delay and calculate the uncertainty of measurement through high speed oscilloscope. In order to determine the exact location of the turning point, the system processes the signal by using the envelope detection method based on Hilbert Transform, and the minimum point of the signal level envelope is used as the turning point. Then, the channel delay of the simulator is finally obtained.

### III. DESCRIPTION OF THE METHOD

#### A. Envelope Detection Based on Hilbert Transform

In mathematics and signal processing fields, the Hilbert transform of  $x(t)$  can be thought of as the convolution of  $x(t)$  with the function  $h(t) = 1/(\pi t)$ , such as shown in equation(1):

$$\overline{x(t)} = H[x(t)] = x(t) * \frac{1}{\pi t} \quad (1)$$

Fourier transform of  $1/\pi t$  as shown in Equation (2):

$$\frac{1}{\pi t} \leftrightarrow -j\text{sgn}(\omega) = \begin{cases} -j & \omega \geq 0 \\ +j & \omega < 0 \end{cases} \quad (2)$$

Assume that the signal can be presented as  $s(t)$ , such as (3) shown in the equation:

$$s(t) = a(t)\cos(\omega_c t) \quad (3)$$

where  $\cos(\omega_c t)$  is the carrier and  $a(t)$  is band limited signal. The fourier transform of  $a(t)$  and carrier is:

$$a(t) \leftrightarrow A(\omega) = \begin{cases} A(\omega) & |\omega| \leq \Delta\omega/2 \ll \omega_c \\ 0 & \text{others} \end{cases} \quad (4)$$

$$\cos(\omega_c t) \leftrightarrow -j\text{sgn}(\omega) = \begin{cases} -j & \omega \geq 0 \\ +j & \omega < 0 \end{cases} \quad (5)$$

The Spectrum of  $s(t)$  is:

$$s(t) \leftrightarrow S(\omega) = \frac{1}{2}(A(\omega - \omega_c) + A(\omega + \omega_c)) \quad (6)$$

The Hilbert transform of  $s(t)$  is:

$$\overline{s(t)} = s(t) * \frac{1}{\pi t} \leftrightarrow -j\text{sgn}(\omega)S(\omega) = -\frac{j}{2}(A(\omega - \omega_c) + A(\omega + \omega_c)) \quad (7)$$

$$\overline{s(t)} = a(t)\sin(\omega_c t) \quad (8)$$

According to the above analyzing, Hilbert Transform of  $s(t)$  shift the phase by  $90^\circ$  and keep the amplitude. The

envelop of  $s(t)$  equals to  $\sqrt{s(t)^2 + \overline{s(t)}^2}$ .

#### B. Measurement of Inter-channel Delay

Among the inuse Global Navigation Satellite System, DSSS modulation is widely used by GPS, BDS and GLONASS for ranging and transmission. Before transmitted in to the air, DSSS signal should be modulated on a carrier by BPSK. BPSK signal can be presented by (3). Once the code make a change between 1 and 0, the phase make a shift by  $180^\circ$  and a reversal point appears. The inter-channel delay equals to the time interval between 1PPS signal and the reversal point.

When navigation signal is accessed into high speed digital oscilloscope, the oscilloscope equivalents to a pass-band filter. The filter spectrum is:

$$F(\omega) = \begin{cases} 1 & |\omega - \omega_0| \leq \omega_c \\ 0 & \text{others} \end{cases} \quad (9)$$

Time domain expression is:

$$f(t) = \frac{\omega_c}{\pi} Sa(\omega_c t) \cos(\omega_0 t) \quad (10)$$

The obtained signal is:

$$y(t) = s(t) * f(t) = \int_{-\infty}^{+\infty} s(\tau) f(t - \tau) d\tau \\ = \frac{\cos(\omega_0 t) \omega_c}{2\pi} \int_{-\infty}^{+\infty} a(\tau) sa[\omega_c(t - \tau)] d\tau \quad (11)$$

According to the above analyzing, the form of  $y(t)$  is amplitude modulation. The envelop is  $\frac{\omega_c}{2\pi} \int_{-\infty}^{+\infty} a(\tau) sa[\omega_c(t - \tau)] d\tau$ . Taking into account of the oscilloscope depth limited, the interval of  $y(t)$  is  $[t_1, t_2]$ . Assuming that when  $\tau = t_0 \in [t_1, t_2]$ ,  $a(\tau)$  changes from -1 to 1, the envelop is such as shown in equation(12):

$$\frac{\omega_c}{2\pi} (\int_{t_0}^{+\infty} sa[\omega_c(t - \tau)] d\tau - \int_{-\infty}^{t_0} sa[\omega_c(t - \tau)] d\tau) \quad (12)$$

As  $sa[\omega_c(t - \tau)]$  is symmetrical with rotating around  $\tau = t$ ,  $y(t) = 0$  when  $t = t_0$ .  $y(t)$  is the reversal point. As shown above, the envelop of BPSK signal can be get by Hilbert transform, the inter-channel delay can be get by measuring the time interval between 1PPS and the lowest point of the envelop.

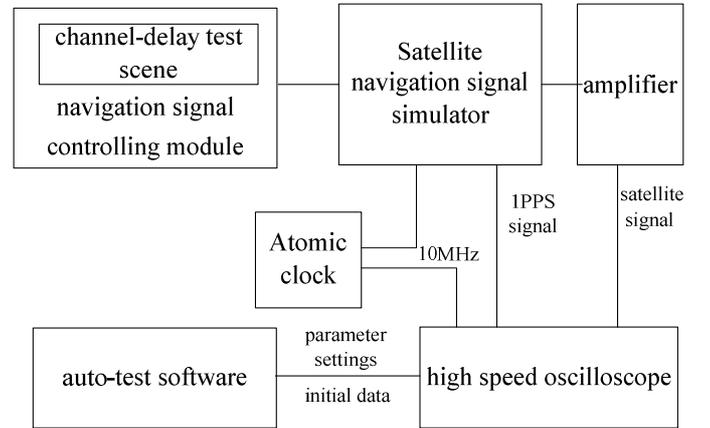


Fig.1. connection diagram of test system

#### C. TEST SCHEME

##### a. Connection diagram

Test platform(Fig.1) includes amplifier, high speed oscilloscope, atomic clock and auto-test software. Among these modules, navigation signal controlling module connecting satellite navigation signal simulator, is in charge of controlling navigation satellite signal to

freely configurate detection environment. If the signal with relatively lower test intensity is needed, the amplifier enlarges the navigational satellite signal so as to be received by high speed oscilloscope, and 1PPS signal is also connected to the oscilloscope as a trigger signal. Atomic clock for providing a reference frequency signal. Test software collects the measured data and calculates channel-delay in real-time.

b. Workflow

- step1. the software reads the time axis and the amplitude axis parameter setting of the oscilloscope;
- step2. the software collects the original measurement data;
- step3. according to the parameter setting and the original measurement data, the amplitude and the time value of the sampling points of the radio frequency signals are obtained;
- step4. calculating the envelope of radio frequency signals using Hilbert transform ;
- step5. the time value of the lowest point of the envelope is used as a single test result of channel delay;
- step6. measuring and calculating the mean and variance repeatedly according to the number of tests.

c. Test procedure

- step1. start the working software of the satellite signal simulator, and the frequency of the simulator is set to the frequency of the satellite navigation signal;
- step2. set up atmosphere model: close the ionosphere and troposphere model, and then close the clock error;
- step3. set up constellation model: select satellite power model for fixed model, retain a geostationary orbit satellite and close other satellite signals, latitude and longitude information is [0 degrees E, 0 degrees N], close navigation message, open pseudo code;
- step4. set receiver position parameters: the initial position of the receiver is [0 degree E, 0 degrees N], altitude set to the altitude of earth synchronous orbit , motion model is a static model;
- step5. the high power signal of the satellite signal simulator is amplified by the low noise amplifier, and then the signal is connected to the CH1 of high speed sampling oscilloscope, 1PPS is connected to the CH2, oscilloscope work in trigger mode, 1PPS signal is set as a trigger signal, and the level is set to half of 1PPS level, the sampling rate of the oscilloscope is set to 4G sample/s, the gain of the time axis and the amplitude axis can be adjusted to ensure that the oscilloscope can stably capture the turning point of the 1PPS signal and the satellite navigation signal;
- step6. start the test software and set the number of measurements (such as 10 times);
- step7. the mean and variance of the test results are calculated.

IV EXPERIMENT

A. Test equipment

The configuration of analyzer is built on the bases of the real time DSO Agilent DSO91204A. Sampling frequency while analyzing is 12.5 GHz. DSO memory is 512 Mpts per channel. The amplifier (ZRL-2400LN+) enlarges the navigational satellite signal. The navigation signal consisting of  $n$  signals comes to the oscilloscope first input. The reference signal of the oscillator at the oscilloscope second input is used to synchronize the analyzer time scale and the oscillator under the test. Atomic clock is used to provide a reference signal. The reference signal frequencies are 10 MHz. Set based on MATLAB software developed automated test measuring 100 times. The system measures the pseudorange to 0 m and 1m channel delay.

B. Test result

Test results of satellite signal simulator are as follows:

Table 1. Test result of channel delay (0m).

frequency point	test times	variance	mean
B1	100	0.15ns	5.33ns
B2	100	0.14ns	5.92ns
L1	100	0.12ns	5.28ns
L2	100	0.22ns	5.72ns

Table 2. Test result of channel delay (1m).

frequency point	test times	variance	mean
B1	100	0.15ns	8.67ns
B2	100	0.14ns	9.22ns
L1	100	0.12ns	8.70ns
L2	100	0.22ns	9.06ns

Table 3. error.

frequency point	theory (pseudorange 1m)	measured value	error
B1	3.33 ns	3.34 ns	0.01 ns
B2	3.33 ns	3.30 ns	-0.03 ns
L1	3.33 ns	3.42 ns	-0.09 ns
L2	3.33 ns	3.34 ns	0.01 ns

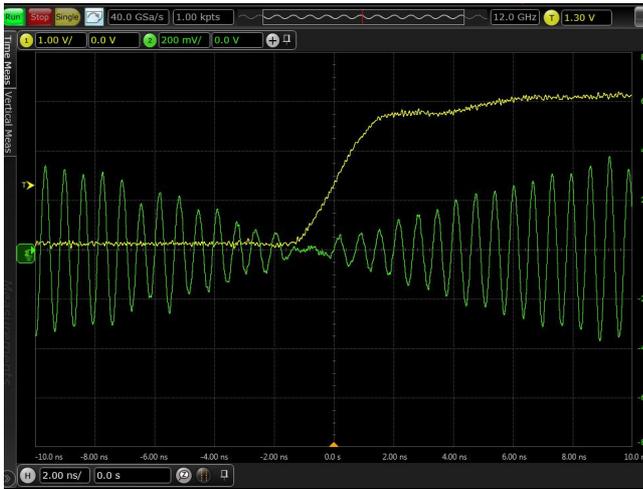


Fig.2.Channel delay test

Table 1 shows the channel delay test results when pseudo-range is 0 m, Table 2 shows the channel delay test results when pseudo-range is 1 m. According to these test results, GNSS simulators B1 frequency channel delay measurement error 0.01ns, B2 frequency measurement error -0.03ns, L1 frequency measurement error -0.09ns, L2 frequency measurement error 0.01ns, channel delay measurement uncertainty better than 0.10ns.

## V. NOVELTIES IN THE PAPER

Hilbert transform and digital envelope detection technique based on design the channel time delay automatic test system, and the automatic test software is developed based on the MATLAB. The test system can be calibrated according to the channel delay of the satellite navigation signal simulator, and the channel time delay measurement can be completed automatically according to the user setting conditions.

## VI. CONCLUSIONS

This paper analyzes the measurement principles and test methods of satellite navigation signal simulator's channel-delay and builds a satellite navigation signal simulator channel-delay test platform based on Hilbert Transform Envelope Detection to verify the correctness, practicality and effectiveness of the test method. Experimental results show that the method is feasible and the results are reliable. Consequently, can efficiently complete satellite navigation signal simulator channel delay calibration. This methods also can be applied to high-precision calibration of GNSS simulator zero value and pseudo-range.

## VII. ACKNOWLEDGMENT

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