ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0056

An Ionospheric Scintillation Monitoring Method Based on Beidou Satellite Navigation System / GNSS

Yong Wang[1], Kaifeng Wang[1]

[1]JSCORS Center, Jiangsu Province Surveying and Mapping Engineering Institute, Nanjing 210013, China.

Abstract

The key technology of ionospheric scintillation monitoring based on Beidou Satellite Navigation System and other GNSS is studied and the system is designed and developed. Firstly, the importance of ionospheric scintillation monitoring is expounded, and the basic principle, technical index and hardware structure of ionospheric scintillation monitoring are studied. Through experiment with JSCORS, the results show that the amplitude of the scintillation index detected by the BDS is between 0.01 and 0.02, and by the GPS is between 0.02 and 0.06, the monitoring data is stable and reliable. These prove that Beidou/GNSS can be used to monitor ionospheric scintillation.

Keywords

Ionospheric monitoring; phase scintillation; BDS.

1. INTRODUCTION

Ionosphere is the main source of GNSS positioning error. When the ionosphere is in a stable state, differential technology or GNSS multi-frequency technology can effectively reduce the impact of ionosphere error. However, when radio signals of BDS/GNSS pass through the ionosphere, the irregular structure of the ionosphere will cause rapid and random fluctuation of the signal strength, phase and other parameters, this phenomenon is called as ionospheric scintillation [1, 2].

Among all the links affected by ionospheric scintillation, GNSS is the most concerned. For GNSS users, the ionosphere is the biggest source of error. Since the frequency used by GNSS satellite navigation is much higher than the maximum critical frequency of ionosphere, the refraction error caused by ionosphere is greatly reduced at this time. However, the positioning error caused by the time delay caused by ionosphere refraction is still relatively large. For GNSS satellite navigation systems, the most serious ionospheric effect is scintillation. In order to avoid the strong amplitude fading in GNSS positioning and the time and area of scintillation, it is very important to develop monitoring and research of comprehensive, systematic and long-term ionospheric scintillation [3-6].

At present, the studies on the ionosphere are mainly based on the post-processing analysis of GNSS data and the real-time calculation of software models [7-9]. In order to facilitate continuous monitoring of ionospheric scintillation, this paper proposed an ionospheric scintillation monitoring method based on Beidou Satellite Navigation System / GNSS, and development a special monitor system for ionospheric scintillation, and used this monitor conduct tests on ionospheric scintillation.

Based on JSCORS, this paper carries out continuous monitoring of ionospheric scintillation, analyzes and studies the ionospheric scintillation data, establishes a prediction model of ionospheric scintillation, and develops an ionospheric scintillation monitoring and early

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0056

warning system to predict ionospheric scintillation. At the same time, observation and study of ionospheric scintillation is also an important means to study the irregular structure and variation characteristics of the ionosphere, which is helpful to study various phenomena in the ionosphere and the corresponding physical mechanism.

2. METHOD

GNSS antenna enters the ionospheric scintillation monitor after receiving the satellite signal, outputs the original signal strength, carrier phase and other information, such information can be transmitted to the server through the communication modules, and then integrate the ionospheric scintillation index model to obtain the amplitude scintillation index S4 and phase scintillation index σ, etc. In order to be able to monitor the ionospheric scintillation condition in real time and save relevant data, the ionospheric scintillation monitor is required to communicate with the PC in real time. Since GNSS satellite signal will pass through the whole ionosphere and the phase of the signal will fluctuate greatly due to the irregular structure of the ionosphere, in order to ensure that the processor can extract accurate information of the amplitude and phase, the ionospheric scintillation monitor is required to have a strong anti-interference ability. Therefore, an internal crystal oscillator source with stable frequency and low phase noise was designed inside the ionospheric scintillation monitor to ensure the reliability of measuring the scintillation intensity in ionospheric scintillation measurement.

In the study of ionospheric scintillation the intensity of scintillation is measured by calculating the amplitude and phase scintillation index. Take the phase scintillation index algorithm as an example, which is usually expressed by the standard deviation of carrier phase

$$\sigma\phi = \sqrt{<\phi^2> - <\phi>^2}$$

Where ϕ is the carrier phase, its algorithm execution steps are as follows:

Step 1: Carrier phase

The carrier phase can be obtained by integrating the carrier frequency of the received repeated GNSS signal.

Step 2: Calculate the carrier phase after the de-trending of the filter

For GNSS receivers, local clock difference, satellite clock difference, troposphere and other factors will also cause the phase change of the received signal, so it is also necessary to reduce this influence by filtering and de-trending. Different from the analysis of amplitude scintillation index, the above phase effects except ionospheric scintillation have the characteristics of slow variation. By selecting a sixth order 3dB high-pass filter with a cut-off frequency of 0.1Hz and allowing the phase observations to pass through the filter, the low-frequency effects below this cut-off frequency can be removed.

The original phase value is taken as the input of the filter:

$$\mu_{1,k+1} = \phi_{in,k+1}$$

The difference between the input and output of the front filter constitutes the input of the last stage:

$$\mu_{i,k+1} = \mu_{i-1,k+1} - X_{i-1,1,k+1;} i = 2,3$$

The final output of the filter is:

$$\phi_{hpf,k+1} = \mu_{3,k+1} - X_{31,k+1}$$

After the high-pass filtering, the input is divided by the high-pass output to obtain a detrending value hovering around 1:

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0056

$$\phi' = \frac{\phi_{in,k+1}}{\phi_{hpf,k+1}} = \frac{\mu_{1,k+1}}{\mu_{3,k+1} - X_{31,k+1}}$$

Step 3: Calculate the phase flicker

$$\sigma\phi = \sqrt{<\phi'^2> - <\phi'>^2}$$

3. SYSTEM IMPLEMENTATION

3.1. System Architecture of Monitor

The monitor mainly includes communication module, management module and GNSS module, the hardware architecture is shown in Fig.1. The communication module is responsible for communication with the main station server, including three communication ways: 4G data communication, LAN local area network, WIFI; GNSS module completes data acquisition; supports RTCM; monitor management module is responsible for forwarding and communication scheduling of GNSS data, it is packaged and sent to the 4G module or WIFI module through another RS-232 serial port in accordance with the NTRIP protocol, and uploaded to the server via wireless network.

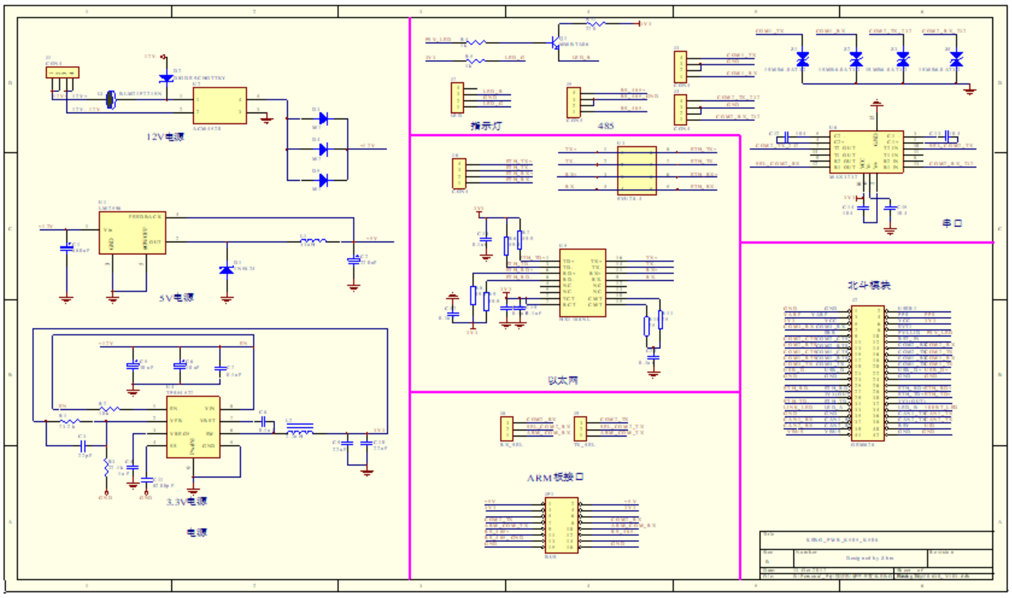

Fig 1. Hardware architecture of monitor

3.2. Interface of Monitor

In order to meet different needs, the monitor is designed with direct and indirect data output and communication ways. As follows:

1. Direct transmission. GNSS module directly communicates with the 4G module and WIFI module through the RS-232 interface, and accesses the server through wireless media, or GNSS module communicates with the main station server through LAN local area network interface.

2. Indirect transmission. The management module is designed in the monitor, which is responsible for data communication scheduling and management. GNSS module communicates with the management module via the RS-232 interface, and the management module communicates with the 4G or WIFI module via another RS-232 interface, furthermore, the monitor management module extends a LAN Ethernet port. The monitor management module receives the data message of GNSS module from the serial port, and after packaging in accordance with the NTRIP protocol, it can be sent to the server via 4G, WIFI, and LAN. The

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0056

management module is designed with the RS-485 interface, it receives data collected by sensors via the RS-485 bus and uploads data to the server via the above three methods.

3.3. Monitor Internal Structure

By combining application requirements, the hardware framework of the monitor mainly includes the following parts.

1) The monitor adopts DC power supply, the power supply and communication interface module complete the conversion from external power supply to internal module and chip working power supply, it also supplies power for GNSS module, management module, and wireless communication module; and output to RS-232 serial communication port Ethernet port, sensor communication port, and other external communication interfaces.

2) GNSS module is installed on the power supply and communication interface module via the connector.

3) The wireless communication module and the management module are designed on another board, they are connected with the power supply and communication interface module via connector, they are designed as flexibly configurable structure, and the monitor can be combined in accordance with different application needs.

4. RESULT

In order to test working performance of the self-developed ionospheric scintillation monitor, the site data of JSCORS is selected, and the monitoring period is from November 6, 2017 to November 9, 2017, and the monitoring time is 72 hours. The data collected by ionospheric scintillation monitor are analyzed below. The test contents include compatibility test of satellite system and analysis test of scintillation index. The comparative testing and data analysis are mainly used, etc. It can be observed from Fig.3 that the monitor is well compatible with satellite navigation systems such as BDS, GPS and GLONASS. The ionospheric amplitude scintillation index which is received from the Beidou C8 satellite and GPS G5 satellite was tested for 72 hours via the self-developed ionospheric scintillation monitor.

According to the test requirements, after selecting the corresponding monitoring point and time period, the scintillation value monitored by the relevant satellites can be analyzed after the data receipt, and the data can be displayed in diagram, the monitored scintillation index and scintillation value are shown in Fig.2 and Fig.3.

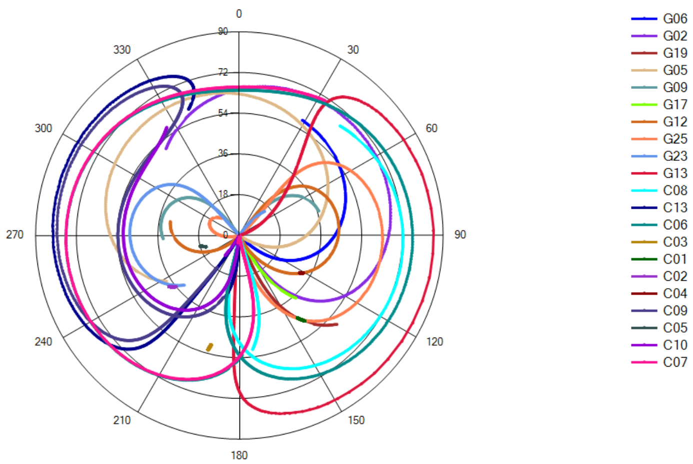

Fig 2. The scintillation index condition monitored by the ionospheric scintillation monitoring receiver

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0056

PRN	L1 phases cintillation	L2 phases cintillation	L1 amplitude cintillation	L2 amplitude cintillation
C10	0.000400	0.000390	0.014320	0.012390
C10	0.000470	0.000500	0.016510	0.016420
C10	0.000460	0.000260	0.016250	0.008400
C10	0.000350	0.000530	0.012600	0.016730
C10	0.000500	0.000610	0.017480	0.019280
C10	0.000360	0.000460	0.012350	0.014880
C10	0.000340	0.000490	0.011830	0.016080
C10	0.000490	0.000290	0.016550	0.009390
C10	0.000390	0.000510	0.013270	0.016760
C10	0.000420	0.000210	0.014420	0.007090
C10	0.000490	0.000490	0.016600	0.016710
C10	0.000470	0.000510	0.016130	0.016960
C10	0.000490	0.000710	0.016710	0.023750
C10	0.000480	0.000410	0.016250	0.013810
C10	0.000670	0.000500	0.022220	0.016950
C10	0.000500	0.000430	0.016500	0.014410
C10	0.000480	0.000530	0.015780	0.017770
C10	0.000430	0.000610	0.014250	0.020630
C10	0.000530	0.000520	0.017650	0.018230
C10	0.000680	0.000330	0.022350	0.011690
C10	0.000460	0.000500	0.014750	0.017540
C10	0.000200	0.000400	0.006300	0.013830
C10	0.000420	0.000390	0.013700	0.013880
C10	0.000450	0.000490	0.014220	0.017310

Fig 3. Scintillation analysis results of ionospheric scintillation monitoring receiver

The map of the data monitored by Beidou C8 satellite and GPS G5 satellite over 72 hours, it can be found that the amplitude scintillation index values monitored by the two satellites are between 0.01-0.07. Among them the amplitude scintillation index values monitored by the Beidou C8 satellite are between 0.01 and 0.02, amplitude scintillation index values of L1 are equivalent to the amplitude scintillation index values of L2, and the two fluctuate consistently within a certain range, the results are shown in Fig.4, Beidou C8 satellite S4 observation results: the amplitude scintillation index values monitored by GPS G5 satellite are between 0.02-0.06, the amplitude scintillation index values of L2 is larger than the amplitude scintillation index value of L1, and the two fluctuate around 0.04 amplitude scintillation index value. The result is shown in Fig.5, GPS G5 satellite S4 observation results; moreover, the amplitude scintillation index values monitored by GPS G5 satellite are larger than the amplitude scintillation index values monitored by Beidou C8 satellite.

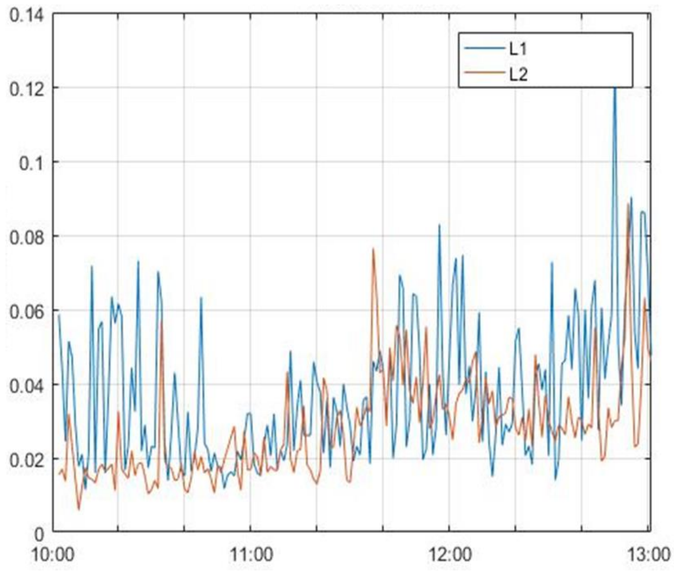

Fig 4. Schematic diagram of the S4 observation results of BDS-C8

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0056

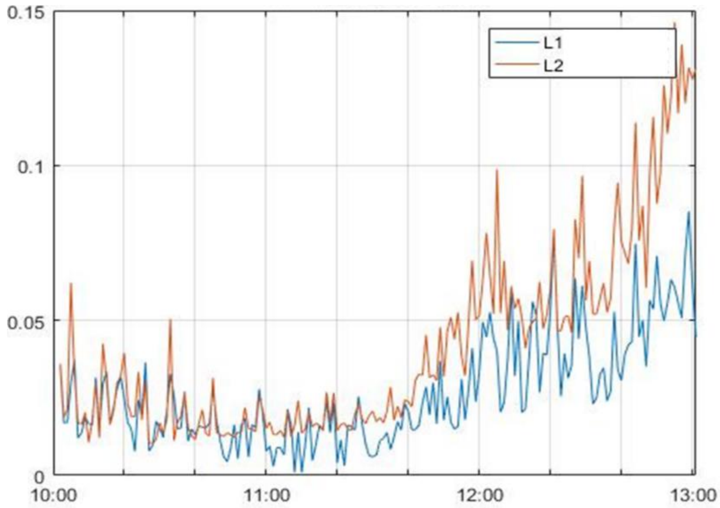

Fig 5. Schematic diagram of the S4 observation results of GPS-G5

It can be found from the analysis of amplitude scintillation index S4 that the amplitude scintillation indexes S4 of Beidou C8 satellite and GPS G5 satellite are both less than 0.1, and it is generally believed that when the amplitude scintillation index S4 is greater than 0.2, it shows that there is an abnormal situation, this shows that the ionospheric anomalies represented by the ionospheric amplitude scintillation index S4 in the Nanjing area over this period are non-abnormal.

5. CONCLUSION

This paper focuses on the key technologies of ionospheric scintillation monitoring based on Beidou Satellite Navigation System and other GNSS, and designs and develops the ionospheric scintillation monitoring hardware system. The importance of ionospheric scintillation monitoring was described, and the basic principle, technical index and hardware structure of ionospheric scintillation monitoring were studied, and the verification and analysis were carried out through JSCORS data.

Through data analysis, the self-developed ionospheric scintillation monitor based on Beidou can well express the amplitude and phase scintillation of Beidou C8 satellite and GPS G5 satellite, and work stably. At the same time, Beidou C3 satellite and GPS G6 satellite are used to predict the ionospheric scintillation. Through data analysis and comparison, it can be found that the ionospheric scintillation monitor can well predict the ionospheric anomalies. It can be proved that the ionospheric scintillation monitor based on Beidou can monitor, describe and predict ionospheric scintillation anomalies.

REFERENCES

[1] Long Qili, Ma Jianmin. VHF amplitude scintillation observation results in Haikou [J]. Radio wave and antenna, 1996, 2:1-4.

[2] Xie Shijie. The Impact of The Ionosphere on GPS[J]. Surveying and Mapping, 1999(2): 64-67.

[3] Y W He, Q L Long. Midlatitude ionospheric scintillation in eastern asia[J]. Chinese Journal of Radio Science, 1994, 9(2):

[4] Dai Bin. Interruption and Measure of Satellite Communication [J]. China Digital Cable TV, 2004(16): 54-56.

[5] T P Zhu, C N Wang, H F Sun, et al.. Ionospheric scintillations observed via 4GHz satellite TV signals [J]. Chinese Journal of Radio Science, 1992, 7(3): 69~74.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0056

[6] A J Van Dierendonck, John Klobuchar and Quyen H ua. Ionosphere Scintillation Monitoring Using Commercial Single Frequency C/A Code Receivers[C]. Proceedings of ION GPS93, Salt Lake City, UT, September 1993, pp.1333-1342.

[7] Ganguly S, Jovancevic A , Brown A , et al. Ionospheric scintillation monitoring and mitigation using a software GPS receiver[J]. Radio ence, 2016, 39(1).

[8] Luo X, Lou Y, Xiao Q, et al. Investigation of ionospheric scintillation effects on BDS precise point positioning at low-latitude regions [J]. GPS Solutions, 2018, 22(3):63.

[9] Alves D B M, De Souza E M , Gouveia, Tayná Aparecida Ferreira. Correlation between ionospheric scintillation effects and GPS positiong over Brazil during the last solar maximum (2012–2014) [J]. Journal of Atmospheric & Solar Terrestrial Physics, 2019.