Performance Analysis of GNSS Receiver allied in High-Orbit Based on SoC Platform

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Abstract. GNSS receiver technologies allied in high orbit altitudes has developed rapidly in recent years and has been used in orbit on many spacecraft. In this paper, TJS-5 Satellite is taken as an example to illustrate the design scheme of the high orbit navigation receiver based on the SoC platform, which takes the characteristics of the weak signals of GEO orbit navigation into consideration, and adopts the high sensitivity acquisition technology and the fast signal acquisition technology. Finally, the 19-day in-orbit data of TJS-5 Satellite are analyzed. The number of available satellites is between 4 and 8, the position accuracy of orbit determination is 15.8133m and the velocity is 0.012108m/s, which meets the needs of autonomous positioning and precise orbit determination in the whole orbit period of the satellite. The calculated results are compared with those of TJS-2 satellite.

1. Introduction
High-orbit spacecraft have important applications in the fields of meteorology, satellite communications (SATCOM), deep space exploration and so on. At present, high orbit spacecraft mainly rely on ground-based measurement to achieve orbit determination. With the increasing demand for high-precision orbit determination of high-orbit spacecraft and the increasing shortage of ground resources, it is an inevitable trend to realize spacecraft in-orbit positioning and navigation by GNSS.

Now, the United States and Europe have developed GNSS receivers for high-orbit spacecraft that support GPS signals and realized in-orbit positioning and navigation [1,2]. In 2014, GNSS receiver of the CE-5T1 spacecraft made by China received GPS signal from the orbit of 120,000 km, and completed autonomous navigation of the Earth-Moon transfer orbit [3]. Based on the foundation of CE-5T1 spacecraft GNSS receiver, China has developed a high-orbit GNSS receiver compatible with BDS, GPS and GLONASS signals, and completed in-orbit application on TJS-2 and TJS-5 [1,4].

Taking TJS-5 as an example and starting from the point of application requirements of geosynchronous orbit, this paper introduces the design scheme of high orbit GNSS receiver based on SoC platform and the acquisition and tracking method of weak signal. The on-orbit performance of the GNSS receiver was evaluated by analyzing the in-orbit operation data of the GNSS receiver from May 20, 2020 to June 8, 2020.
2. High-orbit GNSS Receiver

2.1. Design Scheme

TJS-5 has been working in geosynchronous orbit and is used for satellite communication and broadcasting. According to the overall design requirements of the satellite, the functions and performance requirements of the receiver are shown in Table 1.

Table 1. Function and performance requirements

| Function index | Function | Requirements |
|----------------|----------|--------------|
| Orbit Altitude | 36000km, GEO orbit |
| Frequency      | BDS B1I |
|                | GPS L1CA/L1P |
|                | GLONASS G1 |
| Position accuracy | superior to 50m (1σ, triaxial synthesis) |
| Speed measurement accuracy | superior to 0.1m/s (1σ, triaxial synthesis) |
| Capture sensitivity | -143dBm |

Different from low-orbit satellites, high-orbit GNSS receivers mainly use the sidelobe signal of GNSS, whose power is nearly 15dB lower than that of the main lobe signal [5], because the altitude of GEO satellites are higher than navigation satellites. Therefore, in order to meet the real-time positioning requirements of GNSS receivers in GEO orbit, it is necessary to have the function of weak signal acquisition.

According to the requirements above, the functional block diagram of GNSS receiver designed is shown in Figure 1. The antenna could receive navigation signals of BDS, GPS and GLONASS. The navigation signals will be filtered and amplified by the RF amplifier and be send into GNSS receive. Then GNSS receiver filters different navigation frequency signal, transforms the higher spectrum into the low intermediate frequency spectrum through RF chip, and outputs the digital intermediate frequency signal to the multi-frequency and multi-mode navigation SoC device NS962 by digital-analog conversion of the AD module. The next work of signal tracking capture, the navigation message parsing, and the original observation will be completed by NS962. Finally, the results of the position, speed, clock deviation and clock drift of the receiver terminal are obtained by the least square method and Kalman filter.

![Figure 1. Two or more references.](image-url)
As for baseband module design, NS962 SoC device developed by Space star technology co., Ltd was selected. NS962 chip supports all working frequency points in Table 1, and can quickly capture and track the navigation signals of the above frequency points. The device has been verified in Ningxia-1 Satellite, Tianqin Satellite and other models. Compared with the traditional "FPGA+DSP" architecture of baseband signal processing, the use of NS962 can greatly reduce the power consumption of the receiver. The baseband module adopts double backup design, and the two modules are in hot standby working state.

2.2. High-Sensitivity Acquisition Technology
In order to achieve the acquisition of weak signals, a highly sensitive acquisition mode was designed. This mode does not require the pre-storage of long-term coherent integral data. In the first stage of mixing, the frequency sweep of 50Hz is implemented, and the correlation operation is carried out by the overlapping additive correlator to complete the coherent results of 1ms. After the incoherent accumulation and peak detection is completed, the capture ends if the peak exceeds the threshold, or else the next frequency point will be captured.

Highly sensitive capture is divided into cold-start mode and fast-recovery mode. In cold-start mode, the data of N ms can be compressed into 1 ms in advance for relevant operation. In the fast-recovery mode, the position of the bit edge is determined in advance by tracking, and then the coherent integration operation of more than 16ms can be carried out. As the result, the data of 16ms can be compressed into 1 ms in advance, and then the correlation operation can be carried out. No matter in cold start mode or fast recovery mode, long-term incoherent integration can be enforced to improve the acquisition sensitivity.

2.3. Fast-Acquisition Technology
Due to the use of long time incoherent integration of high sensitivity acquisition technology, the start and positioning process of the receiver will be longer correspondingly. In order to solve the problem of fast acquisition of navigation signals, a fast-acquisition mode is designed. In this mode, long-term coherent integrals can be stored in advance to improve the signal processing gain, and the stored data can be searched by overlapping addition method and Doppler frequency offset search to achieve a fast-acquisition method. The GPS-L1 single star capture time is controlled within 50ms after the actual harvest test.

The overlapping addition method is a piecewise parallel code phase search method, which divides the correlator of 20460 points into 10 FFT operations of 2046 points. Only the correlation operation and coherent accumulation of a small segment of data are performed each time, and then the multi-segment data are combined into different forms by the method of overlap-add, which can form different types of accumulation effects.

Firstly, for the specific design scheme, 50Hz frequency sweep is carried out through the first stage mixer, and 20ms data is stored in RAM in advance. While the overlapping additive correlator is used for correlation operation, the frequency search of multiple frequency points can be implemented quickly by using cyclic shift in frequency domain. When moving half a chip, the frequency step is. So that the frequency sweep with 50Hz resolution between -50KHz and +50KHz could be carried out.

The GNSS receiver runs alternately between the fast acquisition mode and the high sensitivity acquisition mode to achieve the acquisition, tracking and positioning of navigation signals within 10 minutes under the weak signal power of -143dBm.

3. In-orbit Performance analysis
The GNSS receiver based on the above design entered the working orbit along with the TJS-5 satellite on January 7, 2020, and has been started up since the fixed point. During the period of May 20, 2020 to June 8, 2020 (a total of 19 days), the satellite has been in orbit for 20 orbits. The satellite transmitted the original observation data and channel information of two NS962 devices (hereinafter referred to as
SOC1 and SOC2) by the down channel of the satellite, by which the signal receiving characteristics and real-time orbit determination accuracy of the high orbit navigation receiver were evaluated.

In addition, the analysis results of this paper are compared with TJS-2, which was launched on January 5, 2017 and deployed in the GEO orbit, carrying GNSS with the same functional performance requirements as this model.

TJS-2 satellite GNSS receiver adopted the "DSP+FPGA" general architecture scheme, while TJS-5 satellite GNSS receiver used the multi-frequency and multi-mode navigation SoC device to replace the original scheme. What’s more high sensitivity acquisition and fast acquisition scheme are optimized and designed under the design of NS962 chip.

3.1. Signal Reception Characteristics
In the design of GNSS receiver software protocol, GPS, GLONASS and BD are each allocated 8 tracking channels, and the default working mode is the dual system combination mode with GPS priority, namely the combined mode of GPS and GLONASS or of GPS and BDS.

The average number of captured and available stars of GNSS receivers SOC1 and SOC2 for different navigation constellation every day is shown in Table 2 and Figure 2. Statistics show that the number of available GPS stars is concentrated in 4~8, and the number of GLONASS is 3~8 where the navigation receiver will give priority to the star selection strategy of the GPS system under the combined working mode of GLONASS and GPS. The application strategy of BDS is the same as that of GLONASS, and it is also affected by the constellation layout (visible in the IGSO area). The number of available stars in BD mode is 2~8, concentrated in 4~5. Compared with TJS-2, the number of available stars in each system is increased by 2~3.

Table 2. Number of available and captured stars in each constellation

| Project  | GPS system (pieces) | GLONASS system (pieces) | BDS system (pieces) |
|----------|---------------------|-------------------------|---------------------|
|          | TJS-5               | TJS-2                   | TJS-5               | TJS-2               |
| Captured | 5~8, Concentrate in 7~8 | 5~8, Concentrate in 7~8 | 3~8, Concentrate in 6~8 | 1~8, Concentrate in 4~7 |
| Available| 4~8, Concentrate in 7~8 | 2~8, Concentrate in 6~8 | 3~8, Concentrate in 4~7 | 0~8, Concentrate in 0~2 |

Figure 2. The Number of Captured and Available Stars in SOC1 and SOC2(0.5Hz).
As can be seen from the contrast, when the high-orbit navigation receiver based on NS962 device adopts high-sensitivity acquisition and fast-acquisition technology, and BDS system achieved the increase of available stars in global layout, the average number of available stars of each GNSS system can be increased to more than four satellites. Compared with that of TJS - 2, the available number of GNSS satellites have achieved much promotion, complying with the requirement of the orbital period independent positioning.

3.2. Accuracy of Orbit Determination

GNSS original data packets transmitted by the satellite included GNSS pseudo range, carrier phase, Signal-to-Noise Ratio (SNR) and so on, which were used for post-analysis and precise orbit determination. By using the precise ephemeris of the navigation star and the original observation information transmitted by GNSS, the post-orbit precise orbit determination is carried out on the ground computer by means of the dynamic method. Different from the low-orbit satellites, the high-orbit satellites are not affected by the atmospheric resistance perturbation and are not sensitive to the non-spherical gravitational perturbation of the earth. Moreover, the models of the earth's aspherical perturbation and the solar and lunar perturbation are both relatively mature and high precision. The post-orbit precision determination by dynamic method can be used as the true value of the satellite position velocity to evaluate the in-orbit performance of GNSS [6,7].

The original observation data of about 48 hours between June 7 and June 8, 2020 were selected for analysis, and the results of triaxial position accuracy (1σ) and triaxial velocity accuracy (1σ) are shown in Table 3 and Figure 3. The analysis results show that the positioning accuracy of GNSS receiver is 15.8133m and the velocity accuracy is 0.012108m/s.

Table 3. The position accuracy and velocity accuracy of TJS-5 and TJS-2

|                | TJS-5          | TJS-2          |
|----------------|----------------|----------------|
| Triaxial position accuracy (1σ) | 15.8133m      | 26.7312m      |
| Triaxial velocity accuracy (1σ)    | 0.012108m/s  | 0.010743m/s  |
| Remarks                     | shown in Figure 8 | shown in Figure 9 |

Fig. 3 The position accuracy and velocity accuracy of TJS-5.

It can be seen from the analysis above that the actual bit speed accuracy of the high orbit navigation receiver on TJS-5 based on NS962 device meets the requirements of the indicators in Table1. Compared with TJS-2, the accuracy of real-time orbit determination is greatly improved, which is close to the...
performance of navigation receiver on LEO satellite, and can meet the requirements of GEO orbit communication and remote sensing satellites for position accuracy.

4. Conclusion

Taking TJS-5 satellite as an example, this paper designs a high-orbit GNSS receiver system based on the SoC platform according to its orbit characteristics and overall design requirements. The system design and working principle are described, and the high-sensitivity acquisition and fast acquisition technology are studied in view of the weak characteristics of high-orbit navigation signal. The number of captured and available stars in GPS, GLONASS and BDS constellations can meet the requirements of satellite positioning and orbit determination by analyzing the original in-orbit observation data of GNSS receiver. The in-orbit position accuracy of three axes (1σ) and velocity accuracy of three axes (1σ) are 15.8133m and 0.012108m/s respectively. Compared with the analysis results of TJS-2 satellite, it is found that the performance of the receiver based on the SoC platform has been greatly improved. The conclusion further verifies the feasibility of the application of the SoC platform in high orbit, and provides a reference for the subsequent development of high orbit GNSS receiver.

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