Design and Implementation of GNSS Receiver Based on SoC Platform

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Abstract. Benefit from the developed of multi-channel and multi-mode navigation SoC devices, the satellite-borne GNSS receiver scheme with highly integrated SoC platform as the baseband core device has gradually become the mainstream. Based on the NS962 device developed by Space Star Technology CO., LTD, the redundancy design of hardware double backup is proposed. This design is composed of baseband processing module, power management module and interface module. Results show that: the prototype weighs about 3.15kg; size is 198mm × 190mm × 89mm; power consumption is about 17W. It has the capability to process BD B1I/B3I, GPS L1CA/L1P/L2P single and the reliability over 8 years meets the requirement of >0.985. This design provides a new choice for the miniaturized and low-power GNSS receivers.

Keywords: GNSS Receiver; NS962 Chip; Hardware Structure; Reliability; accuracy.

1. Introduction
The global navigation satellite system (GNSS) receiver has been becoming an important components for communication satellites, remote-satellites and other spacecrafts, which are used for autonomous navigation, orbit determination and high precision timing. Since the first spaceborne GNSS receiver was implemented in China in 1996[1], more than hundreds of types of GNSS receivers have been certainly functional in space. Now, the space-borne GNSS receivers mostly adopt the "DSP+FPGA" architecture scheme [2-3]. With the increasing demand for high-performance devices in space missions, the satellite-borne GNSS receiver scheme with highly integrated SoC platform as the baseband core device has gradually become the mainstream. In recent years, some companies have successively developed multi-channel and multi-mode navigation SoC devices, which provides a new choice for the design of miniaturized and low-power GNSS receivers [4-5].

Above all, this paper describes the design architecture, functions and performance indexes of the NS962 chip developed by Space Star Technology CO., LTD. According to the function requirements of the MEO and LEO satellite for the satellite-borne navigation receiver with high precision measurement, a hardware design scheme of the GNSS receiver based on NS962 chip is proposed, in which the composition and function of each module are introduced in detail, and the reliability of the on-orbit application of the receiver is analyzed. The test results show that the designed receiver has the functions of high precision positioning, speed measurement and timing, which meets the index requirements of small volume and low power consumption.
2. Introduction to excitation cabinet
In normal operation, the heat of the excitation cabinet mainly comes from the heating of the components of the rectifier cabinet and the heat of the excitation isolated bus that enters the cabinet through the EA cabinet. According to the data provided by the manufacturer, the maximum heat dissipation of the excitation system is 90kW under the long-term rated operation condition of 1.1. The air inlet of the rectifier cabinet is equipped with temperature monitoring components, which will alarm and trip when the set value is exceeded.

The station is equipped with 6 sets of rectifier cabinets (N-1 configuration), each of which is equipped with a cooling fan for forced convection cooling of the internal components of the rectifier cabinet. The suction air outlet of the cooling fan (shown in the green line segment in Figure 1) is located on the front of the rectifier cabinet, and the exhaust air outlet (shown in the blue rectangle in Figure 1) is located on the upper part, and reaches the back of the rectifier cabinet. In order to solve the practical problems of the station, the station focuses on the optimization and improvement of the cooling system in the Excitation Room, which is also the main content of this paper.

3. Design of Primary Cooling System for Exciter
NS962 is a multi-channel and multi-mode navigation SoC device for space environment. It’s composed of three main function modules: baseband processing module, SPI module and processor module. The object and block diagram of the chip’s function is shown in Figure 1.

![Fig.1 The Object and Block Diagram of the Chip’s Function](image)

Baseband processing module is composed of capture module and tracking module. It supports A/D data input for GPS L1, L2, BD B1, B2, B3, GLONASS L1F, L2F frequencies (up to 7 frequencies at the same time). The capture module supports fast capture of the above frequencies, while the tracking module realizes the tracking function. The baseband processing module can be used for the closed-loop tracking of the tracking channel, including the carrier tracking loop and code tracking loop.

SPIs include UART, SPI, SPF, I2C, GPIO, Watchdog and 1PPS interfaces. The chip exchanges data with the satellite service through CAN Bus or 1553B Bus.

The processor is based on the dual-core ARM Cortex-A9 processing subsystem, and the dual-core has the function of data interaction. The internal part of processor includes an operation unit, a digital phase-locked loop (PLL) and a SRAM unit, which are respectively equipped with the functions of instruction parsing operation, clock working frequency configuration and supporting the online operation of programs.

The SoC chip designed has the navigation signal processing function of traditional "FPGA+DSP" architecture. The characteristic indexes are shown in Table 1.
Table 1. Characteristic Indexes of NS962

| NO. | Characteristic Indexes                  | Characteristic value                                      |
|-----|----------------------------------------|----------------------------------------------------------|
| 1   | Navigation Signal System               | GPS L1CA/L1P/L2P/L5, BD B1I/B2I/B3I, Glonass L1f/L2f     |
| 2   | Tracking channel                       | 96                                                       |
| 3   | Sensitivity                            | L1CA: -143 dBm, GEO: -145 dBm                           |
| 4   | Accuracy of Position                   | ≤10m                                                     |
| 5   | Accuracy of Velocity Measurement       | ≤0.01 m/s                                                |
| 6   | Accuracy of PPS                        | ≤100 ns                                                  |
| 7   | Total anti ionizing dose               | >100 Krad (Si)                                           |
| 8   | Threshold of anti SEL                  | No less than 75 MeV•cm²/mg                               |
| 9   | Anti Single Event Upset                | GEO orbit less than 8×10⁻⁸ /day                          |
| 10  | Anti Single event function interruption rate | GEO orbit better than 6×10⁻⁵ /day                      |

4. GNSS Receiver Hardware Design

4.1. Technology Indicator Requirement

In order to meet the typical functional requirements of satellite-borne navigation receiver with high precision measurement, the following indexes are put forward:

Table 2. Technology Indicator Requirement

| Function Item                  | Qualification                                      |
|--------------------------------|----------------------------------------------------|
| orbit altitude                 | 500~700 km                                         |
| frequency                      | BDS B1I/B3I, GPS L1CA/L1P/L2P                       |
| Cold-start positioning time    | Less than 5 minutes                                |
| Hot-start positioning time     | Less than 1 minutes                                |
| Positioning accuracy           | Higher than 7 m (1σ, Triaxial synthesis)           |
| Velocity measurement accuracy  | Higher than 0.05 m/s (1σ, Triaxial synthesis)      |
| Absolute timing accuracy       | Less than 100 ns(1σ)                               |

4.2. Hardware Design of GNSS Receiver

Thanks to the characteristics of miniaturization and multi-functional compatibility of SOC device NS962 which also features multi-frequency and multi-mode navigation, the redundancy design of hardware double backup is adopted in the baseband module in this scheme in order to improve the reliability and safety of single machine on orbit operation. The receiver is composed of three functional boards: power management board, baseband processing board and interface board. The system structure is shown in Figure 2.
The power management board mainly completes the secondary voltage transformation of the primary power bus and provides the working voltage for each single board of the receiver. The main functions include Overcurrent Protection module, anti-surge module, power switch control module, EMI filtering module, DC/DC transformation and analog voltage module, temperature telemetry module.

The baseband processing board consists of two circuits with exactly the same design, which are made up of RF module and baseband processing module. The RF, clock processing unit uses the SX363 device developed by CETC-24 to complete the filtering, amplification and down-conversion of the received signal, and then carries out the analog-to-digital conversion, and outputs the digital IF signal to the NS962 chip. With the cooperation of BaseBand, M-core and S-core, baseband processing module with NS962 chip completes the capture and tracking of navigation signals, the interpretation of navigation messages and the acquisition of original observations. Finally, the position, speed, clock difference and clock drift results of the receiver terminal are calculated by the Least Square method.

The interface board is equipped with two parallel interface circuits. The NS962 chip is used as the interface processor to receive and optimize the baseband board data internally, while to output protocol of the receiver externally required by all users.

4.3. Structure and Production Process

The main structure of the navigation receiver are made of 2A12 aluminum alloy material out of consideration of weight, strength and corrosion resistance considerations, in order to improve the strength and stiffness of the structure of its own at the same time, as far as possible to reduce the overall size of the structure. The cabinet surface is black anodized to enhance the radiative heat dissipation ability. Fig3 shows the Internal and external surface of receiver.

In addition, the device in the receiver with high heat dissipation is connected with the heat dissipation convex on the chassis structure through the heat conduction pad, so that the heat generated by the device can be directly transmitted to the bottom plate of the structure through the heat conduction pad, which reduces the thermal contact resistance between the printed board and the chassis shell, and builds a good thermal conduction path for the heat conduction of the chip.
5. Reliability Analysis

The receiver reliability model based on the above design is shown in Figure 4. The receiver is composed of baseband board, power supply board and interface board in series, and each function board is made up of two completely consistent function modules in parallel.

The reliability prediction of a single unit is calculated by the formula

$$R = e^{-\lambda t}$$

Where: $R$- reliability; $\lambda$- failure rate; $T$ - time (unit: hour, $t = 70080$ at the end of the 8th year).

When the reliability model of multiple elements is a series model and the failure of each element is statistically independent, it can be satisfied as follows:

$$R_S = \prod_{i=1}^{m} R_i$$

Where: $R_S$-the reliability of the system; $R_i$ - Reliability of unit $i$.

When the reliability model of multiple elements is a parallel model and each element is statistically independent of failure, it can be satisfied as follows:
\[ R_s = 1 - \prod_{i=1}^{m} (1 - R_i) \]

Where: \( R_s \) - the reliability of the system; \( R_i \) - Reliability of unit i.

According to the new failure rate data sources from standard "MIL – HDBK-217F notice revise II" and standard GJB/Z 299C, this paper calculates the failure rate of each function board respectively with the method of element stress analysis. As the result, the failure rate and reliability of the functional units of power panel, baseband board in the interface board are as shown in table 3.

**Table 3. The Failure Rate and Reliability of Each Module**

| Module          | Failure Rate \( \lambda \) | Reliability |
|-----------------|-----------------------------|-------------|
| Power Panel R1  | \( 0.3411 \times 10^{-6} \) | \( R_1 = 0.976379 \) |
| Baseband Board R2 | \( 0.747765 \times 10^{-6} \) | \( R_2 = 0.948946 \) |
| Interface Board R3 | \( 0.5501 \times 10^{-6} \) | \( R_3 = 0.962182 \) |

Then, the reliability of GNSS receiver at the end of 8th year is expected to be:

\[ R_s = 1 - (1 - R_1 \times R_2 \times R_3)^2 = 0.98822588 \]

The reliability over 8 years meets the requirement of > 0.985.

6. Functional Verification

The test results show that, the size of the prototype based on the above design is 198mm×190mm×89mm, the weight is about 3.15kg, and the power consumption is about 17W. Also, the receiver has the capability to process BD B1I/B3I, GPS L1CA/L1P/L2P signal and can be configured to dual-mode and dual-frequency.

In order to verify the function of the receiver, this paper used GNS8000 simulation signal source to test validation. While testing, the GPS and BDS satellite system with -130dBm output power were setted. Also, the user satellite orbital was setted to be 607.05 km altitude of the sun synchronous orbit, the semi-major axis to be 6987.36 km, the eccentricity ratio to be 0.0012814574, and the orbital inclination to be 97.823965 deg. Based on the setting above, this paper calculates and analyzes the results of the triaxial synthesis positioning precision \( \sigma_p \), speed measuring precision \( \sigma_v \) and the timing accuracy of the navigation receiver. The results are shown in Figure 5~ Figure 7. And the positioning accuracy \( \sigma_p = 1.24m \), the velocity measurement accuracy \( \sigma_v = 0.0024m/s \), and the timing accuracy is 67.866ns or less.

According to the above test results, the indicators of the satellite-borne navigation receiver designed in this paper meet the requirements in Table 2.

![Fig. 5 The test result of the triaxial synthesis positioning precision](image)
7. Conclusion
Based on the NS962 chip developed by Space Star Technology CO., LTD, this paper designed and developed the spaceborne navigation receiver hardware platform which is suitable for LEO satellite with high precision and low power consumption. Besides the receiver has the characteristics of miniaturization, high reliability and high precision, and can be compatible with process BDS and GPS dual system navigation signals. According to the test results, the positioning precision is 1.24m, speed measuring precision is 0.0024 m/s and the timing accuracy is better than 67.866ns. All the indicators above meet the requirements of high precision measurement type navigation receiver, which provides a reference for the design for LEO satellite navigation receiver.

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