CAPS Kunming Orbit Determination Station Postprint

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Abstract

Based on satellite two-way time and frequency transfer technology, transponder-based satellite orbit determination technology can precisely measure the distance between ground stations and satellites, while achieving high-precision time synchronization among stations.

The Chinese Area Positioning System (CAPS) has established a VSAT (Very Small Aperture Terminal) transponder-based satellite ground orbit determination network optimized for domestic deployment, with Kunming Satellite Ground Station serving as one of its key components.

Kunming Satellite Ground Station operates with all instrument frequencies provided by high-precision atomic clocks, features configurable instrument parameters, and enables real-time accurate measurement of instrument delays. As a fully automated transponder-based satellite ground station, it provides robust support for high-precision satellite orbit determination for the Chinese Area Positioning System.

Full Text

Preamble

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Kunming Orbit Determination Station

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Abstract

Satellite orbit determination by transfer, based on Two-Way Satellite Time and Frequency Transfer (TWSTFT) technology, can precisely determine the distances between ground stations and satellites while enabling high-precision time synchronization among stations. The Chinese Area Positioning System (CAPS) has established a transfer-based satellite ground orbit determination network with Very Small Aperture Terminal (VSAT) stations according to an optimal domestic layout, and the Kunming satellite ground station is an important component of this network. All instrument frequencies at the Kunming satellite ground station are provided by high-precision atomic clocks, instrument parameters can be configured, and instrument delays can be measured in real time with high precision. It is a fully automatic transfer-based satellite ground station that provides strong support for high-precision satellite orbit determination for CAPS.

Keywords: Satellite orbit determination by transfer; Two-way satellite time and frequency transfer; Kunming satellite ground station

1. Introduction

1.1 Satellite Navigation Systems

Currently, international satellite navigation systems include the Global Positioning System (GPS), Russia’ s Global Navigation Satellite System (GLONASS), and China’ s BeiDou Satellite Navigation System, among others. The composition and working principles of these systems are basically similar[1]. Satellites are equipped with high-precision atomic clocks that transmit spread-spectrum codes containing time information and satellite position data. When a receiver acquires signals from more than four satellites, it can determine its three-dimensional position and receiver clock offset. The precise orbits of satellites in navigation systems are all determined by the time difference between the received satellite clock signals and the receiver clock. Evidently, the most fundamental element in a satellite navigation system is accurate system time.

1.2 Chinese Area Positioning System

The Chinese Area Positioning System (CAPS) is a novel satellite navigation system whose main components are ground-based. Its navigation signals are generated and transmitted from the ground, with only the satellite segment leasing Geostationary Earth Orbit (GEO) satellites to broadcast navigation information and signals[2]. The greatest advantage of GEO satellites is their excellent coverage performance, making them particularly suitable for regional navigation systems (Japan and India also use GEO satellites for their regional navigation systems). However, because such satellites have relatively small motion with respect to the ground[3], instrument system errors are difficult to separate, making precise orbit determination for GEO communication satellites considerably difficult.

The National Time Service Center invented the transfer-based satellite orbit determination method, which broadcasts navigation signals via GEO communication satellites, with both signal transmission and reception performed on the ground. The greatest advantage of this method is that satellite orbit determination and time determination are independent of each other, and instrument observation system errors can be determined in real time on the ground, greatly improving satellite orbit determination accuracy and solving the difficult problem of precise orbit determination for GEO satellites.

2. Transfer-Based Satellite Orbit Determination Method

2.1 Principle and Schematic

The transfer-based satellite orbit determination method is illustrated in Figure 1. Ground stations use high-precision atomic clocks to transmit time signals, which are forwarded by the satellite transponder. Each ground station can receive time signals transmitted by all stations via the satellite transponder. Code Division Multiple Access (CDMA) technology enables multiple stations to simultaneously transmit their respective time signals to the same satellite at the same frequency without interference[3]. According to requirements, received signals can be combined in different ways, and the transfer-based satellite orbit determination method can be implemented in multiple modes.

[Figure 1: see original paper] Schematic diagram of orbit determination by transfer

2.2 Operation Modes

Self-transmitting and self-receiving mode: In this mode, station *i* transmits a ranging signal to the satellite, which is forwarded back and received by the same station *i*, determining the round-trip path delay. Time synchronization errors between stations mainly affect the time tags of satellite observations[3], so the precision requirement for time synchronization among orbit determination stations is not high.

One-transmitting and multi-receiving mode: Only one station transmits an uplink signal, while other stations only receive that station' s signal. This mode is particularly suitable for uplink spot beam situations. Satellite orbit determination is performed using one-transmitting and multi-receiving technology.

Multi-transmitting and one-receiving mode: All stations transmit uplink signals, but only the master station receives signals from other stations. This mode is particularly suitable for downlink spot beam situations, where received data is only at the master station.

Paired observation mode: Two stations form a pair, each receiving the other' s time signal. This is equivalent to the satellite being on an ellipsoid with the two stations as foci, providing better satellite constraints. With N stations in the system, there are N independent observations per station, improving orbit determination accuracy. Due to symmetric observations, adding the observations eliminates the clock differences between the two stations.

3. Kunming Station System

3.1 System Overview

The Kunming transfer-based satellite orbit determination system is one of the main stations in the CAPS network. The VSAT satellite ground station consists of a high-precision time system, ground station terminal, automatic monitoring system, ground station delay calibration system, automatic weather station, and self-calibration system. Its system configuration is identical to other orbit determination stations.

[Figure 2: see original paper] Diagram of satellite orbit determination by transfer

The station is equipped with 5 m and 3.7 m aperture parabolic antennas, each with signal transmission and reception capabilities, and transmit-receive isolation better than 40 dB. The Kunming station satellite orbit determination system transmits uplink signals via the antenna to the satellite, which forwards the signals. The ground station receives the forwarded downlink signals. The downlink carrier signal operates at frequencies in the (4 GHz/6 GHz) band. The computer controls modem signal transmission while simultaneously receiving data from meteorological microwave radiometers and other sensors.

3.2 High-Precision Time System

The core of the orbit determination observation time system is a high-precision atomic clock that generates high-precision time and frequency. The Kunming station uses GPS 1 pps signals to compare with the atomic clock's 1 pps through a counter, achieving initial synchronization between the local atomic clock time and Coordinated Universal Time (UTC), with synchronization to within several tens of nanoseconds. The synchronization process needs to be repeated before observations. Through the system' s own time transfer function, the orbit determination system achieves strict synchronization with the station' s time system. All commands during observations are automatically executed by the industrial computer according to preset programs. The time of the station' s orbit determination system and the master control station' s time achieve high-precision synchronization while performing orbit determination.

3.3 Satellite Time and Ranging Equipment

The Satellite Time and Ranging Equipment (SATRE) is the key terminal of the CAPS satellite orbit determination system, used to measure pseudo-range from observation stations to satellites while simultaneously achieving time synchronization. The ground station terminal modem has the capability to transmit time spread-spectrum signals and receive signals.

The SATRE includes a transmission channel and multiple receiving channels. Using pseudo-code spread-spectrum technology, each station simultaneously transmits its own time signal with a different pseudo-code to the satellite. Ground stations receive signals forwarded by the satellite transponder and measure the delay over the entire path. The SATRE receiving terminal generates a pseudo-noise modulated signal in the transmission channel, which contains known information. This generated signal is modulated onto an RF carrier as an uplink signal transmitted to the satellite. The SATRE receiver receives the signal at the correct frequency and correct pseudo-code. The signal passes through the communication path to become a downlink signal. The counter data is read out by measuring the time interval between the transmitted 1PPS (TX 1PPS) and the received 1PPS (RX 1PPS), with the atomic clock providing the reference frequency for the counter. The actual measurement process is continuous.

3.4 Delay Calibration System

The ground station delay calibration system is analogous to a ground target in laser ranging, measuring the delay relative to a reference point. Although the system design incorporates constant temperature design for critical instrument components to mitigate temperature effects on delay, a dedicated ground station delay calibration system was specially designed to avoid instrument system error variations caused by inconsistent instrument states. This system measures instrument system errors in real time every hour, with measurement states (power, etc.) identical to satellite ranging states. The real-time instrument system measurement has considerably high precision, generally better than 0.02 ns for calibrating Kunming station instruments, equivalent to a determination error of 6 mm.

[Figure 3: see original paper] A typical measurement of instrumental system error at Kunming Station

3.5 Automatic Monitoring System

The Kunming satellite orbit determination station has an automatic monitoring system that configures and monitors all equipment in real time. Once configured, the instruments achieve full automation, with antennas automatically tracking satellites. The system collects orbit determination data and equipment status parameters from the satellite orbit determination system, as well as time synchronization data from the satellite ground station and self-calibration system data for ground station system errors. All data and equipment status parameters are transmitted to the master station via a dedicated network for orbit calculation.

3.6 Two-Way Time Transfer

Satellite Two-Way Time Transfer (TWSTT) is currently one of the highest-precision time comparison technologies internationally. The TWSTT principle is illustrated in Figure 4. The transfer-based satellite orbit determination system inherently has two-way time transfer capability[4]. The master clock 1PPS signal at Station A is modulated by the terminal and sent to the satellite, which forwards it to Station B. Station B demodulates the 1PPS signal from Station A and uses a time interval counter to measure the time difference between the received 1PPS signal and Station B' s master clock 1PPS signal, obtaining high-precision time comparison results. Station B' s process is the same as Station A' s. Due to the symmetry of the paths between the two stations, path effects basically cancel out. High-precision atomic clocks are the time standard for orbit determination station observations. Coarse time synchronization between master and subordinate stations is achieved through GPS time, while high-precision synchronization between the subordinate station's orbit determination equipment time and the master control station' s time is realized simultaneously with orbit determination.

[Figure 4: see original paper] Observation statistics of Kunming station in 2015

4. System Characteristics

Leveraging high-precision ground atomic clocks (which have higher stability than spaceborne atomic clocks) and utilizing pseudo-code orthogonality, each station uploads signals to the same satellite at the same frequency using Code Division Multiple Access (CDMA). Each satellite ground station' s uploaded signal is equivalent to a GPS satellite transmission, which is equivalent to having N GPS satellite signals. Using very high-rate pseudo-code ranging (higher than GPS P-code rate) achieves high measurement precision, with internal ranging precision better than 1 cm. Ranging signal generation and measurement are both performed at the ground station.

Instrument transmission system errors and reception system errors are calibrated in real time through the designed instrument self-calibration system. In principle, time comparison and satellite orbit determination do not interfere with each other, and observation results eliminate instrument error effects[5]. Single instrument error determination is 6 mm, and low transmission power is required—the system can still work normally when signals are 23 dB lower than strong signals and can operate in a piggyback mode. The transfer-based orbit determination can achieve high-precision orbit determination with high satellite orbit accuracy[6]. With large spread-spectrum gain and based on the above advantages, satellite orbit determination residuals are better than 10 cm.

5. Operation Status and Performance

At the beginning of the year, equipment was upgraded with a new cesium clock as the system's time/frequency standard. The cesium clock model is OSA3235B with accuracy better than $\pm 1\times10^{12}$ and stability 2.7×10^{13}. The station equipment is in good condition.

In 2015, Kunming station completed observation tasks for 5 communication satellites, of which 3 were routine observation tasks and 2 were temporary observation tasks. While routine observations proceeded smoothly, the station also successfully completed temporary observation tasks.

Due to its geographical advantages, Kunming station holds a special position in satellite observations, particularly for inclined orbit satellites. The transfer-based satellite orbit determination system at the station has considerably high observation precision and can achieve full-arc satellite observation.

[Figure 5: see original paper] Orbit determination residuals of observational data obtained by Kunming station on June 17

The transfer-based satellite orbit determination method demonstrates high-precision orbit determination performance[7]. The Kunming station CAPS system features: sampling interval 10 mm, equipped with cesium atomic clock, time synchronization precision better than 1 ns, stable and reliable instrument operation, and a self-calibration system. It is particularly suitable for GEO satellite orbit determination.

Kunming station collaborates with the National Time Service Center in the transfer-based satellite orbit determination project, coordinating with the entire satellite orbit determination system to complete various stages of joint testing, routine observations, and various tasks. Its geographical location makes it an indispensable satellite orbit determination station in the domestic layout of CAPS. The station' s 1 pps is synchronized with UTC within 1 ns, clearly demonstrating Kunming station' s special status.

6. Conclusion

The Kunming transfer-based satellite orbit determination station is a critical component of the CAPS network, providing high-precision orbit determination capabilities through its advanced time system, self-calibration capabilities, and strategic geographical location. The station' s performance demonstrates that the transfer-based method effectively solves the challenges of GEO satellite orbit determination while achieving exceptional time synchronization precision.

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Kunming Satellite Orbit Determination Station for Chinese Area Position System (CAPS)

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Abstract: Determination of satellite orbit by transfer, based on the Two-Way Satellite Time and Frequency Transfer, is implemented with the observations of multi-stations. The distances between a satellite and ground stations are determined. The net of ground stations with the VSAT system is established for the CAPS project. Kunming station is one of them. The frequency of all equipment in Kunming is controlled by an atomic clock and all status can be set up as well as monitored. The time delay of instruments can be determined. It can carry out functions such as orbit determination and time synchronization at remote stations.

Keywords: Satellite Orbit Determination by Transfer; Two-Way Satellite Time and Frequency Transfer; Kunming Substation of Satellite Orbit Determination

Note: Figure translations are in progress. See original paper for figures.