

The Present and Future of China's Sea-based Space Tracking and Communications

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Abstract. Space tracking ship plays a crucial role in China's spaceflight tracking and data network. In this paper, the history of China's space tracking ship is reviewed, the main subsystems of the tracking ship are introduced with the emphasis being put on its technical features. Special problems such as antenna stabilization, EMC, system calibration are elaborated in detail. Future possible missions and the technical challenges are also analyzed in the final part.

1. Introduction

In spaceflight missions, ground tracking support and telecommunication, usually being referred to as TT&C (Tracking, Telemetry and Command), play important roles. The TT&C system is able to track the spacecraft, obtain its trajectory and telemetry data, monitor the status of, and communicate with, the satellite or spaceship and control its behavior.

To meet the needs of space program, early in 1960s, China's space tracking network was planned and reliability, economy were its main concerns. Nowadays, the whole tracking network mainly consists of land-based, sea-based and space-based tracking stations and operation centers.

In 1965, China began to consider the tracking ship program. The first two space tracking ships were constructed in 1979 and since then the ground support of China's spacecraft was extended to the ocean. China became the fourth country which owns the space tracking ship after the United States, the former Soviet Union and France.

Coming into the 21st century, as more space programs, such as space station and deep space exploration are being planned and more challenging requirements are proposed, new-generation tracking ships were constructed to replace the old ones. Unified S Band, unified C band, unified X band, tracking radar, etc. were installed and many advanced techniques, new materials were widely used which made the performance further and greatly improved.

The tracking ship can support manned or unmanned spaceship, lunar exploration satellite and other various flight missions. Compared with other approaches such as establishing or renting oversea ground stations, the construction and maintenance cost of the tracking ship are relatively higher but as mobile tracking station, the convenience and flexibility in deployment, and consequently the ability to support missions that can't be supported by land-based stations, is its unique advantage.





Figure 1. China's new-generation space tracking ship.

2. Main systems of the space tracking ship

2.1. Radar Tracking System

The radar tracking system aboard the Yuanwang space tracking ship is capable of providing continuous accurate spherical-coordinate information of the target in real time for mission operational decisions and for future evaluation of performance. The radar can be used as a single system, or as one of a chain of radars along a flight path to ensure continuous tracking throughout the entire flight.



Figure 2. tracking radar on space tracking ships.

This tracking radar is high-accuracy, long-range, amplitude-comparison monopulse radar which is capable of manual or automatic acquisition and tracking of objects in flight or orbit. Provisions are incorporated for selecting either a single-pulse output for skin tracking or a coded-pulse group for beacon tracking.

The transmitter output pulse is channeled through the microwave components to a multimode feed and parabolic reflector radiating system. A pencil beam directivity pattern is formed by the combination of the feedhorn and the antenna reflector.

The RF return signal is directed by the multimode feed into a comparator where it is separated into a reference component, an elevation error component and an azimuth error component. These signals (azimuth, elevation, and reference) are feed to separate channels in the tracking section of the receiver. Error outputs from the azimuth and elevation error channels are fed to the angle tracking subsystem of the radar set, where they are amplified and used to position the antenna.

Range tracking subsystem determines the slant range of the target in space, and provides range data outputs which are fed through the digital data subsystem to the computer.

To increase the probability of acquisition during the normal acquisition mode, the radar generates analog (joystick) or accepts digital scan command from the computer.

In addition to accepting stabilized designation data, the radar will accept feed-forward signals to reduce the effects of ship's motion during tracking. Further refinement of ship's motion compensation is achieved by the use of rate gyros which are part of the radar mount.

2.2. *Unified Systems*

Unified system integrates separate functions onto one carrier and can accomplish tracking, telemetry, command, communication etc. simultaneously.

The USB (Unified S-Band) operates in five modes, i.e., standard TT&C, coherent SS(Spread Spectrum) TT&C, noncoherent SS TT&C, DDT(Digital Data Transmission) and PCM/FM.

The UCB(Unified C-Band) operates in the mode of noncoherent standard TT&C which doesn't have the ability of range rate measuring. But compared with USB, UCB has the ability of synchronizing control of spinning satellite. In addition to coded telemetry, it also has the function of analog telemetry. Furthermore, on the new-generation tracking ship, UCB shares antenna and servo system with C-band pulse radar, shares BBE with USB.

2.2.1 Antenna Sharing As mentioned above, on the new-generation tracking ship, UCB and C-band pulse radar shares the same antenna and servo system. This is due to limited room for large antenna on the tracking ship and the requirement to increase the effect-cost ratio.

This composite system, called "C+C", has three operation modes: pulse radar operating independently, UCB operating independently, pulse radar and telemetering of UCB. Several radio switches were installed in the feed network to realize transmitter switch between UCB and pulse radar, and polarization switch, and to provide radio channels for three operation modes

2.2.2 Spread Spectrum TT&C The technique of spread spectrum was adopted in the unified systems onboard the new-generation tracking ship to improve security and anti-jamming ability.

SS TT&C (Spread Spectrum TT&C) operates as following. In the BBE, command information is modulated with short PN code onto the carrier using BPSK, ranging PN code (long code), which is synchronized with the short PN code, is modulated directly onto an orthogonal carrier also by using BPSK. Then, the two carriers are added together to form a new one. After being up-converted, amplified, the carrier is transmitted through the antenna to the spacecraft. The transponder of the spacecraft, after receiving the uplink signal, firstly accomplishes the acquisition and tracking of the short PN code, and demodulates the command information, then with the aid the short PN code, accomplishes the acquisition, tracking and regeneration of the long PN code. Telemetry information and downlink ranging code are modulated by using the same method as that in the ground station, and transmitted. The BBE processes the downlink signal and gets telemetry data, range and range rate, which is computed from the Doppler frequency.

2.2.3 Base Band Equipment The concept of software-defined radio was widely used in the design of the unified systems of the new-generation tracking ship and the part below 70MHz was integrated into one multifunctional BBE(Base Band Equipment) and the reliability, maintainability and flexibility were greatly improved. The BBE, by loading different software, can be configured with various operation modes, i.e., standard TT&C, SS TT&C, DDT (Digital Data Transmission), PCM/FM.

(1)Standard TT&C

Standard TT&C is just the operation mode of the conventional USB. In this mode, the BBE integrates the functions of ranging, range rate measurement, command, telemetry etc. into an industrial control computer.

(2)Spread Spectrum TT&C

The BBE supports both coherent SS TT&C and noncoherent SS TT&C and in this mode, multiple-object tracking can be accomplished.

(3)Digital Data Transmission

In this mode, the BBE can receive and demodulate signals with various modulations such as PCM - BPSK / QPSK /DQPSK / SQPSK / UQPSK, etc. and accomplishes voice and video communication.

(4)PCM/FM

Compared with land-based ones, a significant feature of the USB onboard the tracking ship is that the PCM/FM receiver for rocket telemetry was incorporated. To combat the fading of the rocket telemetry signal, polarization diversity was adopted.

(5)Spacecraft Simulator and Rocket Telemetry Simulator based on BBE

Spacecraft simulator consists of demodulation/modulation platform and simulation computer, and by using which tests and trainings can be implemented. Rocket telemetry simulator generates the telemetry data with the same time sequences as that of a real mission to test the data processing system.

To fully exploit the current equipment and save the installation space, which is limited on the tracking ship, a spacecraft simulator and rocket telemetry simulator based on the hardware of BBE were proposed and developed. In some sense, these simulators can be seen as BBE's built-in components, so except for the benefit of low development cost, the interfaces were also simplified.

2.2.4 Dual-Frequency Tracking The Chang'E satellite utilizes two antennas, each with a different frequency, for downlink transmission and covered the ground station alternatively. In order not to lose the linkage, a scheme called Dual-Frequency Tracking was proposed for USB. In this scheme, USB demodulates angle error signals from the two frequencies simultaneously, and according to some rules, selects and sends one to the ACU(Antenna Control Unit) to realize seamless switch between the two frequencies. This scheme is actually a sort of frequency diversity, although not for communication but for tracking.

2.3. Ship Attitude and Position Measuring System(SPAMS)

The Ships Position and Attitude Measuring System (SPAMS) is one of the principal systems of the tracking ship. This system comprises subsystems and equipments-integrated to provide data for stabilization of the shipboard antenna systems and for conversion of angle information from deck-referenced coordinates to earth-referenced coordinates. The system also provides for measurement of ship's velocity and for monitoring antenna mount flexure.

The functional diagram of the SAPMS of the tracking ship is shown in Fig. 1. The major subsystems of the SPAMS are as follows: INS(Inertial Navigation Subsystem), GNSS(Global Navigation Satellite Subsystem), FMS(Flexure Monitor Subsystem), DVL(Doppler Velocity Log) and calibration theodolite, etc.

The key subsystem in the SPAMS is the Integrated Navigation System (INS). The INS supplies extremely precise information concerning the ship's latitude and longitude; position North, East, and vertical components of velocity; roll, pitch, and heading.

Inertial components, gyros and accelerometers, incorporated into this system are not error free; thus their outputs will degrade with time. These errors are unacceptable in Shipboard application and must be reduced by a reset. System reset is possible when accurate position information is available from one of several sources: Navigation Satellite, and the Marine Star Tracker.

Three mutually orthogonal axes are required as a reference for measurement of all shipboard equipment tracking angles and are established by the SINS. For this reason it is very important that the ship's structural foundation meet certain requirements. To meet these requirements a specially designed bedplate, supported by rigid ship's structure, is provided.

Being compared with those onboard other vehicles, the INS of the tracking ship cares more about the accuracy of attitude rather than that of position. Positioning is mainly accomplished by GNSS which is independent with INS and also provides time synchronization.

Flexure monitor subsystem provides simultaneous automatic measurement of rotation about three mutually orthogonal axes: X (axis parallel to the roll axis of the ship), Y (axis parallel to the pitch axis of the ship) and Z (axis parallel to the yaw axis of the ship) for both the Unified S-Band and the C-Band radar antenna foundations. These measurements are referenced to the INS bedplate. The purpose of these measurements is to determine the alignment error between the INS bedplate and the antenna foundations due to flexure. This data is provided to the CDPS in digital form for use in correction of trajectory data.

Calibration theodolite is a kind of celestial navigation system, which tracks stars to calibrate the course error of INS or angle error and range error of radio tracking systems.

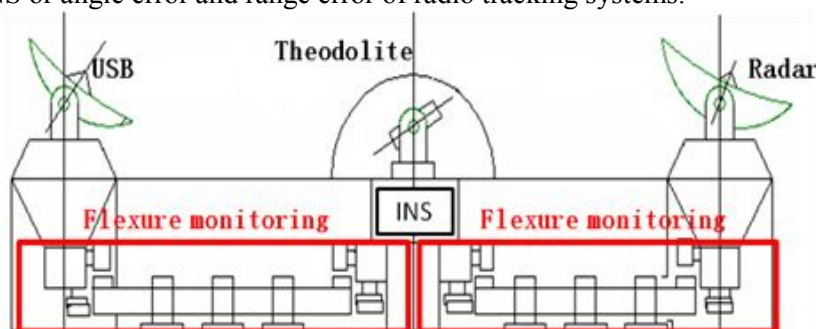


Figure 3. Functional Diagram of SAPMS of the Space Tracking Ship.

2.3.1 GPS Attitude Determination The technique of GPS attitude determination is based on GPS carrier phase measurement. In early 1990s, many institutes and universities began the research on attitude determination and course determination based on GPS carrier phase measurement by theoretical analysis and experiment. Compared with INS, GPS attitude determination has the advantages of low-cost, weather-irrelevant, fast-startup, no-error-accumulation and can work in regions of high latitude.

On the space tracking ship, the accuracy of GPS attitude determination is affected by factors such as complex electromagnetic environment, shadowing of large tracking antennas and ship's deformation. After intensive experiments, the feasibility of applying this technique on tracking ship was verified. Design schemes of appropriate GPS antenna array, system calibration and coordinate reference unification was proposed and successfully applied.

2.3.2 Information Fusion of SAPMS INS can provide continuous navigation information of position and attitude, but because of its error accumulation with time, it can't work alone and needs frequent calibration. GNSS can provide high-precision navigation information globally, but is apt to be interfered. Any kind of navigation system alone has its pros and cons and is impossible to meet all the tracking ship's requirements simultaneously. To realize highly precise, highly reliable, global, all-weather, continuous navigation, the new-generation tracking ship adopted an information fusion scheme based on federated Kalman filter and improved chi-square fault detection method, which fully exploits the inherent redundancy in the data and achieves high reliability and fault tolerance.

2.4. Central Data Processing System

The Central Data Processing System (CDPS) accepts digital data from the various systems and presents a processed data to various end equipments for control, display, recording or sends to the operation center through communication system.

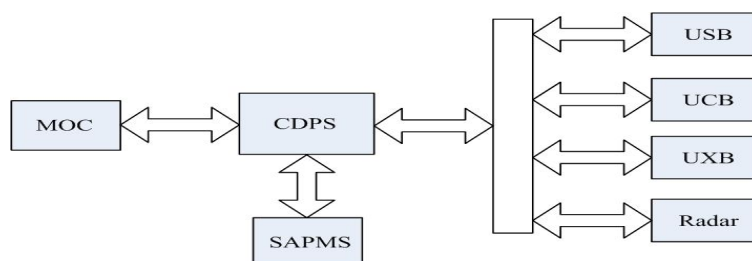


Figure 4. The working principle of Central Data Processing System on tracking ship.

To assist in acquiring the target, CDPS provides acquisition programs which direct the tracking system to the target.

2.5. Communication System

The purpose of the communication system is to provide linkage between the tracking ship and the mission control center, in Beijing or Xi'an for the ship's daily operation and for support of space missions.

2.6. The Operations Control Center

The Operations Control Center provides for centralized control and coordination of all an-board systems.

3. Special Issues of the Space Tracking Ship

Besides the problem of antenna stabilization just mentioned in the last section, there are many special issues and challenges must be addressed in the space tracking ship.

3.1. Electromagnetic Compatibility Design

Located on the top deck of the ship are dozens of antennas with various sizes. In order to eliminate electromagnetic interference, during design and layout, a rational selection is made of the operating frequencies and frequency spectra of the electronic equipment; there is a rational layout of the equipment and antennas, and strict antenna selection and cable-laying. Furthermore, shielding, restricting and filtering technology must be used.

3.2. Measures to Overcome Adverse Environments

The tracking ship sails the oceans for long periods of time and will frequently encounter high temperatures, high humidity, waves, and salt fog. To ensure normal and reliable operation and long life of the electronic equipment on board the ship, it is equipped with waterproof portholes and doors. All the cabins are air-conditioned. Electrical devices use large-scale integrated circuits and are sealed and heated. Exposed portions are treated against moisture, salt fog, and mildew.

3.3. System Calibration

Parameter drift, especially under adversary conditions, will increase the system error and sometimes will even cause failure of a mission, so regular and frequent maintenance, test and calibration is necessary to guarantee the required performance. For example, the zero value of the radar needs regularly check, the amplitude-phase inconsistency of the momopulse tracking channel must be carefully measured before each mission.

4. Future Missions

The development and deployment of China's tracking and data relay satellites brings unprecedented challenge to the space tracking ship, but because of many factors, especially the tracking ship's unique advantage, the space tracking ship is still going to play a critical role in the future.

In the future, the space tracking ship will continue to support various space programs including:

4.1. Space Station Program

As the most complicated space program of China, the objective of the space station program is to build a manned space laboratory to commit scientific research, and it also needs a much stronger ground support. In this mission, the tracking ship might will participate in the launch phase, orbit tracking or as voice/video relay.

4.2. Lunar Exploration and Deep Space Exploration

The ambitious goals of China's lunar exploration probably include astronaut's landing and surveying on the moon. In this and subsequent deep space explorations, the tracking ship might will participate in the launch phase and the return phase.

4.3. BeiDou Navigation Satellite System

The BeiDou Navigation Satellite System (BDS) is planned to be completed before 2020 and it needs the tracking ship to provide service of vehicle telemetry and satellite tracking in launch phase. The tracking ship will continue to support this grand plan in several years.

5. Future Challenges

These and other possible missions propose more rigorous requirements. The challenges that the tracking ship confronts, which are also the development trends of it, include:

5.1. Larger Operation Range

The diameter of the tracking antenna, limited by the size of the tracking ship, can't be very large and will prevent the tracking ship to take part in the deep space exploration of which the downlink signal is very weak due to long range.

Possible approaches to increase the operation range include using high frequency, array of all antennas onboard a single ship, coding and using very-low-temperature amplifier.

The beam of the reflector operating in high frequency is very narrow, and because of the ship motion, the stabilization of the antenna must be paid much effort.

5.2. Higher Tracking Accuracy

Because of operating in a dynamic environment, the tracking ship has much more error sources than land-based station. To further improve the measurement accuracy is a very difficult task and also an important research direction. For this aim, some promising data processing methods have been studied and tested, such as data fusion algorithm and adaptive method.

The accuracy of ship position and attitude measurement affects greatly the final result, and some new advanced techniques such as strap-down inertial navigation system and star-matching-based star sensor are now under consideration.

5.3. Higher data rate

In future missions, video from the space station or observation data of deep space explorer will have much higher data rate, so the tracking ship needs to expand its bandwidth to receive and relay those data.

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