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Rongjun Shen
Weiping Qian *Editors*

第27届中国飞行器测控学术会议论文集

测控的空间更广阔

Proceedings of the 27th Conference of Spacecraft TT&C Technology in China

Wider Space for TT&C

清华大学出版社 Springer

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内 容 简 介

本书精选并收录了第27届中国飞行器测控学术会议的优秀论文54篇。全书分为飞行器测量科学与技术、空间任务与操作、空间目标探测与识别、通信与信息系统4个部分，反映了我国航天测控领域的最新科研进展，可供相关领域的研究人员以及工程技术人员阅读参考。

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Preface

As a result of over 50 years of development, China has already built state-of-the-art full-fledged spacecraft TT&C systems. TT&C means are more diversified, their capabilities are greatly uplifted, and the scope of work of TT&C systems has been expanding. TT&C systems play an indispensable role in fields including space launch missions and routine operation management of spacecraft.

With the prosperous development of China's space endeavors, TT&C systems are facing new challenges and opportunities. They are required to support deep space missions farther into the universe. They are required to provide more complicated and higher accuracy on-orbit management of spacecraft. They are required to maintain formations and constellations of more satellites and to play a bigger role in detection and cataloguing of smaller space objects. To meet the new requirements, TT&C systems have to enhance their long-distance space information transmission capability, weak signal extraction and processing capability, high accuracy space instrumentation and navigation capability, and long delay operation and control capability. Moreover, the accuracy of TT&C systems has to be further increased to provide more reliable, secure, flexible, and efficient support to spacecraft.

Taking "wider space for TT&C" as its theme, the 27th Conference of Spacecraft TT&C Technology of China highlights more utilization of modern technologies to lift the effectiveness of spacecraft TT&C systems to meet the demands of long-term development of space activities in the backdrop of China's growing deep space missions, maturing Beidou satellite navigation system and explosive workload on China's spacecraft TT&C systems.

From over 330 papers authored by scholars and specialists from different fields, 55 are selected for publication by Springer. The objective is to further increase the influence of the Spacecraft TT&C Committee of the Chinese Society of Astronautics and to promote international academic exchanges by sharing China's latest research achievements and engineering experiences in the field of spacecraft TT&C systems with the global space-faring community.

November 2014 Rongjun Shen

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Part I
Spacecraft Instrumentation Science and Technology

Chapter 1
The Application of the GNSS Receiver in the Third Stage of China Lunar Exploration Program

Changyuan Wen, Meng Wang, Lin Qi, Dongjun Li and Yuehua Qiu

Abstract Lunar exploration puts forward higher requirements in terms of performances for the subsystems. As for the navigation system, the GPS receiver provides autonomous navigation service on board in Low Earth Orbit environment, so it calls for a possible extension to Earth-to-Moon missions. This paper, referring to the Third Stage of China Lunar Exploration Program mission which is "returning" in the three stages "circling landing and returning", investigates such a possibility, considering present and foreseen available GNSS signals. Carrier-to-noise levels achievable during the mission are evaluated. Moreover, the high-sensitivity GNSS receiver system design is discussed.

Keywords Lunar exploration · GNSS receiver · High sensitivity · Earth orbit determination

1.1 Introduction

With the successful task completion of Chang'E-1, Chang'E-2 and Chang'E-3, marking China's lunar exploration project into the Third Stage of China Lunar Exploration Program mission. According to three step strategy, which is "circling landing and returning", the Third Stage of China Lunar Exploration Program mission will be mainly probing on the moon landing and return. How to successfully landing on the moon, and accurately returns to the earth, asks for higher request to the track measurement and control detector.

At present, China existing deep space exploration spacecraft mainly use ground navigation and celestial navigation as the main means of navigation for orbit

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parameters measurement. Ground navigation takes the VLBI as the main means, which has the limitation of the ground station, data transmission, and the real-time and the measurement error, so it is difficult to meet the requirements of high precision measurement of orbit. The GNSS receiver is mainly applied in the low orbit satellite, which is used for navigation and positioning. With the deep research of GNSS receiver, the use of GNSS receiver in the above GNSS constellation orbit, which received the GNSS signal from the earth opposite especially side-lobe, got more development, such as America AMSAT OSCAR-40 satellite during apogee 59,000 km has successfully received the GPS signal [1, 2].

So using the GNSS receiver in the lunar mission was considered for real-time receiving GNSS satellite signal, through which the three-dimensional velocity and three-dimensional position, UTC time was calculated, those results were put together with other inertial navigation system to constitute the integrated navigation system, which can be used to correct the orbit errors, realize the transfer phase of the orbit control, with real-time, low power consumption, small size, high ratio of performance to price advantage.

This paper is based on the GNSS receiver in the application of the Third Stage of China Lunar Exploration Program mission as the background. The high sensitivity receiver and GNSS autonomous orbit determination of Kalman filter, which is to provide the navigation service for the lunar spacecraft, was designed through the analysis of the visibility of GNSS receiver for the Earth-Moon-Earth orbit transfer task and the characteristics of the weak GNSS signal power.

1.2 Lunar Mission Availability for GNSS

Take the Chang'E-1 transfer orbit parameters as an example to analyze the availability of GNSS signal in the Earth-Moon-Earth transfer orbit. The transfer instantaneous orbit elements are numbered in the Table 1.1 [3]:

Earth-Moon-Earth transfer orbit is highly elliptical orbit (HEO), with perigee 200 km and apogee 380,000 km. Figure 1.1 shows the relative position of the HEO satellites and GNSS geometric diagram where ε is unilateral GNSS satellite antenna coverage angle, Φ is the angle between the GNSS satellites unilateral main-lobe, θ is the angle between the GNSS satellites and Earth unilateral tangent. α is for the receiver and GNSS satellite receiver connection point geocentric angle between the

Table 1.1 Earth–Moon transfer orbit elements for simulation

Epoch	2007/4/23 22:41:41
Semi-major axis (km)	212,857.337
Eccentricity	0.967199 336
Inclination angle (°)	30.983
Argument of perigee (°)	179.983
RAAN (°)	180.485
True anomaly (°)	0

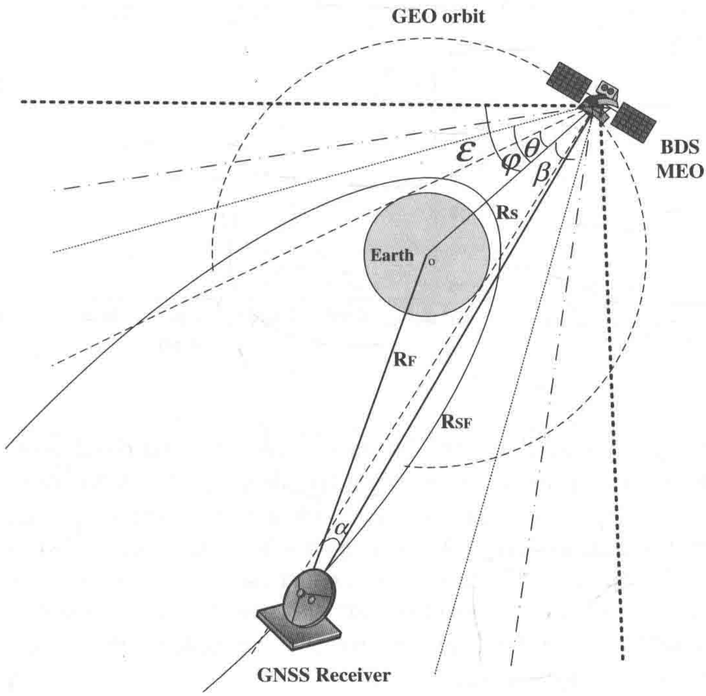

Fig. 1.1 Earth—Moon—Earth orbit GNSS signal receiver geometry schematic

direction, β is the angle between a link of the GNSS satellite to receiver and the direction of GNSS satellite pointing to center of the earth.

Seen from the Fig. 1.1, When the GNSS receiver orbit height less than GNSS satellite orbit height, it is required to receive GNSS signal from the zenith; When the GNSS receiver is higher than the height of the orbit of GNSS satellite orbit height, it is required to receive GNSS signal from the earth opposite for positioning.

1.2.1 Simulation Setting

According to the official GPS website information, into the March 14, 2013 satellite TLE file, the GPS constellation normal in operation is 31 satellites, not available is PRN 27. According to the published ICD, BDS design the constellation composed of 5 geostationary orbit (GEO) satellites, 27 circular earth orbit (MEO) satellites and 3 inclined geosynchronous orbit (IGSO) satellites [4].

GPS transmitting power is set to 14.28 dBW, GPS satellite antenna gain pattern (see Fig. 1.2) is saddle shaped gain, maximum gain value is 16.22 dB. Transmitting power and antenna gain of BDS is made by GPS.

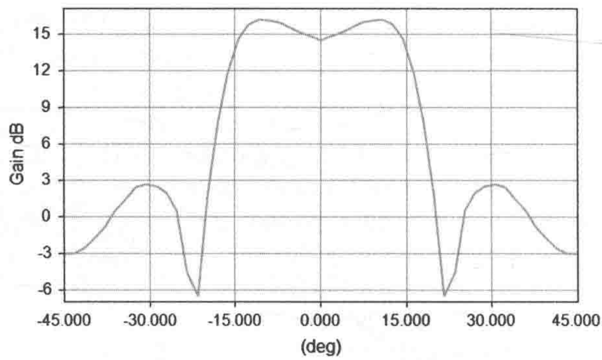

Fig. 1.2 Transmitting antenna gain pattern

Consider in the ascent of Earth-Moon transfer orbit and the decent of Moon-Earth transfer orbit, when the orbit height less than GNSS satellite orbit height, it needs to receive the zenith signal; and the track height is higher than that of GNSS satellite orbit height, it needs to receive signals from the earth opposite, so GNSS receiver for lunar phase three use double antennas, antenna pointing to the earth and from the earth. In order to adapt to the different stages of task demands, the direction point to the zenith will use the high gain antenna, another direction will be the wide field receiving antenna.

The highest gain of the high gain antenna (see Fig. 1.3) is 10.1 dB, ensure the ±30° gain greater than 7 dBi. Wide field receiving antenna (see Fig. 1.4) installation point to the zenith, the gain is more than 0 dBi for the ±60° beam width.

According to the analysis of GNSS constellations and lunar exploration satellite geometry, and the GNSS signal link budget equation, and taking into account the current level of receiver design, it is known that in the Earth-Moon transfer orbit on the position of 100,000 km the received power (including high-gain receiving antenna reception gain) is about –175 dBW maximum [2], so the simulation is set to receive power threshold –175 dBW, the minimum elevation angle of cut in 5°.

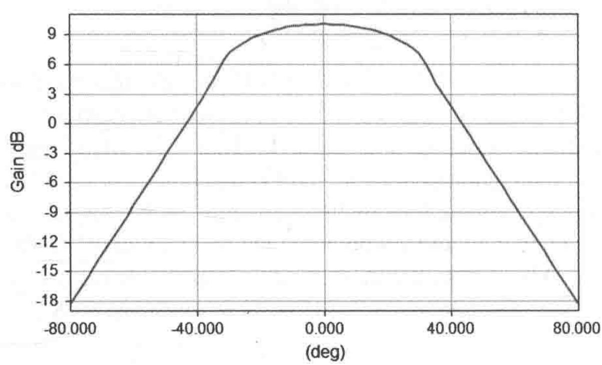

Fig. 1.3 Received antenna gain patterns towards the down-side