Chinese Journal of Aeronautics, (2016), 29(2): 470–478

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

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SNR periodical variation of Chang'E-3 spacecraft orbiting the Moon

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Received 29 April 2015; revised 5 December 2015; accepted 7 January 2016
Available online 23 February 2016

KEYWORDS

2 bits quantization;
Elevation angle;
Moon radiation;
SNR periodical variation;
VLBI

Abstract Chang'E-3 spacecraft was orbiting the Moon from December 6–14, 2013, and very long baseline interferometry (VLBI) observations were performed to improve the accuracy of its orbit determination. In the process of recording VLBI raw data, 2 bits quantization was implemented. Interesting phenomenon was that signal-to-noise ratio (SNR) of each VLBI station experienced periodical change and had large variation on amplitude while in the Moon's orbit, whereas SNR kept in a stable level after Chang'E-3 landed on the Moon. Influence of varying elevation angle on SNR was analyzed and compensation of 2 bits quantization harmonics to SNR calculation was investigated. Most importantly, telescope system noise temperature increase caused by the Moon was computed along the time of Chang'E-3 orbiting the Moon, and well matched SNR changing trend in terms of correlation coefficients.

1. Introduction

With the advantage of short distance to earth, the Moon has been of interest for many space projects for better understanding the universe, such as well-known Apollo project, JAXA's SELenological and engineering explorer (SELENE/KAGUYA),[1] India's Chandrayaan-1,[2] etc. And China has just launched its third lunar spacecraft, Chang'E-3, on December 1, 2013, which went into the Moon's orbit on December 6, and then started orbiting the Moon in a two-hour polar orbit until it landed on the Moon on December 14, 2013. In the stage of orbiting the Moon, Chang'E-3 was first in a circular orbit (December 6–10) of 100 km in average altitude, and then entered into an elliptical orbit (December 10–14) with 15 km in perigee and 100 km in apogee. For the whole journey, very long baseline interferometry (VLBI) observations were performed, which involved telescopes of TianMa (TM:65 m), Beijing (BJ: 50 m), Kunming (KM: 40 m), and Urumqi (UR: 25 m), with the main purpose of improving the accuracy of its orbit determination.[3] Signal-to-noise ratio (SNR) of those received signals was calculated, and it kept in a stable level after landing on the Moon. However, at the time of orbiting the Moon, it experienced periodical change and had large variation on amplitude, which may affect the accuracy of engineering and scientific results, and on the other hand may carry

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Peer review under responsibility of Editorial Committee of CJA.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.cja.2016.01.006
1000-9361

scientific information. This paper mainly studies the reasons behind these variations.

SNR variations are attributed to changes in signal power or noise power, or both of them. Changes in noise power can be partly caused by the Moon, as the Moon radiates energy at microwave wavelengths and Chang'E-3 was flying near it. In previous studies,[4–6] a 34-m-diameter telescope experienced a system noise temperature increase about 189 K at X band (8.4 GHz) with antenna beam center pointed to the Moon disk center and it was discovered that with antenna beam center pointing to the Moon center, antenna system noise temperature would increase more if the beam is sharper, and if the beam center gradually points away from the Moon center, antenna system noise temperature will decrease.[7] With actual data of Chang'E-3, this paper highlights the relation between SNR variation and system noise temperature increase due to the Moon.

In Section 2, we introduce the methods of obtaining SNR and present the results of both at the time of orbiting the Moon and after landing on the Moon. In Section 3, we mainly analyze SNR variation at the time of orbiting the Moon from aspects of elevation angle, 2 bits quantization harmonics and telescope system noise temperature increase due to the Moon. In Section 4, some other reasons for SNR variation are discussed and nonuniform brightness temperature T_b distribution is mentioned. Time in this paper is in coordinated universal time (UTC).

2. SNR acquisition

2.1. Signal flow

While ground radio telescopes were used to observe Chang'E-3, signal flow inside telescopes was as Fig. 1 shows (ADC means Analog-to-digital converter; AGC means automatic gain control). Raw data of VLBI were recorded by 2 bits, whose influence on SNR calculation will be analyzed in Section 3.2, and then transmitted to Shanghai VLBI center via communication network for further processing.

2.2. SNR calculation methods and results

As supported by Shanghai VLBI center, we calculated SNR values of the 4 stations, individually, both at the time of orbiting the Moon and after landing on the Moon.

When Chang'E-3 was orbiting the Moon, it transmitted differential one-way range (DOR) signals with carrier frequency f_c of 8470 MHz. We picked up the carrier channel (2 MHz bandwidth) and implemented the following methods to calculate SNR.

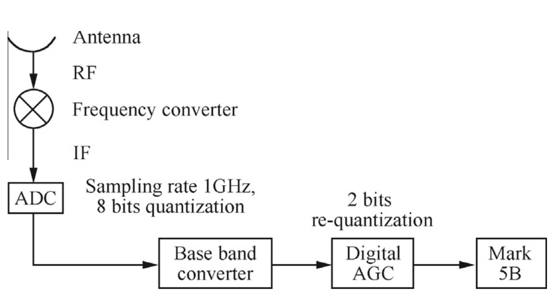

Fig. 1 Signal flow of VLBI stations.

First, obtain the auto-correlation power, and sum up all the values, labeled as P. Second, fit noise power, and sum up all the fitted values, labeled as P_n. Third, SNR = $(P - P_n)/P_n$. Fig. 2(a) gives an example of auto-correlation power of DOR carrier channel and noise fit result, from TM station, December 9, 2013. In Fig. 2(a), ($f_c \pm 65$ kHz) are telemetry signals, ($f_c \pm 500$ kHz) are range tones, and other lower peaks are higher harmonics of telemetry signal.

It should be noted that we didn't calculate SNR of single carrier frequency, because there were fence effect and power leakage in the process of doing fast Fourier transform (FFT). As a result, SNR of single carrier frequency departed from its true values and varied in the same manner as Doppler shift frequency variation. However, the above methods avoided these undesired effects and SNR calculation results of December 9, 2013 are shown in Fig. 3.

In Fig. 3, there are some gaps in SNR values. The big gaps (around 1 h) were caused by Chang'E-3 flying to the far side of the Moon, and the small gaps (around 5 min) were caused by telescopes directed to radio sources for VLBI calibration. An interesting phenomenon is that SNR changes periodically around every two hours, and has large amplitude variation. We have not seen this phenomenon in other papers, although this may also apply to other lunar orbiters.

To better understand this phenomenon, SNR after Chang'E-3 landed on the Moon was necessary to be calculated, and to serve as a reference. After Chang'E-3 landed on the Moon, it separated into a rover and a lander. The lander continuously sent data transmission signals for about 10 h a day at center frequency of 8496 MHz and bandwidth of 5 MHz (Fig. 2(b)).[3] We used the peak point (A) and trough point (B) to calculate its SNR, and results of December 23, 2013 are shown in Fig. 4, in which the time after 24 h represents early morning of December 24, 2013.

3. SNR variation analysis

Compared with SNR after landing on the Moon (Fig. 4), SNR of orbiting the Moon (Fig. 3) experienced more complicated variations. In Fig. 3, TM had the largest variation of about 8 dB, while other three stations suffered more or less 5 dB, and they had periodical change of around 2 h. It was unlikely to be caused by the attitude of the orbiter, because antenna on the orbiter was with effective isotropic radiated power (EIRP) of 0 dBw for 80% of radiating direction, and of −3 dBw for the rest of 20%. It is the main purpose of this study to know the reasons and information behind those variations. However, individual investigation on noise power variation or signal power variation was not feasible, because digital AGC unit was introduced in the signal flow (Fig. 1), which kept the total power as a constant. In this chapter, we analyze SNR variation of orbiting the Moon from aspects of elevation angle, 2 bits quantization harmonics, and radiation energy from the Moon. SNR after landing on the Moon is mainly served as a reference and its variation is analyzed only in Section 3.1.

3.1. Elevation angle

After Chang'E-3 landed on the Moon, the lander was in a fixed position. And as one can see in Fig. 4, SNR of TM and BJ are stable with time, while SNR of KM and UR have some