Takahiro Iwata et al.: Results of the Critical Design for the Selenodetic Mission using Differential VLBI Methods by SELENE , IVS 2002 General Meeting Proceedings, p.377–380
http://ivscc.gsfc.nasa.gov/publications/gm2002/iwata

Results of the Critical Design for the Selenodetic Mission using Differential VLBI Methods by SELENE

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Abstract

Global mapping of the lunar gravity field will be conducted using two micro sub-satellites of SELENE; the Relay Satellite (Rstar) and the VLBI Radio Satellite (Vstar). Differential VLBI observations will be conducted for three pairs of S-band and one pair of X-band carriers emitted from "The Differential VLBI Radio Sources (VRAD)" on Rstar and Vstar. Four-way Doppler measurements toward the SELENE Main Orbiter above the lunar far side will be conducted by "The Relay Satellite Transponder (RSAT)" on Rstar. These sub-satellites are requested to have long arcs of orbit without maneuver to detect orbit turbulence perturbed by lunar gravity, and to be simple design, therefore, there is no orbital and attitude control except spin stabilization. We have designed the simple structured and light weighted release mechanism, and confirmed the release properties by ground tests. Attitude analysis shows that the nutation caused by the tip off by the release mechanism is dominant for the attitude inclination.

1. Introduction

The spatial distributions of the lunar gravity field have been investigated from the orbit perturbations which had been observed by two-way range and range rate (RARR) measurements for spacecraft in lunar orbits. The orbital determination data till Lunar Prospector have produced and improved the models of the lunar gravity field [1]. The gravity data above the lunar far side were, however, less accurate than those above the near side, because they were observed from higher orbits or estimated from the near side data which were affected with accumulated acceleration by the far side gravity.

SELENE, the SELenological and ENgineering Explorer, is under development by National Space Development Agency of Japan (NASDA) and Institute of Space and Astronautical Science (ISAS), and will be launched in 2005 to elucidate lunar origin and evolution. SELENE is composed of Main Orbiter, and two micro sub-satellites: the Relay Satellite (Rstar) and the VLBI Radio Satellite (Vstar) which will be used for selenodesy experiments [2]. Rstar and Vstar will be injected into the initial elliptical orbit of 2,400-100 km and 800-100 km in altitude, respectively. Main Orbiter will be controlled to keep the circular orbit of 100 km in altitude. These satellites will be used to obtain selenodetic data of higher accuracy by differential VLBI observations and four-way Doppler measurements. We report results of the critical design of the SELENE sub-satellites in the following sections.

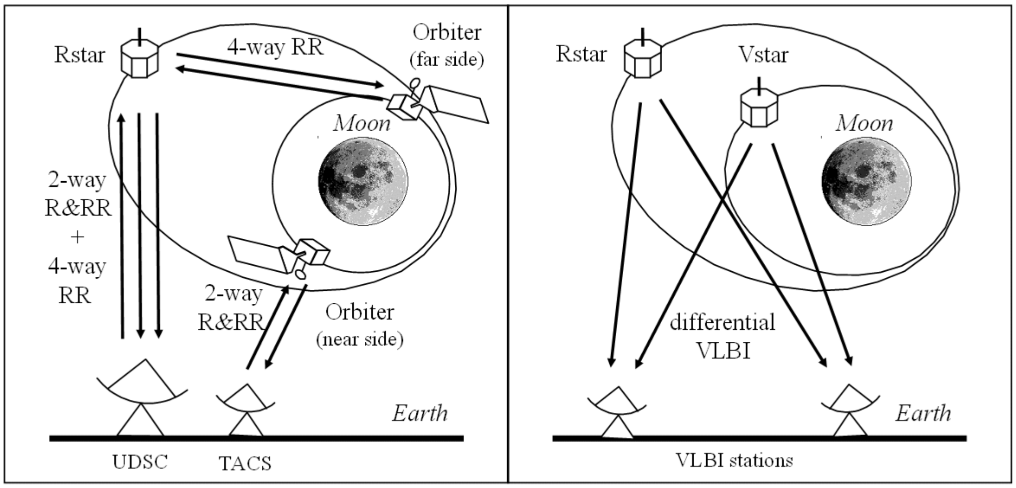

Figure 1. , The concept of the gravity field measurements using SELENE. Left is range (R) and range rate (RR), and right is differential VLBI.

2. Outline of the Mission

2.1. VRAD: Differential VLBI Radio Sources

Orbits of Rstar and Vstar will be determined with the highest accuracy by differential VLBI observation methods toward S- and X-band radio sources on Rstar and Vstar [3]. Figure 1 (right) shows the mission concept of the differential VLBI observations using VRAD, the Differential VLBI Radio Sources. VRAD-1 and VRAD-2 will be installed on Rstar and Vstar, respectively.

Each radio sources has three S-band carrier signals and one X-band carrier signal to calibrate the delay by the terrestrial ionosphere and to solve uncertainties over one wave length. Narrow bandwidth VLBI terminals for this mission have been developed and are planned to be established at three stations of VERA and four stations in China (Shanghai and Urumqi), Australia, and Europe. The accuracy of the satellite positions determined by VRAD are estimated to be about 20 cm [4], which are more precise by three orders than those obtained by hitherto two-way RARR methods. Because neither Rstar nor Vstar have orbit and active attitude control, the longest arc of orbits are analyzed to produce the highest sensitivity for the lower degrees of lunar gravity coefficients [3].

2.2. RSAT: Relay Satellite Transponder

The orbit of SELENE Main Orbiter above the lunar far side will be directly determined by the four-way Doppler measurements relayed by Rstar [2]. The orbit of Rstar will be simultaneously measured by two-way RARR method. Figure 1 (left) shows the mission concept of the four-way Doppler measurements using RSAT, the Relay Satellite Transponder. RSAT-1 and RSAT-2 will be installed on Rstar and Main Orbiter, respectively.

RSAT-1 receives ranging signals of S-band from 64-m antenna at Usuda Deep Space Center (UDSC) and returns the signals to UDSC to produce two-way RARR measurements. RSAT-1 relays the carrier signals to RSAT-2 at Main Orbiter above the lunar far side simultaneously.

RSAT-2 receives carriers and returns to RSAT-1. RSAT-1 receives those, converts the frequency to X-band, and transmits the carrier signals to UDSC to produce four-way Doppler measurements. Signal frequencies of these loops will be coherently converted. Four-way Doppler measurements derive the first direct orbit determination of low lunar orbiter above the lunar far side, which produce the first global gravity map of the moon. Analysis of the coverage considering the four-way links shows that our method derives fully covered gravity map [5].

3. Design of the System

3.1. Outline of Rstar and Vstar System Design

Communications toward ground stations will be linked by an S/X-band coaxial vertical dipole antenna with a toroidal beam of about 40 degrees width at Rstar and Vstar. Communications toward Main Orbiter will be linked by two pairs of S-band patch omni-directional antennas with a conical beam of about 140 degrees width at Rstar.

Rstar and Vstar are designed to be light-weight enough and cost-effective to conduct selenodesy experiments. Size of each main body is 1m x 1m x 0.65m which is determined by the size of the highly efficient silicone cell solar array to supply the demanded electric power of 70W. There are no orbital and attitude control except spin stabilization on these satellites to lighten the mass. The separation velocity and the spin will be injected by the simple structure and light weight release mechanism which has been developed for Rstar and Vstar [6]. The mass distribution of both Rstar and Vstar are adjusted to be the same, and the total masses of these satellites are designed to be 45 kg.

3.2. Spin and Attitude Properties of Rstar and Vstar

Spin stabilization without orbital and attitude control maneuver is useful to obtain longer arcs of orbit, which is effective to detect orbit turbulence perturbed by lunar gravity. The spin and attitude properties are, however, affected by the characteristics of the separation of Rstar and Vstar from Main Orbiter. These properties were measured by ground tests of the release mechanism using the terrestrial gravity cancel mechanism. The full width of the nutation caused by the tip off at the separation is reported to be 11.4 deg in the maximum [7]. The nutation is also caused by the slant of the inertia axis against the mechanical axis of Rstar and Vstar. The measurement of the momentum of inertia and the product of inertia using the mechanical test model of Rstar and Vstar reported that the full width of the nutation caused by the slant is less than 6 deg [7]. The allocated values of each attitude fluctuation factor derived by the attitude analysis suggest that the nutation caused by the tip off at the separation and the slant of the inertia axis is larger than the inclination caused by the torque of the solar radiation pressure and the gravity field inclination.

4. Summary

SELENE Relay Satellite (Rstar) and VLBI Radio Satellite (Vstar), which will be used for the differential VLBI observations and the four-way Doppler measurements for selenodesy, have been designed. These sub-satellites are requested to have long arcs of orbit without maneuver, therefore, spin stabilization is adopted to avoid active attitude control. We have designed the simple structure and light weight release mechanism, and measured the release properties by ground tests to estimate the nutation angle caused by the tip off at the separation. We also measured the momentum and product of inertia of Rstar and Vstar mechanical test model to estimate the nutaion angle caused by the slant of the inertia axis.

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