MUSES-B Satellite System for VSOP

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Abstract. The ISAS’s satellite MUSES-B for conducting VLBI observations from space is described. The satellite carries a deployable antenna with an aperture diameter of 8 m and operates as an orbiting radio telescope. The satellite system design was almost completed in the summer 1993 and the hardware manufacturing is starting. The satellite will be launched in the summer 1996 by the ISAS’s M-V rocket.

1. Introduction

The Institute of Space and Astronautical Science (ISAS) is developing a satellite named MUSES-B, a satellite for conducting VLBI observations from space. The VLBI observation program is called VSOP, which is the abbreviation of the VLBI Space Observatory Programme. The development of MUSES-B started in 1989 (HIROSAWA, 1991), and is now in the second year of the three-year flight model (FM) development phase. Since the start of the program, substantial progresses have been made in the developments of the key technologies necessary for space VLBI. This paper describes the design of the MUSES-B satellite and the present (September 1993) status of the satellite development.

2. Satellite System

MUSES, which stands for Mu Space Engineering Satellite, is the name of the engineering satellite series of ISAS. The satellite for VSOP has been given the name MUSES because a large number of new technological developments are required to realize a satellite for space VLBI.

MUSES-B is going to be launched on the first flight of the ISAS’s new rocket, M-V. The development of M-V started in 1990 and is under progress. Based on the expected capability of M-V, we have selected an orbit for the satellite with an apogee height of about 20,000 km, a perigee height of about 1,000 km and an inclination angle of 31 degrees, giving a mass constraint to the satellite of 800 kg.

The satellite is designed such that it can operate as a radio telescope on orbit, forming a VLBI network in cooperation with ground radio-telescopes over the world. Figure 1 shows the configuration (external view) of the satellite in orbit.

In the following we describe the key elements of the satellite system in the final satellite design that we have reached after detailed design studies, experiments,
trade-off and international interactions in the three-year proto-type model (PM) development phase and in the FM phase until today.

2.1 Large deployable antenna

An antenna with a substantial size is an essential element of the space VLBI satellite. Development of a large deployable antenna is one of the most important subjects of the MUSES-B program.

As seen in Fig. 1, MUSES-B carries a large dish antenna deployed on orbit. The main reflector of the antenna is formed of wires and meshes, supported by six extendible masts. Wires form a complex network following the wire-tension-truss concept developed by Miura (1986). The sub-reflector supporting structure is also extended in orbit. The effective aperture diameter of the antenna is 8 m and the maximum structural diameter is 10 m. The focus length is 3.7 m. The frequency bands of the antenna are 1.6, 5 and 22 GHz.

There are many engineering challenges in the development of this antenna (Natori et al., 1993), and among them, the most important ones are:
- Reliable deployment of the main dish.
- Realization of a highly-accurate reflector surface at 0 G, while it must be formed (tuned) on the ground under 1 G environment.

On the former, we have already derived a reliable deployment mechanism
through a hardware model experiment. On the latter, theoretical studies and simulations on the gravity compensation procedure are in progress. We will apply the procedure when the flight hardware is completed.

2.2 Onboard radio astronomy system

The onboard radio astronomy system is composed of: low noise amplifiers (LNA) at 1.6, 5 and 22 GHz (single LNA at each band, no cooling), down converters for the three frequency bands, an intermediate frequency signal switch, two frequency synthesizers, two image rejection mixers, two A/D converters, a formatter, and calibration signal generators. The base-band channel is formed of two parallel circuits, each of which operates in two modes: 16 MHz bandwidth and 2 bits sampling, or 32 MHz bandwidth and 1 bit sampling. The bit rate of the output signal of the formatter becomes 128 Mbps in each mode. The details of the onboard radio astronomy system and its development status are presented by Hirabayashi et al. (1993).

We add a comment here on cooling of LNA: We studied to cool the 22 GHz LNA by using a Stirling cycle cooler in the PM phase (HiroSAWA, 1991), but did not include the cooling in the final design. The reason was to avoid complexities that the cooling could give to the total satellite system implementation, and for satellite mass reduction.

2.3 Science data transmission and phase transfer

We are sending science data and phase transfer signal by Ku-bands. The high bit rate of the science data and effects of the ionosphere in the phase transfer have led us to use Ku-band instead of using X- or longer-wavelength bands. We have proposed to use 14.2 GHz for the science data transmission and 15.3 GHz for the phase transfer to the Telecommunications Bureau, the Ministry of Posts and Telecommunications, Japan. We also got an approval from SFCG (Space Frequency Coordination Group) on transmitting the phase transfer signal with no modulation at 15.3 GHz to avoid possible coherency degradation due to spectrum spreading.

The onboard equipments are composed of: a QPSK modulator, a Ku-band transmitter, a Ku-band steerable parabolic antenna with a diameter of 45 cm, a diplexer, a Ku-band receiver, a local signal generator and a reference signal distributor. The Ku-band antenna is attached to a deployable boom to increase the field of view of the antenna. The Ku-band antenna tracks the ground station autonomously using orbit prediction data stored on the satellite and satellite attitude data supplied from the onboard attitude control system.

The ground link stations making the Ku-band telecommunications with MUSES-B will be the ISAS’ s Usuda station, NASA DSN stations at Goldstone, Canberra and Madrid, and the NRAO’s Greenbank station.

2.4 Attitude and orbit control

The attitude and orbit control system has three functions:
- Antenna pointing and re-targeting maneuver.
- Safe-hold control.
- Attitude and orbit controls in the initial phase.

The goal of the accuracy of the antenna pointing is 0.01 deg (the accuracy necessary for 22 GHz observations using 8 m diameter antenna). A large solar pressure, complex thermal effects, and flexibility of structures are the main factors that have been considered in the control system design.

Figure 2 shows the block diagram of the control system. The system consists of the Attitude and Orbit Control Electronics (AOCE), the Attitude and Orbit Control Processor (AOCP), four 6 Nms reaction wheels (RW), magnetic torquers (MTQ) for unloading, two Star Trackers (STT), an Inertial Reference Unit (IRU) composed of mechanical gyroscopes, another IRU using an optical fiber gyroscope (IRU-F), a geomagnetic aspect sensor (GAS), six Sun Aspect Sensors (CSAS), accelerometers (ACM), and the Reaction Control System (RCS).

The RCS, consisting of eight 3N thrusters and four tanks, is mainly used for the orbit control in the initial orbit insertion phase.

2.5 Electric power system

The satellite has two solar paddles with a total area of 7 m². The generated power is about 700 W after one year on the orbit. The power system contains two sets of Ni-Cd batteries. The capacity of a single Ni-Cd cell is 28 AH, and each set consists of 16 cells connected in series.

2.6 Telemetry, command and data handling

The standard S-band telemetry and command system of the ISAS’s science satellite is used. Since all the science data is transmitted through the Ku-band link
in real time, the satellite has only a small onboard memory mainly for recording satellite health check data.

2.7 Structure

The satellite main body is box-shaped with a size of 150 cm (L) × 150 cm (W) × 100 cm (H). Inside the body contained is a cylindrical thrust tube, which works as a load path between the large dish antenna and the rocket.

2.8 Orbit determination

The satellite orbit must be known accurately for correlating the science data obtained by the satellite with the data obtained by the ground telescopes. We are making orbit determination using Doppler data from the Ku band links, together with Doppler and range data obtained from the S band links. Besides, we are conducting an onboard orbit-determination experiment using GPS.

3. Present Status of Satellite Development

The outline of the MUSES-B satellite system has been described in the previous chapter. Having finished the design and trade-off studies, we are now proceeding to manufacturing of the flight hardware.

Figure 3 shows the time schedule of the MUSES-B development. As already mentioned, the satellite development is now in the second year of the FM phase. We conducted the structural model test in February and the thermal model test from July to August this year (1993). Manufacturing of the satellite is just starting and will continue until the end of March 1994. After it, the interface tests and the subsystem
Table 1. Satellite mass estimate (June 1993).  

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio-Astronomy Payload and Ku-band Communication</td>
<td>62.8 kg</td>
</tr>
<tr>
<td>Deployable Antenna</td>
<td>246.5</td>
</tr>
<tr>
<td>GPS Receiver</td>
<td>7.8</td>
</tr>
<tr>
<td>Electric Power</td>
<td>121.5</td>
</tr>
<tr>
<td>S-band Communication</td>
<td>8.4</td>
</tr>
<tr>
<td>Command and Data Processing</td>
<td>15.7</td>
</tr>
<tr>
<td>Attitude and Orbit Control</td>
<td>77.8</td>
</tr>
<tr>
<td>Reaction Control System (RCS)</td>
<td>30.0</td>
</tr>
<tr>
<td>Launch Operation</td>
<td>8.0</td>
</tr>
<tr>
<td>Thermal Control</td>
<td>26.7</td>
</tr>
<tr>
<td>Structure</td>
<td>107.2</td>
</tr>
<tr>
<td>Wire Harness and Others</td>
<td>45.0</td>
</tr>
<tr>
<td>RCS Propellant</td>
<td>62.0</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>819.4 kg</strong></td>
</tr>
</tbody>
</table>

Final tests follow. The construction and tests of the large deployable antenna take a longer time and will finish in March 1995. The final integration and the system test of the satellite start around November 1995. The satellite will be launched in the summer 1996.

Table 1 shows the satellite mass estimate at June 1993. There is an excess of 19.4 kg (about 2.3%) from the goal (800 kg), and continuous efforts on weight reduction are required. Note that the mass of the deployable antenna is exactly 30% of the present total mass.

In parallel with the development of the satellite, we have started development of the satellite operation system and software.

4. Summary

The design and development status of the MUSES-B satellite have been described. The satellite will be launched in the summer 1996 and be operated for the VSOP under international cooperation. The nominal design life of the ISAS’s science satellites is one year, but most of the satellites have lived longer than the nominal life. The solar cells and batteries in the power system of MUSES-B are designed expecting three year operation.

At the end, we wish to thank to the contractors who are contributing to the development of MUSES-B: NEC Corp. (Satellite system design, attitude control, electric power system, TT&C communications, thermal control, structures, 5 and 22 GHz LNA’s, on-board radio astronomy system, and Ku-band telecommunications), Mitsubishi Electric Corp. (Large deployable antenna), Japan Aircraft MFG Co. (Extendible masts of the large antenna), Mitsubishi Heavy Industry (Reaction control system), Toshiba Corp. (GPS receiver and CSAS), Nihon Tsushinki Co. (1.6 GHz LNA), Mitsubishi Precision Co. (Reaction wheels), Japan Aviation Electronics Industry (IRU), Meisei Electric Co. (GAS), Matsushita Communication Industrial Co. (House keeping and timer), Sharp Corp. (Solar cells), Furukawa Battery Co. (Batteries), and Fujitsu Corp. (Orbit determination software).
REFERENCES


