

Development of the large and high accuracy deployable antenna for the VSOP-2 mission

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Abstract

We are developing the satellite for the space VLBI mission for radio astronomy, called VSOP-2[1,2]. Details of this mission will be presented in the papers in Commission J in this meeting. We need to make the satellite small enough to fit the nose fairing of the launcher, the M-V rocket developed by JAXA, and to make a large antenna to get enough sensitivity for radio astronomy. The on-board large deployable antenna, which will be used at a shortest wavelength of 7-mm, is one of the key parts of the spacecraft. We should make this large antenna light and small enough to fit the launcher and sufficiently reliable to use in space.

The VSOP-2 satellite has a 9-m antenna consisting of 7 hexagonal modules. The radial rib structure is newly adopted for the antenna modules to help to shape a surface accuracy as high as 0.4 mm-rms. We developed a new full scale test module for checking the concept of the radial rib surface module. We tested how to adjust the surface of the module, how to measure the surface, how the deployment mechanism works, and the mechanical interface while the module is folded for the launch. The surface of the module is formed of the mesh knitted by the gold-coated molybdenum wire. We confirmed we can use this mesh up to 43 GHz by making measurements of the reflection loss. We show the overall antenna system in this paper.

Introduction

In order to increase an order of magnitude in angular resolution and interferometer sensitivity in comparison to VSOP mission, VSOP-2 is required to have a large deployable reflector (LDR) with a diameter of 9 m and a with reflecting surface accuracy of 0.4 mm rms (figure 1). Generally, the choice of the deployment mechanisms and a segmented scheme for the reflecting surface is essential for the design of LDR's that are deployed in orbit. Since a HALCA type main reflector, consisting of a mesh shaped by tension-truss arrangement, is difficult to achieve a reflecting surface accuracy as high as 0.4 mm rms, further consideration and technical development was required and has been in progress over the last five years. We obtained a good

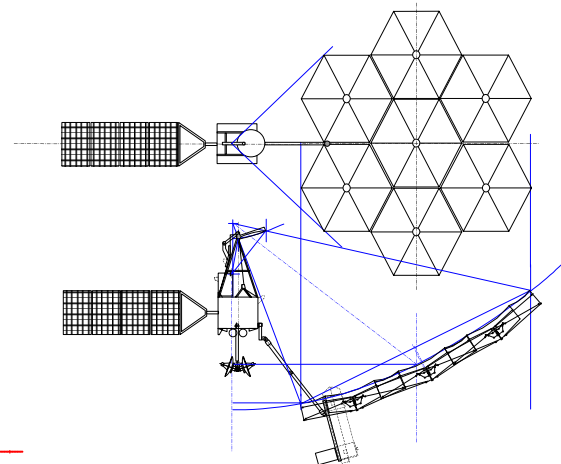


Figure 1 The VSOP-2 satellite in orbit configuration with 7 module 9.1 m LDR from 2 directions.

prospect to achieve reflecting surface accuracy of 0.4 mm with a mesh antenna shaped by segmented 7 small modules consisting of radial ribs and hoop cables (figure 2). The backup and deployment structure of the antenna are designed based on the ETS-VIII [3] antenna, which will be launched 2006.

Basic design

VSOP-2 planned to have an off-axis paraboloid antenna for the merits of large freedom of placement of main and sub reflectors and receiver feeds, small curvature of reflecting surface due to the long focal length, small limitation from sun angle because of the long separation between main reflector and satellite body itself, easy construction of interface between main reflector and satellite body, and so on. In order to achieve high surface accuracy, the LDR shaped by connecting small modules, with each module consisting of 42 radial ribs and 7 hoop cables [4]. As the LDR must be stowed in the launcher, the LDR is planned to be formed by 7 modules with each module diameter of 3.9 m, for a total aperture diameter is planned to be 9.10 m, with a focal length of 7.0 m. The diameter of sub reflector is planned to be 1.10 m and its focal length will be 1.88 m. The weight of main reflector will be 145 kg, and that of sub reflector will be 7 kg. Then, the weight of antenna whole structure (including boom etc.) will be 188 kg, and it will be 69 kg lighter than that of HALCA (257 kg). In addition, VSOP-2 will have in-orbit alignment adjusting mechanism with three degrees of freedom for main reflector and two degrees of freedom for sub reflector, while HALCA has no in-orbit alignment adjusting mechanism.

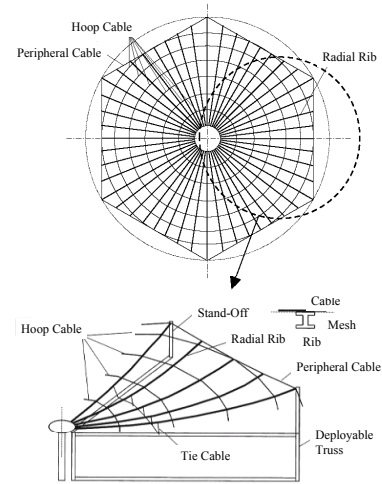


Figure 2 Structure of the module for the VSOP-2 LDR.

Shaping of reflecting surface

It was essential for VSOP-2 to develop and achieve an accurate enough reflecting surface module to make observations at 43 GHz, whereas the LDR of ETS VIII is designed to use in the 2 GHz band. In order to achieve a high surface accuracy with a mesh antenna, it is standard to divide the reflecting surface into small regions consisting of a tension-truss, and each module forms a part of ideal parabolic shape with high surface accuracy. The assembled structure also forms an ideal parabolic shape. The mesh is attached to this structure to make the reflecting surface, and achieve a high surface accuracy.

Instead of the complex cable network which is used for HALCA (VSOP satellite) and ETS-VIII, we developed a simple and highly accurate scheme in order to achieve high surface accuracy with simple adjustments. In the scheme, the reflecting surface consists of radial ribs and hoop cables, and the curvature of parabolic surface is formed using elastic deformation of radial ribs by adjusting the tie and hoop cables which affect to deformation of each rib, and the mesh is attached. With this scheme, we will be able to achieve high surface accuracy simply by adjustment of ties and most outer hoop cables.

Error budget for surface accuracy

The expected causes of error in the surface accuracy for radial ribs and hoop cable scheme are shown in table 1, with the magnitude of their estimated errors.

The error for facet itself ((1) and (2)) can be reduced to around 0.16 mm rms by employment of a small facet and shaping of radial ribs and hoop cables. With detailed analysis and evaluation of the test model, we have a prospect to reduce the error for the surface accuracy of each module (3) to less than 0.2 mm rms. Error from assembling modules (4) can be expected to be 0.2 mm rms based on achievement of LDR of ETS-VIII. Compensation of zero gravity (5) will be achieved with detailed analysis and adjustments. For the reproducibility of deployment (6), high accuracy of less than 0.16 mm rms can be achieved by minimizing flexibility of the linking hinge and using of pre-loaded springs for deployment. The effect of hygroscopic deformation of material (7) will be small, since interference between truss and reflecting surface will be low with this design. And it can be reduced to less than 0.1 mm rms by incorporating the expected deformation into design. The attitude variation (8) and the thermal deformation (9) also can be

reduced to less than 0.1 mm rms with development of materials that have low linear expansion coefficients. Totally, we have a good prospect to achieve 0.4 mm rms for surface accuracy at present, which is sufficient for observation at 43 GHz.

Table 1 Summary of expected error of surface accuracy

Causes	Budget (mm rms)	Improvements
(1) Linear approximation of each facet	-----	employment of small size facet, shaping of radial ribs
(2) deformation of each facet	0.16	using of small size facet
(3) surface accuracy of each module	0.20	adjustment with stand off
(4) assembling modules	0.20	adjustment under +/- 1 G
(5) compensation of zero gravity	0.00	wobbly of link hinge and using of pre-load spring
(6) reproducibility of deployment	0.16	analytical compensation, improvement of material
(7) hygroscopic deformation	0.10	attitude control, limitation for operation
(8) attitude variation (short term)	0.10	reduce interaction with reflecting surface
(9) thermal deformation (long term)	0.10	improvement of material
Total	0.40 (rms sum)	

Developments for effective reflector

Development of test module

Based on the half size model developed in 2001 and analytical studies with numerical simulations, we developed one module of the LDR as test module and evaluated prospects to achieve enough surface accuracy (figure 3). The test module size is relatively larger than that of the planned flight model's module, as the diameter of the test model is 4.8 m, while that of the planned flight model's module is 3.9 m.

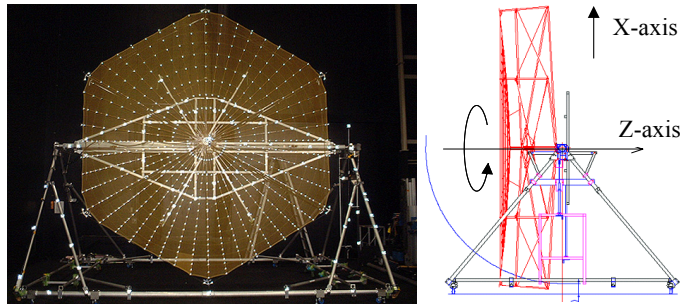


Figure 3 Measurement of the test module of the LDR

Also the test model consists of 48 radial ribs and 8 hoop cables, while that of the planned flight model's module is consisted of 42 radial ribs and 7 hoop cables. In addition, the result of analytical studies for test module shows that surface accuracy less than 0.118 mm rms can be achievable.

An adjustment error of 0.35 mm rms is now achieved with several adjustment process, and we obtained a good prospects to achieve a surface accuracy of 0.2 mm rms with more adjustment process. In addition, we obtained knowledge about the width and thickness of the radial ribs, affects for adjustment sensitivity by positioning of tie and hoop cables, adjustment method under gravity.

Mesh for the reflecting surface

Considering electric characteristics, fineness of mesh and elasticity in each direction, we chose a single satin stitch with 28 gauge per inch of a gold-coated molybdenum wire as a candidate. The mesh of single satin stitch is prominent, since it dose not have particular direction for the elasticity (i.e. the elasticity of direction is uniform). We measured the transmission and reflection coefficients from 18 to 110 GHz. Reflection loss and transmission loss are -0.2 dB, and -18 dB, respectively at 22 GHz, and they are -0.6 dB and -18 dB, respectively at 43 GHz. These coefficient at 86 GHz are -1.2 dB and -11 dB, respectively. Assuming expected antenna efficiency with expected surface accuracy, it would be 50 % at 43 GHz.

Alignment adjusting mechanism

Alignment adjusting mechanism for the optics of the main and sub reflectors will be installed to achieve high efficiency antenna in orbit. Using this mechanism, maximum gain can be obtained by adjustment of alignment using radio sources, even if misalignment due to vibration during the launch occurred.

We plan to have alignment adjusting mechanism (AAM) on the back side of sub reflector and a focus and alignment adjusting mechanism (FAAM) on the edge of the boom at main reflector side, that connects main reflector and satellite body itself. The AAM has two degrees of freedom to adjust the alignment of 2 angles. On the other hand, the FAAM have three degrees of freedom, which add the function of adjusting

the focal length to the function of the AAM. The AAM will be used for the ETS-VIII satellite, and FAAM will be manufactured with similar design as AAM.

Deployment mechanism

In the case of HALCA's center-fed main reflector, extensible masts are required to have enough strength to suspend complex network of tension-truss cables. Therefore, it is difficult to reduce the weight of reflector and achieve a surface accuracy of 0.4 mm rms. We chose the deployment mechanism of LDR of ETS-VIII, which can reduce the weight of reflector, and its reliability of deployment from stored state to deployed state is confirmed by tests using flight model consisting of 14 modules. The LDR of ETS-VIII consists of 14 hexagonal modules, has a deployment truss structure which is similar to an automatic single push button type umbrella.

The modules of VSOP-2 are connected to each other with six links. Deployment of each module is achieved by driving the links results of releasing of springs installed center of modules, like an automatic single push button type umbrella. Deployment speed of each module is controlled by motors, and deployment speeds between modules are synchronized. The motor is installed only three modules, while the springs for deployment are installed to all modules. Based on experience of deployment test of ETS-VIII, it takes 60 \pm 10 minutes for deployment of reflector, and 10 \pm 1 minutes for deployment of the boom. Deployment time for reflector of VSOP-2 can be shortened to 30 min since LDR of VSOP-2 consists of only 7 modules. On the other hand, deployment time for the boom will not be short since a large mass has to move and latch and the time depends on the mass ratio between satellite body and reflector.

Using a proto test module, we evaluate the stored state and deployed state of proto test module. We show the stored and deployed state of proto test module in figure 4. As is the same to LDR of ETS-VIII, LDR of VSOP-2 are stored with under the condition of radial ribs extending from the connecting point to the module center. Standing radial ribs are supported by brackets on the backup structures, and launched in a stable state. We found that module can be easily stored under the “cup down” state, since the shortest ribs gather to the center surrounded by increasingly longer ribs. The folded mesh is stored between ribs. Additional knowledge for storing LDR, such as size of brackets and material of brackets, has also been obtained.

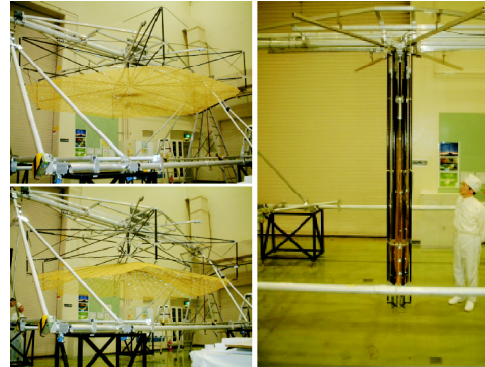


Figure 4 Storage of a single module of LDR

Conclusions

We are now developing the 9-m, high accuracy LDR for the VSOP-2 mission. We have already developed how to adjust the surface of module. We are also studying the additional issues about the LDR, such as the natural frequency of the LDR for the attitude control system, the production of the ribs, better material of the mesh of the surface, and we confident we can manufacture the VSOP-2 LDR as expected.

References

- [1] H. Hirabayashi, et al. “The VSOP-2 Project: A Second Generation Space-VLBI Mission Ranging to mm-Wavelengths,” in *Optical, Infrared, and Millimeter Space Telescopes*, J.C. Mather, Ed. Proc. SPIE, 5487, 1646–1656, 2004.
- [2] H. Hirabayashi, et al. “On the Near-term Space VLBI Mission VSOP-2,” in *Proc. 7th EVN Symposium*, Eds. R. Bachiller, F. Colomer, J.-F.; Desmurs, and P. de Vicente, p.285–288, 2004.
- [3] K. Sintate et al. “3.3 Laege Deployable Reflector (LDR)”, in *Journal of Journal of the National Institute of Information and Communications Technology Vol.50 Nos.3/4* p.33-39, 2003
- [4] M.C. Natori et al. “Modular Antenna Concept Consisted of Radial Ribs and Hoop Cables for Space VLBI Mission”, in *25th ESA Antenna Workshop on Satellite Antenna Technology*, ESA/ESTEC, Noordwijk, The Netherlands, Sept. 2002