# CHARACTERISTICS OF THE LARGE DEPLOYABLE ANTENNA ABOARD HALCA IN-ORBIT

[1)]Shinji KURODA, [1)]Masanori KATAOKA, [1)]Tadashi TAKANO,
[2)]Hideyuki KOBAYASHI and [2)]Noriyuki KAWAGUCHI

[1)]Institute of Space and Astronautical Science
3-1-1 Yoshinodai, Sagamihara 229-8510 Japan
[2)]National Astronomical Observatory
2-21-1 Osawa, Mitaka 181-8588 Japan

E-mail : kuroda@radionet.isas.ac.jp

## 1 Introduction

Halca was proposed and developed in Institute of Space and Astronautical Science (ISAS) for the VLBI Space Observatory Programme (VSOP). It was launched on 12 February 1997, and placed in the orbit with 31-degree inclination to the Earth's equator with an apogee of 21,400 km from the Earth's surface and a perigee of 560 km, respectively. The antenna was fully deployed on 28 February 1997[1].

The radiation characteristics before the launch were not actually measured in the far field nor in the near field[2]. In order to verify the deployed state and design validity, it is necessary to measure the characteristics in orbit. In this paper, we propose the antenna measurement method using radiostars and a geostationary satellite as radiowave sources, and describe the measurement results in these method.

## 2 Constitution of the Antenna

The deployable antenna on Halca mainly consists of the main reflectors with an effective diameter of 8m (maximum diameter 10m), hexagonal subreflector inscribed in a 1.1m-diameter circle, and 2.5m-long feed horn (Fig.1). The main reflector is composed of six extensible masts, cables and reflecting mesh. Cables are tensioned by the masts to form 144 triangular trusses which approximate a parabolic surface[2]. Even if several wires of the cables or meshes are broken, the antenna keeps parabolic shape.

Before launch, the reflector shape in the orbit is simulated by next method; the reflector shape in zero-gravity is estimated on the basis of a mathematical model which is tuned up in 1-G environment. The reflector accuracy is expected to reach to $0.57\mathrm{mm}_{\mathrm{rms}}$ without the thermal deformation[3]. The effect of the thermal deformation caused by sun light is able to be measured only after launch.

Next, we explain the summary of the Halca's observation system. Halca's system is designed for receive-only. Frequency band widths for observation are 1.60 to 1.73 GHz (L-band), 4.7 to 5.0 GHz (C-band) and 22.0 to 22.3 GHz (Ka-band), which are the radioastronomy bands. The received signals are amplified by a low noise amplifier (LNA) and down-converted to intermediate frequencies, and furthermore down-converted to video frequencies. After down-converting, the signals are sampled with 64MHz/32MHz high-speed samplers. These sampled signals are transmitted at 14.2 GHz (Ku-band) to the Usuda Deep Space Center (UDSC).

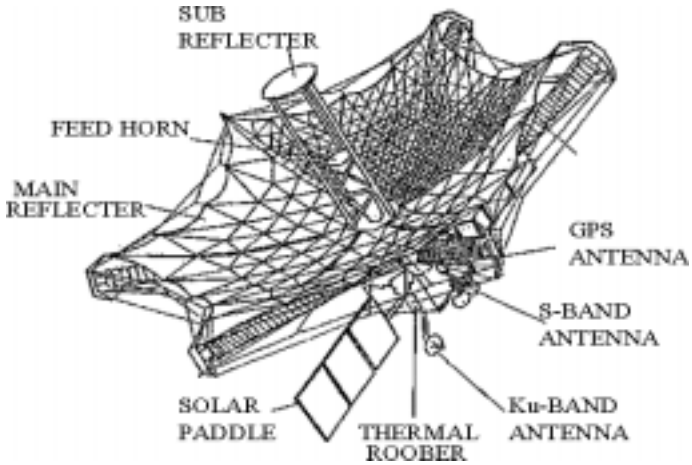

Figure 1: Halca satellite

## 3 Measurement Using Radio Stars

The pointing of the Halca antenna was measured using strong compact radio sources, Cyg-A, Cas-A, and Tau-A as continuum sources and Orion-KLburst $H_2O$ masers for Ka-band with the cross scan method. The aperture efficiency is obtained to 0.1 percent at 22GHz, 35 percent at 5GHz, and 25 percent at 1.6GHz[4]. The data in Ka-band (22GHz) is not reliable because of too weak reception level. Before launch, antenna efficiency was estimated including the measured data of surface roughness and others. Those data are listed in Table 1. The difference of the two values shows the gain degradation in orbit from the estimated gain. At 1.6GHz and 5GHz, the expected aperture efficiency is 37 percent and 53 percent respectively[3]. So possibly 1.7dB and 1.8dB losses at 1.6GHz and 5GHz are caused by some reason. If we assume the additional loss is caused by the degradation of the surface roughness of the main reflector, the loss can be converted to the equivalent surface roughness $\varepsilon$ using the Ruze's formula[5];

$$L = e^{-(\frac{4\pi\varepsilon}{\lambda})^2} \tag{1}$$

The results are added to Table 1, and do not show good coincidence in L- and C-bands. Therefore, it may be concluded that the additional loss is caused by other reasons rather than the surface degradation of the main reflector. But if the surface error is not random but systematic, we can not exclude the possibility of the main reflector degradation.

Next, we refer to the system noise temperature ($T_{sys}$) was measured by the radiowave emission from the Earth and dark space.

In Fig.2, the time profiles of $T_{sys}$ in C- and Ka-bands are shown as the Earth passed through the main beam of the satellite[4]. At C-band the $T_{sys}$ increases during 0.7 to 1.3 hour indicating the Earth's disc. The lower temperature of 100K corresponds to the dark space and LNA noises, and the higher temperature of 300K to the Earth and the LNA noises. Because the effective temperature of the Earth is 100K for the ocean area and 200K for the ground area, the loss of the antenna feed at C-band must be about 0dB. From this result, the additional loss in the Table.1 is thought to be almost from the degradation of aperture efficiency.

At Ka-band, the $T_{sys}$ is high at 400K almost anytime, or regard to the Earth's disc. As the noise factor of the LNA corresponds to 200K according to the ground test, another noise of 200K seems to be added to the LNA without regard to the antenna. Looking carefully, a small hump of 5K can be recognized during the passage in the Earth's disc.

Now, we are investigating the relationship among the added noise of 200K, the small hump of 5K and the antenna efficiency of 0.1 percent assuming several system models.

Table1. Measured and estimated antenna efficiencies and additional loss

| | L-band | C-band | Ka-band |
|---|---|---|---|
| Estimated Efficiency[2] | 37% | 53% | 40% |
| Measured Efficiency[4] | 25% | 35% | 0.1% |
| Additional Loss | -1.7dB | -1.8dB | -26dB |
| Equivalent Surface Roughness | 9.3mm | 3.0mm | 2.7mm |

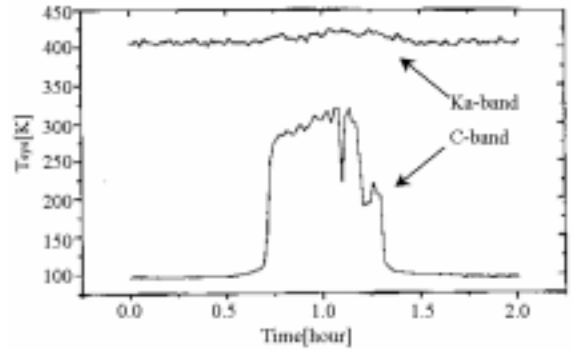


Figure 2. Time profile of system noise of Ka-band and C-band

## 4 Measurement Using Himawari Wave Source

The characteristics of Halca's antenna in orbit is measured using a radiowave from Himawari satellite, which the measurement system is shown in Fig.3. Himawari is located in the GEO about 36,000km from the Earth's surface, and it's orbital revolution period is about 24 hours. Halca's attitude is fixed in a inertial frame during measurement. As Halca goes around, the angle $\Delta\theta$ between the antenna boresight and the Himawari direction changes. The antenna pattern is obtained by measuring the signal level of reception from Himawari, and using the following Friis's equation;

$$P_r = P_t + (G_t - \Delta G_t) + (G_r - \Delta G_r) + L[\mathrm{dB}], \tag{2}$$

where $P_r$ and $G_r$ mean the receiving beam-power and gain of the Halca antenna respectively, and $P_t$ and $G_t$ mean the transmitting beam-power and gain of the Himawari antenna, respectively. $\Delta G$ is the gain reduction due to offset from the boresight, $L$ is a free space loss given by $(\lambda/4\pi r)^2$, and $r$ is a distance between Halca and Himawari.

For performing an actual measurement, there are the following requirements which must be fulfilled;

1. Halca should be seen from UDSC 10m-antenna which receives Halca's observation data.
2. Halca should pass near the center of the beam from Himawari.
3. The sun should be located in limited directions in relation to Halca's z-axis.

Considering those requirements, we chose the day, 13 May 1998 for measurement.

The far field pattern can be obtained by subtracting the free space loss and the reduction of Himawari's transmission antenna gain from the measured data. Because the free space loss and the reduction of transmission gain can be calculated from the orbital parameters of both satellite, the far field radiation pattern of Halca antenna in orbit is obtained as shown in Fig.4. This pattern consists of 3 parts. The first is obtained from the VLBI correlator data. Correlator data is processed from auto-correlation function of the measurement data. Low level part of the pattern, from -4 to 14dB becomes clear by the correlator data. The second is obtained from the on-board data of an amplifier detector on the sampler and formatter (SSF). The on-board data reveal the medium level part of the pattern, from 13.5 to 17.5dB. The sidelobes are clearly shown using two kinds of data in Fig.4.

The third data are obtained by extrapolating the SSF data. The objection is to extend the dynamic range of the receiver system, and to estimate the shape of the main lobe and eventually the maximum gain of the pattern. The number of the adopted data is depicted in the figure. The main lobe shape is optimized to the data using the least square method. At the peak of the main lobe, the gain is about 30.5dBi and the probable error bar is ±1dB. The gain obtained

from Himawari wavesource is about 8dB lower than the estimated gain of 38.7dBi. One factor for this loss is that the boresight direction of Halca is several degrees offset from the direction of Himawari. The minimum angle between the boresight and Himawari direction from Halca was estimated about 0.5 degree from orbit analysis. The pointing error angle corresponds to 3.4dB from the antenna pattern obtained from the experiment on the ground. The other factor is the L-band efficiency degradation of 1.7dB obtained from Table.1[4].

Although considering these two losses, there is still unknown loss of about 3dB. The probable reason for this loss is that the main lobe is now estimated from too narrow fitting region. If the fitting region becomes more spread, the gain of main-lobe may be approach to the estimated value of 33.6dB.

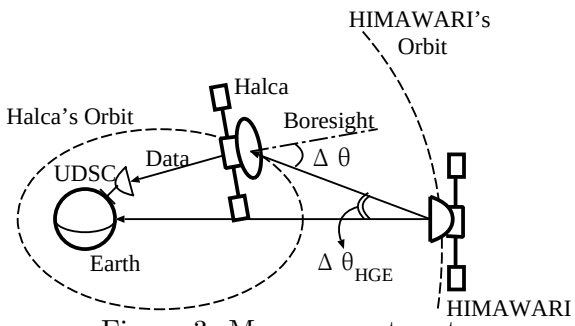

Figure 3. Measurement system

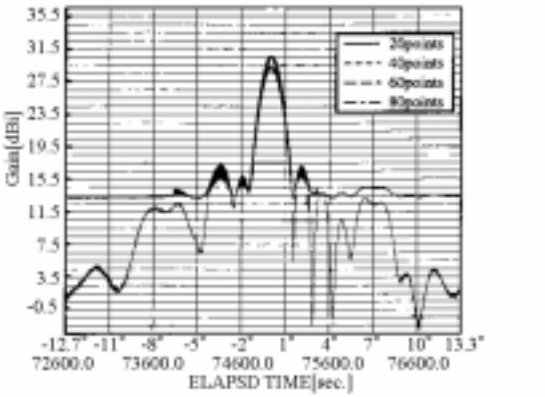

Figure 4. Antenna radiation pattern (far-field)

## 5 Conclusion

The antenna aperture efficiencies at L- and C-bands are measured using radiostars and obtained to the 25 percent, 35 percent, respectively. This result shows that unknown losses around 1.7dB and 1.8dB are exist at L- and C-bands. From this results, the maximum antenna gain of L- and C-bands calculated to 37.6dB and 39.1dB, respectively. The $T_{sys}$ measurement shows the antenna feed loss almost 0dB at C-bands. At Ka-band, the obtained results are now being investigated quantitatively.

Halca antenna's radiation pattern was also obtained using Himawari satellite as a radiowave source. The result clearly showed radiation patterns even of higher sidelobes at L-bands.

For more accurate analysis, the relationship between the reflector deformation and the characteristics degradation is planned to be simulated.

## Acknowledgment

The authors wish to thank Mr. Ota and staffs of Japan Meteorogical Agency, and Prof. Hirosawa, Prof. Hirabayashi and the members of V.S.O.P group.

## References

[1] H. Hirabayashi et al., "Overview and Initial Results of the Very Long Baseline Interferometry Space Observatory Programme", Science, Vol.281, 18. Sep. 1998.

[2] T. Takano, M.Natori and K.Miyoshi, "Characteristics Verification of a Deployable On-board Antenna of 10m Maximum diameter", 48th Congress of I.A.F., IAF-97-U.2.04, Oct. 1997.

[3] T. Takano, et. al., "Large Deployable Antenna with Cable Constitution for Satellite-Use", Trans. IEICE, Vol. J81-B-II, No.7, pp. 673 - 682, 1998 (in Japanese).

[4] H. Kobayashi, et. al., "HALCA onboard VLBI observing system performance", 32nd COSPAR, E.1.3-0002, Jul. 1998.

[5] J. Ruze, "Antenna Tolerance Theory - A Review", Proc. IEEE, Vol. 54, No.4, pp. 633 - 640, 1966.

[6] M. Kataoka, et. al., "Measurement of a Large Antenna on HALCA using a Radiowave from Himawari", Proc. of 1998 IEICE Spring Conf., B-1-186,Sep. 1998 (in Japanese).