

Electrical Performance of the Large Deployable Reflector Antenna

Masaki SATOH, Teruaki ORIKASA, and Yoshiyuki FUJINO

ETS-VIII was equipped with the Large Deployable Reflector Antenna(LDRA) for land mobile communications. This paper describes the electrical performances of that antenna. We measured signal level of radio wave from LDR at some ground receiving stations. This result is daily variation of receiving level and precipitous variation during the satellite-eclipse. We considered this phenomenon was caused by thermal distortion of reflector. We made correct the antenna beam position and measured the receiving level for improvement of this variation.

1 Introduction

The Engineering Test Satellite VIII (hereinafter ETS-VIII) was developed by the Japan Aerospace Exploration Agency (JAXA), Nippon Telegraph and Telephone (NTT) and the National Institute of Information and Communications Technology (NICT). It carries a large deployable antenna with an electrical aperture size of 13-meter class (Large Deployable Reflector (LDR), with square wings of approximately $19 \text{ m} \times 17 \text{ m}$), for the purpose of mobile satellite communication experiments. The feeding system of this LDR is equipped with two kinds of Beam Forming Networks (BFN) from different approaches^[1]. The BFN developed by NICT employs the integrated direction control method^[2], a simplified form of direction control method, while the one developed by NTT realizes the independent control of all beams with high integration by large-scale MMIC technology^[3]. In the experiment, we obtained the data that used a BFN for transmission and carried out an electrical characteristics evaluation, although the satellite was equipped with LDR and BFN for transmission and reception, the BFN for reception was not available due to trouble with the low noise amplifier of the receiving system of ETS-VIII. In the following, we will explain the evaluation results^{[4][5]}.

Since the antenna beam width of the large deployable antenna is narrow, it is necessary to accurately arrange several multi-beams at intended service areas. In the experiment, we allocated five nominal multi-beams across the country and observed their beam patterns in order to verify the electrical characteristics of this large deployable antenna in orbit. Consequently, certain changes were

observed at the reception level at ground stations, which were presumably caused by thermal distortion of the large antenna's reflectors. Also, we compensated beams using the electrical beam shifting function of the power feeding section and reduced the variation width of reception levels at earth stations.

2 Multi-beam formation

In order to form multi-beams, ETS-VIII uses the method of phased array (PA) feeding, in which 31 micro strip antennas (MSAs) are placed on positions that defocus the LDR from its focal surface to the reflector side in the feeding section. The PA feeding method can flexibly form beams by changing the excitation distribution of many equipped phase shifters and amplifiers, and ensure redundancy against failure of some elements and feeding systems because they are composed of many elements. The transmission system can mitigate any problem of power durability in feeding by spatial power combining that uses multi-elements.

On the other hand, it will be important to precisely control the excitation of the feeding array in order to secure the area gain (i.e. a minimum gain within intended areas) and beam isolation (i.e. a level ratio between the main lobe gain of a beam and the side lobe of another beam using the same frequency). In addition, unlike the direct radiation array, the directivity of the PA feeding method will usually deteriorate if a scan angle from a boresight increases. Here, we also evaluated the levels of the beam isolation and side lobes.

3 Verification of radiation patterns of large deployable antenna

3.1 Measurement method of radiation patterns

First, in order to verify the general characteristics of the large deployable antenna system, we measured the radiation patterns of transmission antenna. Figure 1 shows the locations of earth stations for the measurement of nominal beams and antenna patterns for mobile communication. We set up five beams as nominal beams for mobile communication: the Kyushu beam (beam1), the Shikoku beam (beam2), the Tokai beam (beam3), the Kanto beam (beam4) and the Tohoku beam (beam 5). JAXA and NICT jointly carried out measurements. They set up six receiving stations, in Kakuta City (JAXA), Kashima City, Yokosuka City, Akashi City, Kitakyushu City and Yamagawa-cho, Ibusuki City, across the country as shown in Fig. 1. The satellite attitude was scanned at those stations in order to obtain data required for the measurement of antenna patterns, and the beacon signals from ETS-VIII were received at each station at the same time.

The satellite scanning method employed here was, as

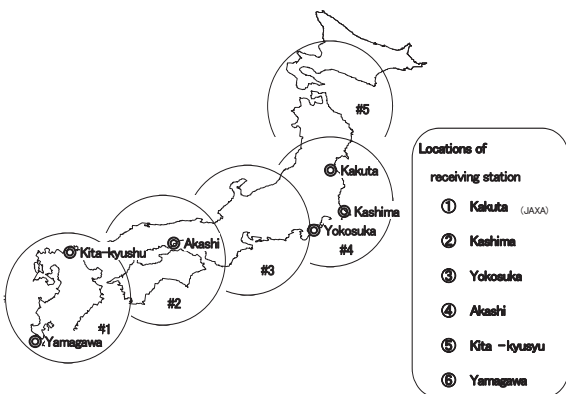


Fig. 1 Multi beams and grand stations

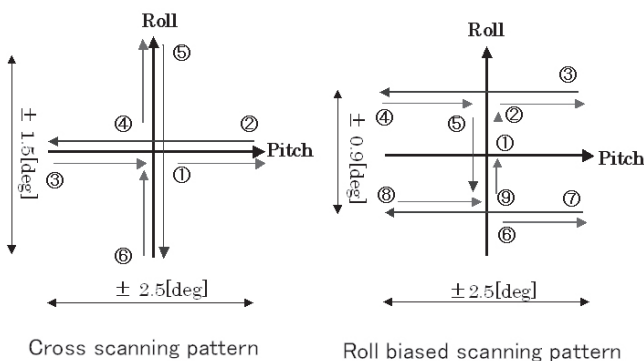


Fig. 2 Scanning pattern of Satellite attitude

shown in Fig. 2, to make the satellite rotate along the pitch axis (i.e. the beam moves in the east-west direction) and the roll axis (i.e. the beam moves in the north-south direction) in both cross and roll-biased manners (hereinafter referred to as cross and roll-biased scanning, respectively). The widths of cross scanning are $\pm 2.5^\circ$ and $\pm 1.5^\circ$ for the pitch and roll axes, respectively, while those of roll-biased scanning are $\pm 2.5^\circ$ and $\pm 0.9^\circ$. Also, we rotated the satellite at a low speed (0.004°/sec) so as not to distort the mirror surface of the large deployable antenna^[7]. By conducting cross and roll-biased scanning at the six stations across Japan, we can obtain the same data as can be obtained at measuring points as shown in Fig. 3. It is desirable that receiving stations are located at the same intervals both in latitude and longitude; therefore, this time we set up receiving stations within the facilities of JAXA and NICT so that they are as evenly distanced from each other as possible. Also, the signals from satellites to be received at the earth stations are beacon signals outputted from switching equipment mounted on satellites.

3.2 Evaluation of radiation patterns

We prepared a 3D contour figure of each beam by scanning the pitch axis (east-west direction) of the satellite attitude and measuring the two dimensional cut patterns of satellite antenna patterns at each station^{[8][9]}. Figure 4 shows an example of the cut patterns of Kyushu-beam (beam1) at Kitakyushu station. A comparison of the cut patterns calculated from the measurement data and the predicted mirror shape reveals that the peak reception level (i.e. boresight) in the former is located approximately 0.2° east of the latter. This difference was considered to be mainly

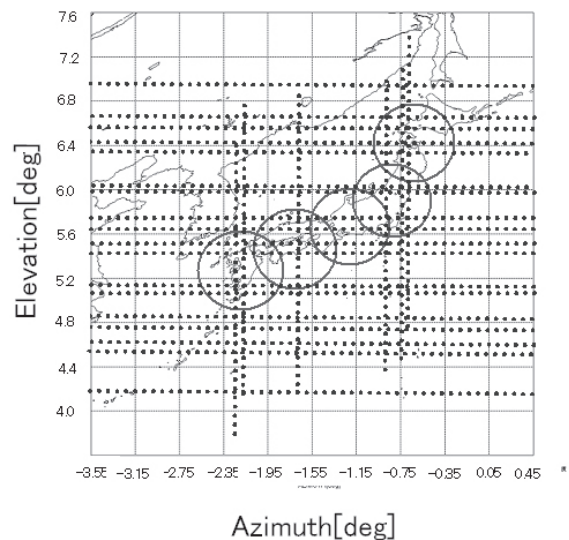


Fig. 3 All measurement points by satellite attitude scanning

due to the LDR's initial deployment and installation errors, and mirror distortion, however the installation error is considered to be small because the mirror shape was measured before launching the rocket, so the main reason is now considered to be thermal distortion of the LDR. In addition, a similar report has been made with the evaluation of BFNs developed by NTT^[5].

Also, Fig. 5 shows the contour figure of the Kyushu-beam prepared from the data gained at each measuring point shown in Fig. 3. Also from Fig. 5, we can see that the boresight (measurement) determined from the measurement data is located to the east of the one determined from the calculated value. However, the contour figure prepared from the measurement data shows minor strain compared with the one prepared from the calculated value, which is presumably due to the locations of the earth stations that were not evenly distanced from each other in terms of latitude and longitude.

3.3 Evaluation of side lobes for reusing frequencies

In terms of the transmission multi-beam as shown in Fig. 1, frequencies are to be reused within the groups of

beams 1 and 4, and of beams 2 and 5, respectively. Although it is difficult to accurately evaluate side lobes for the purpose of frequency reuse due to constraints such as the range of scanning satellite attitudes, and the number and locations of earth stations, we made a rough evaluation from the Az cut patterns of each station obtained in 3.2. Figure 6 shows examples of cut patterns obtained at Yamagawa station in Yamagawa-cho, Ibusuki, Kagoshima where the Kyushu-beam (beam1) was set up and at Kashima station, Kashima, Ibaraki, where the Kanto-beam (beam4) was set up. As for the side-lobe rejection areas filled in grey in Fig. 6, they represent the areas of frequency usage in the Kyushu area in relation to the cut pattern of the Kanto-beam and those in the Kanto area in relation to the cut pattern of the Kyushu-beam.

Although we designed the side lobe as a matter of beam formation targeting a value 20dB lower than the boresight^[10], the measured cut patterns in the side-lobe rejection areas in Fig. 6 were 20dB less for Kanto-beam and 15dB less for Kyusyu-beam than the peak values. Whereas we consider frequencies can be reused in the case of -15dB for side lobes, we are making efforts to optimize excitation distribution using the rotating element electric field vector method (REV method) because side lobes are expected to be reduced by means of further adjustment of excitation distribution of BFN^[11].

4 Verification of beam direction

4.1 Beam direction during eclipse time

Certain variations were observed in the reception level of beacon signals from ETS-VIII during eclipse time when the satellite passes into the earth's shadow; therefore, we conducted a correction experiment to investigate their causes and reduce such variations.

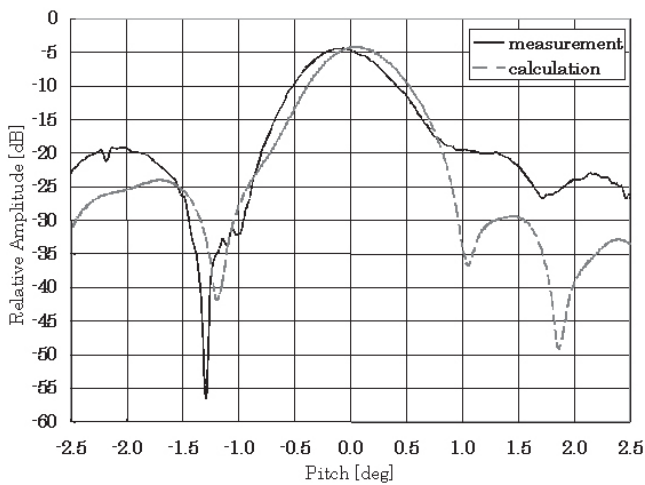


Fig. 4 Measurement result of Kyushu-beam cut pattern

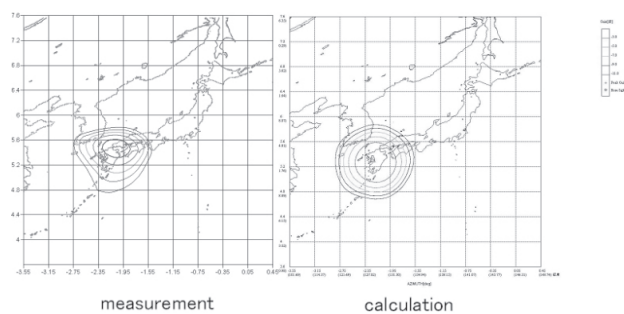


Fig. 5 Measured and calculated pattern of the Kyushu-beam

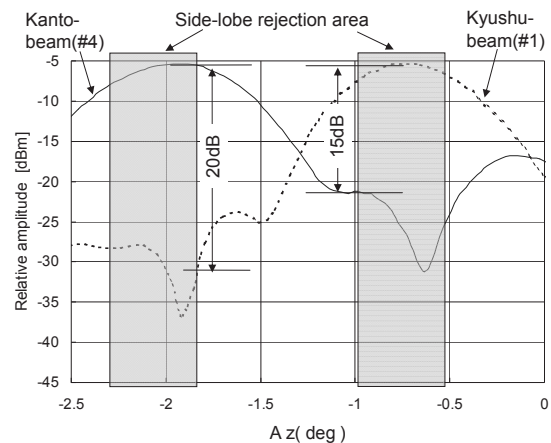


Fig. 6 Example of LDRA side-lobe

4.1.1 Shifts in beam direction during eclipse time

Figure 7 illustrates the variations in the reception level of the Kyushu-beam (beam1) at the Kashima, Yokosuka, Akashi, Kyushu and Yamagawa stations during eclipse time. Also, Fig. 8 shows the power output of the solid-state power amplifier (SSPA) for transmitting telemetry data and the temperature of the antenna mirror surface that indicate the state of the satellite during this time. We consider that the variations in the reception level at earth stations during eclipse time were due to distortion of the mirror surface caused by the variations in the large antenna's temperature because while there was no change in the SSPA's power output during eclipse time there was a decrease in the antenna temperature by 180K. Also, the beam direction was determined from the receiving data at earth stations located across the country. Figure 9 indicates that the beam direction moved eastward by approximately 0.2° during eclipse time. In addition, the phenomenon of the beam direction moving eastward during eclipse time corresponds to the pre-launch analysis results.

4.1.2 Correction of beam direction during eclipse time

From the above analysis, it can be seen that the beam direction moves eastward by approximately 0.2° during eclipse time; therefore, we carried out an experiment to

reduce the reception level at earth stations by correcting the beam direction. The method of this experiment was to set a threshold to maintain the pre-eclipse reception level, to change the phase excitation distribution of BFN to recover the reception level at the earth stations if the threshold is exceeded, and to shift the beam direction back to its pre-eclipse state. We determined the degree of beam shift from antenna patterns and, more specifically, shifted the beam direction westward by 0.05° when the reception level declined by 0.5dB after the beginning of eclipse, and returned the beam direction eastward after eclipse. Also, since we can form beams more flexibly using the PA feeding method, we formed two Kanto-beams (beam4) simultaneously and compared the earth-station reception levels between the cases where the beam direction was corrected and those where it was not. Figure 10 shows the experiment results. A comparison of the greatest values (i.e. peak-to-peak: p-p) of variation widths suggests that we were able to reduce the variation width by 1dBp-p when the beam direction was corrected, while the variation width was approximately 2.5dBp-p when the beam direction was not corrected.

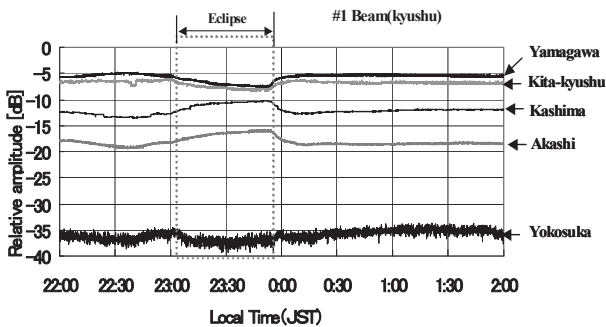


Fig. 7 Level variation of grand stations during the eclipse

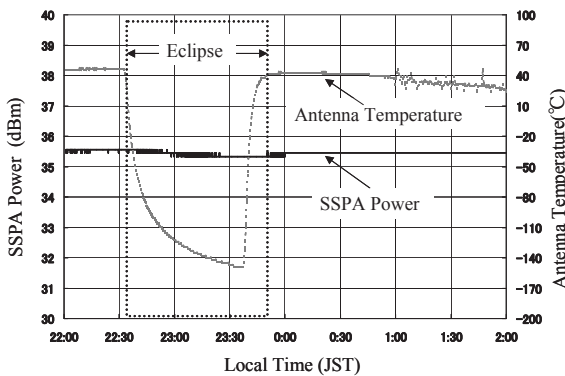


Fig. 8 Telemetry of antenna temperature and SSPA power

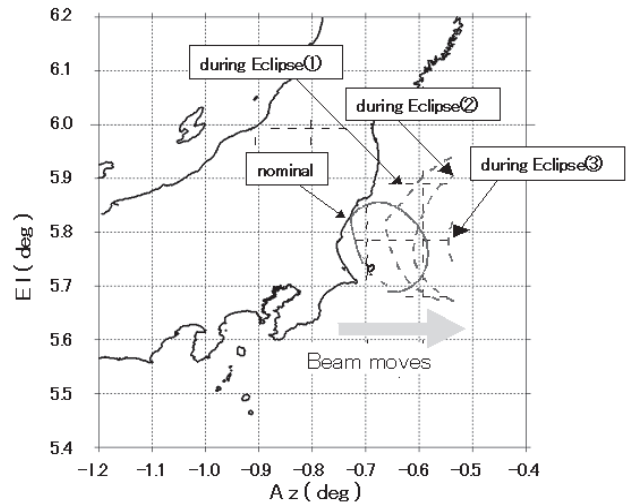


Fig. 9 Beam moves during the eclipse

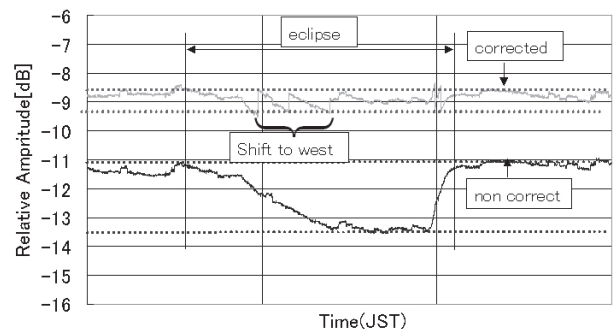


Fig. 10 Correction of receiving level during the eclipse

4.2 Daily shifts in beam direction

4.1 explained the shift in beam direction that is considered to be due to the influence of thermal change on the antenna mirror during eclipse time. In the following, we will report the daily shifts in the beam direction of the large deployable antenna.

4.2.1 Measurement of beam direction

For the purpose of investigation into daily shifts in beam direction, we formed the Kyushu-beam (beam1) as shown in Fig. 11 and received the beacon signals from the satellite at the Akashi, Kitakyushu and Yamagawa stations at the same time.

First, Fig. 12 shows the Az (east-west direction) cut patterns of the Kyushu-beam (beam1) at the three stations. These cut patterns were measured by scanning satellite attitudes as shown in Fig. 2. As the pre-launching review had already suggested that beam-direction errors occurred due to thermal distortion of antenna mirrors mainly in the case of the pitch-axis (east-west direction) rotation, this investigation was confined to that direction. The Pitch=0°

of a beam boresight direction from a station means right above that station, while the plus and minus sides for the pitch axis represent the west and east sides, respectively. For example, Fig. 12 suggests that the boresight of the Kyushu-beam (beam1) is located to the west of Akashi station as the peak is on the plus side in the cut pattern of Akashi station. Similarly, it shows that the Kyushu-beam (beam1) is located to the east of the Kitakyushu and Yamagawa stations.

4.2.2 Daily variations in reception levels at earth stations

Figure 13 shows the variations in reception levels when the Akashi, Kitakyushu and Yamagawa stations received beacon signals from the satellite. The measurement was conducted from 6 p.m. to 8 a.m. Figure 13 shows that the variations in reception levels at the Kitakyushu and Yamagawa stations have the same trends, while those at the Akashi station increase and decrease almost symmetrically. Thus, we consider that shifts in beam direction cause variations in reception levels at earth stations. The variation width of reception levels at Akashi station is approximately 3dB (p-p), and from the cut patterns shown in Fig. 12 it is estimated that the shifting width of beam direction there is approximately 0.25°.

4.2.3 Correction of reception levels at earth stations

Next, we carried out an experiment to reduce the variation width of reception levels at earth stations. The correction method here is the same as the one employed for correcting variations in reception levels at earth stations during eclipse time described in 4.1.2. We changed the phase excitation distribution of BFN and shifted the direction of the Kanto-beam (beam4). As before, since the pre-launching review had already indicated that beam-direction errors occurred due to thermal distortion of

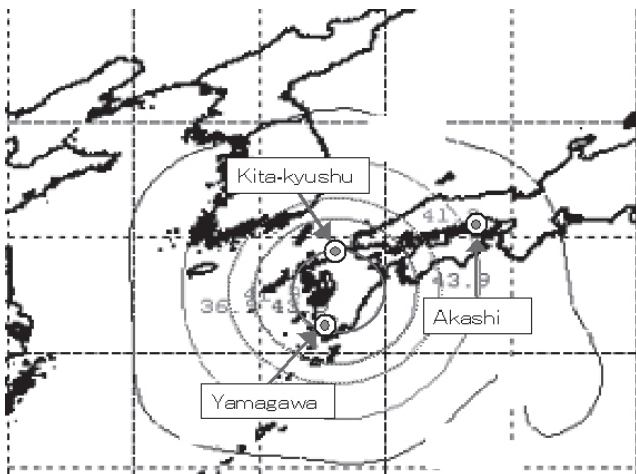


Fig. 11 Kyushu-beam and allocation of grand stations

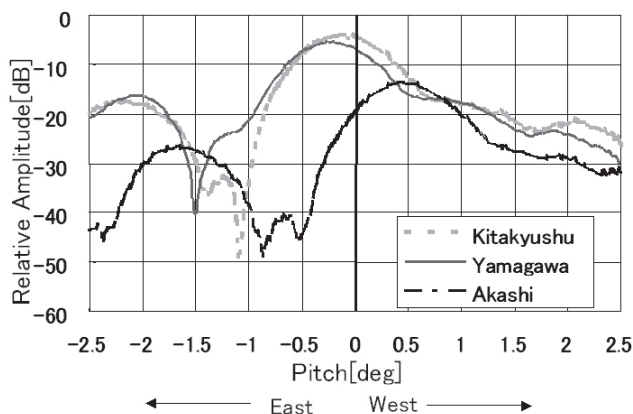


Fig. 12 Cut-pattern of the Kyushu-beam

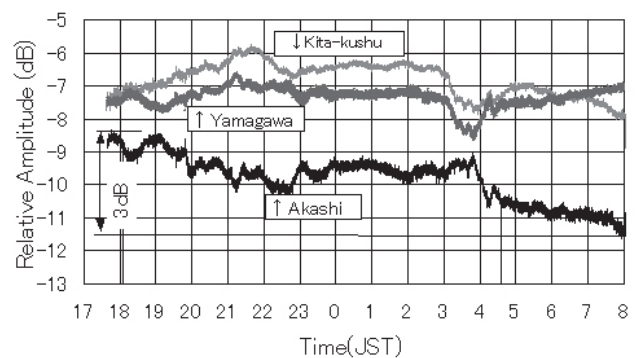


Fig. 13 Receiving Level of the Kyushu-beam

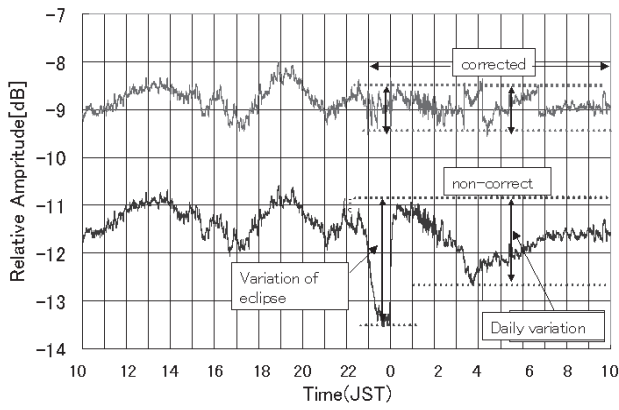


Fig. 14 Correction of receiving level variation

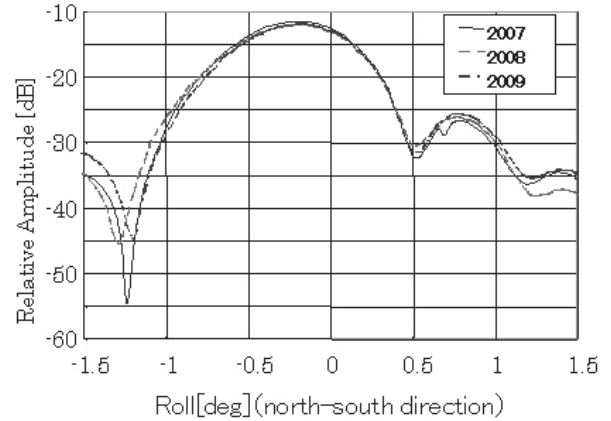


Fig. 16 Secular change of cut-pattern at kashima station (north-south direction)

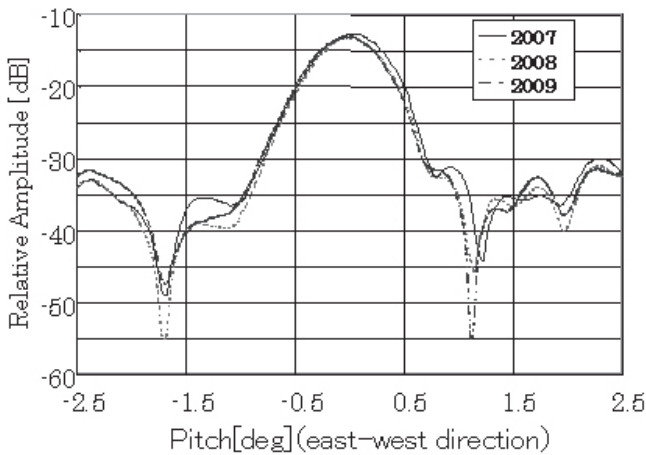


Fig. 15 Secular change of cut-pattern at kashima station (east-west direction)

reflecting mirrors of the large antenna dominantly in the east-west direction, we confined the beam direction to that direction in the experiment to correct reception levels at earth stations. The method of correcting reception levels at earth stations was to set a threshold on the reception level and, if the threshold was exceeded, to shift the beam direction so that the reception level returned to the range of standard value. We formed two Kanto-beams (beam4) simultaneously and corrected only one of them; Fig. 14 shows the results of the comparison of the variation widths of reception levels between the cases where the beam4 was corrected and those where it was not. In this regard, we were able to reduce the variation width by correcting the beam: the greatest value of the variation width was 1dBp-p when the beam was corrected, while it was 2dBp-p when the beam was not corrected. In addition, Fig. 14 includes the results of an experiment for correcting variations in reception levels during eclipse time, specifically at around midnight. Also, in this tendency of variations, their cycle corresponds to the one in the pre-launch estimation, but their polarities are almost opposite. This requires us to

investigate the cause in the future.

4.3 Secular changes in beam direction

For the purpose of grasping secular changes in the beam direction of the large deployable antenna, we summarized the cut patterns of Kanto-beam (beam4) around the summer solstices for three years at Kashima station. Figures 15 and 16 show the results. Although there are certain differences between the amplitude of side lobes and nulls, there is no significant change in the shape of main lobes in terms of both the pitch (east-west direction) and roll (north-south direction) axes. Thus, we consider that the secular change was small for three years.

5 Conclusion

This study evaluated the electrical characteristics of the large deployable antenna mounted on the ETS-VIII satellite. It was verified that the direction of antenna patterns, as estimated by scanning the satellite attitude, covered the expected area in spite of an approximately 0.2° difference from the designed value, and that BFN was correctly operating in geostationary orbit. Also, we have been making further efforts to optimize the excitation distribution of BFN, although the largely favourable results were obtained as the side lobe was 15 dB lower than the boresight based on the evaluation of the side lobe for the purpose of reusing the frequency of the multi-beam for communication.

This time, although certain changes were observed in the reception level at earth stations, presumably due to thermal distortion of mirror surface of the large deployable antenna, we were able to reduce the variation width thanks to the BFN's function to adjust the beam direction. The measurement of these phenomena and the results of

experiments to correct them will contribute to designing satellites^[12] to be equipped with future large deployable antennas.

Acknowledgment

We are grateful to all the JAXA staff who reviewed the method of scanning satellite attitudes and operated the satellite in our measurement of antenna patterns.

References

- 1 Y. Kawakami, S. Yoshimoto, Y. Matsumoto, T. Ohira, and N. Hamamoto, "S-band Mobile satellite communications and multimedia broadcasting onboard equipment for ETS-VIII," *Trans. IEICE* Vol. EB82-B, No. 7, pp. 1659–1666, 1999.
- 2 Y. Matsumoto, Y. Hashimoto, T. Ide, M. sakasai, N. Hamamoto, and M. Tanaka, "Beam former with a Single Set of Variable Phase Shifters for the Pointing Control of Multi beam Satellite Antenna," *Trans IEICE on Communications (Japanese edition)*. Vol. J80 B-II, No. 7, pp. 617–621, 1997.
- 3 T. Ohira, Y. Suzuki, H. Ogawa, and H. Kamitsuna, "Megalithic microwave signal processing for phased-array beamforming and steering," *IEEE Trans. Microwave Theory and Tech.*, Vol. 45, No. 12, pp. 2324–2332, 1997.
- 4 Y. Suzuki, Y. Imaizumi, and K. Ohira, "In-orbit test of an onboard beam forming network for Engineering Test Satellite VIII," *IEICE Society Conference (in Japanese)*, B-2-3, March 2007.
- 5 Y. Suzuki, Y. Imaizumi, and K. Ohira, "Short Time Measuring Method of Onboard Antenna Pattern and In-Orbit Test Results of Beam Forming Network on Engineering Test Satellite VIII," *Trans IEICE on Communications (Japanese edition)*, Vol. J91-B No. 12 pp. 1569–1577, 2008.
- 6 Y. Matsumoto, M. Masato, and T. Orikasa, "Development of Cup-MSA Feed Array Element for Phased Array Satellite Antennas," *Trans IEICE on Communications (Japanese edition)*, Vol. J82 B-II, No. 7, pp. 1420–1424, 1999.
- 7 M. Usui, H. Kohata, T. Hamaki, and Y. Yamasa, "Antenna pattern measurement of the large deployable reflector of the ETS-VIII," *ISTS*, j-02, 2009.
- 8 T. Orikasa, Y. Fujino, M. Satoh, H. Kohata, and M. Usui "Electrical performance of large deployable reflector antenna equipped on Engineering Test Satellite (ETS-VIII)," *IAC-09.B2.6.6*.
- 9 M. Satoh, Y. Fujino, T. Orikasa, S. Nagai, S. Kozono, H. Watanabe, S. Yamamoto, and S. Taira, "Electrical performance of large deployable reflector antenna equipped on Engineering Test Satellite (ETS-VIII)," *IEICE Society Conference (in Japanese)*. BS-2-4, 2007.
- 10 Y. Matsumoto and T. Ide, "Beam forming network," *Journal of the national institute of information and communications technology*, Vol. 49, Nos. 3/4, pp. 63–71. Sept./Dec. 2003.
- 11 T. Orikasa, Y. Fujino, and M. Satoh, "Measurement of radiation of large deployable reflector antenna equipped on Engineering Test Satellite(ETS-VIII) on orbit," *ISAP2008,TP-26 1645008*, Oct. 2008.
- 12 T. Minowa, M. Tanaka, N. Hamamoto, Y. Fujino, N. Nishinaga, R. Miura, and K. Suzuki, "Satellite /Terrestrial Integrated Mobile Communication System for Nation's Security and Safety," *Trans IEICE on Communication (Japanese edition)*, Vol. J91-B, No. 12, pp. 1629–1640, Dec. 2008.

Masaki SATOH

Manager, Collaborative Research Department
Space Communication, Antenna



Teruaki ORIKASA, Dr. Eng.

Senior Researcher, Spacere Communication
Systems Laboratory, Wireless Network
Research Institute
Space Communication, Antenna



Yoshiyuki FUJINO, Dr. Eng.

Senior Researcher, Wireless Network
Research Institute (Currently Professor of
Toyo University)
Satellite Communications, Wireless Power
Transfer