PAPER *Special Issue on Historical Review of Antenna Systems in Japan*

Satellite Onboard Reflector Antennas

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SUMMARY This paper describes a historical review of satellite onboard reflector antenna systems in Japan.
key words: *Satellite antennas, reflector antennas*

1. Introduction

History of satellite antennas in Japan started by introducing the technologies from America in the late 1960's. Studies of domestic satellite communication systems began in the late 1970's. Along with the increased demand for satellite communication, various types of antennas have been developed.

This paper summarizes some historical review of satellite onboard reflector antenna systems in Japan. A summary of shaped beam antennas, multibeam antennas, shaped/multibeam antennas, reconfigurable beam antennas, frequency selective surface, gridded reflector antennas, large deployable antennas, reflector antennas fed by active phased array is described.

2. Shaped Beam Antennas

Shaped beam antennas are defined as the antennas whose radiated beams are shaped to a prescribed pattern. It is required to optimize the phase and/or amplitude distribution on the antenna aperture in order to realize the desired shaped beam patterns, such as patterns matching to the shapes of Japanese main islands. As for reflector antennas, two methods are generally used for this purpose; one is a shaped reflector antenna, the other is a reflector antenna with multiple feed antennas. We will review the corresponding developments in Japan.

2.1 Shaped Reflector Antennas

A typical antenna of this type is the shaped-beam horn-reflector antenna used in Japanese Communication Satellite 2 (CS-2). This antenna was designed using wavefront control method to fit Japanese islands[1]. The design theory is based on geometrical optics. At the first step, the shape of the wavefront near the aperture is determined to correspond to desired beam shape. The shape of the reflector is then determined by the law of the optical path. Figure 1 shows the reflector assembly of the antenna and the feed assembly[2]. Figure 2 shows measured radiation patterns of the antenna[2]. The aperture diameter is 2.2 m. The antenna was designed at Ka band.

Figure 3 shows a fabricated model of contoured beam shaped reflector antenna for broadcasting satellite[3]. The antenna is a single offset shaped reflector fed by single horn. The reflector is shaped as follows: first, the phase of the current induced on the reflector is optimized discretely on an aperture square grid, second, the reflector is shaped to realize the obtained phase distribution. In this method, however, discontinuities in the reflecting surface remain in obtaining the reflector shape. The problem of the discontinuities is circumvented by setting a restriction on the phase difference between a point and its adjacent point on the square grid. Figure 4 shows co-polar (RHCP) radiation patterns calculated and measured at 11.996GHz[3]. The aperture diameter is 2.3 m. The similar optimization method[4] of a single shaped reflector which is based on the equivalent array antenna was proposed before their study. On the other hand, shaped dual reflector antenna[5] was also developed, where phase and amplitude distributions are optimized independently by main and sub reflectors, respectively.

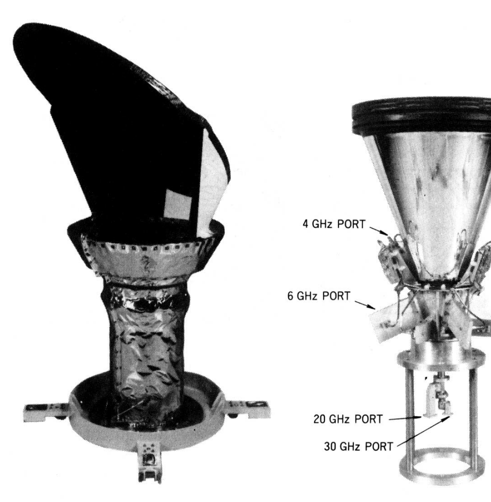

Fig. 1 Communications antenna for CS-2: (a)reflector assembly, (b)feed assembly [2].

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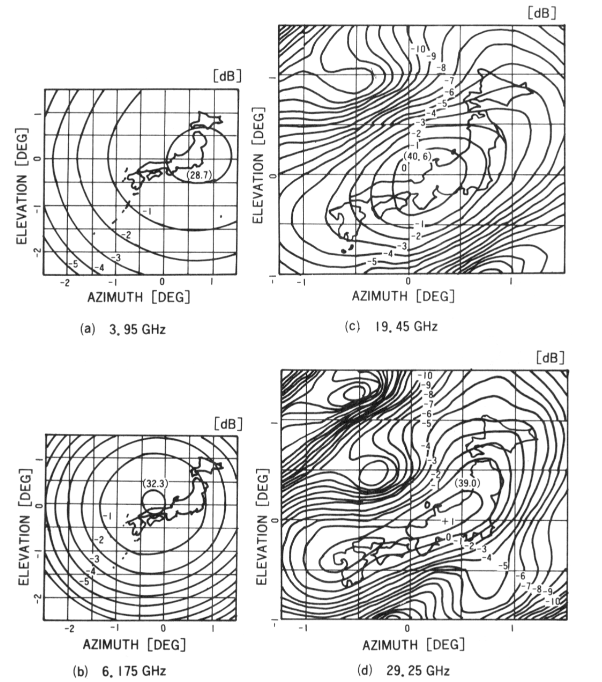

Fig. 2 Measured radiation patterns of the communication antenna for CS-2: (a)3.95GHz, (b)6.175GHz, (c)19.45GHz, (d)29.25GHz [2].

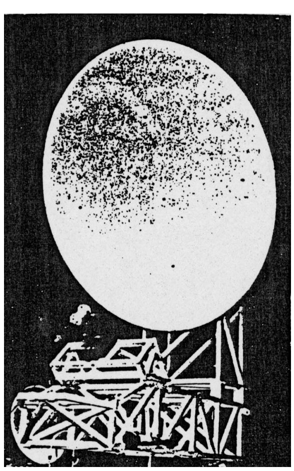

Fig. 3 Fabricated shaped reflector antenna [3].

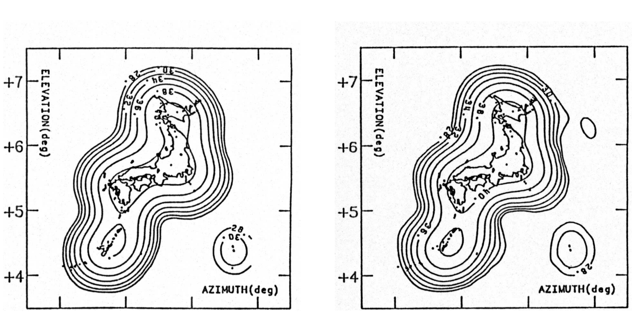

Fig. 4 Co-polar (RHCP) radiation pattern calculated (left figure) and measured (right figure) at 11.996GHz (dBi) [3].

2.2 Multiple Feed Antennas

Shaped beam antennas for broadcasting satellites were developed and launched in 1978 by BSE(Broadcasting Satellite for experimental purpose), and in 1984 by BS-2(Broadcasting Satellite-2). The Japanese satellite broadcasting service was started by BS-2, which uses 12 GHz-band for downlink and 14 GHz-band for uplink. The BS-2 antenna[6] consists of an offset parabolic reflector and multiple feed horns, as shown in Fig. 5 and Fig. 6. By optimizing the excitation distribution of each feed horn, the shaped beam pattern which covers Japanese main islands and remote islands was realized, as shown in Fig. 7. Japanese satellite broadcasting service was handed over by BS-3(Broadcasting Satellite-3). In this antenna system, the gain improvement toward remote islands was required. To achieve this requirement, the new multiple feed horn system with an elliptical corrugated horn was developed, as shown in Fig. 8[7].

Fig. 5 Photograph of BS-2 antenna.

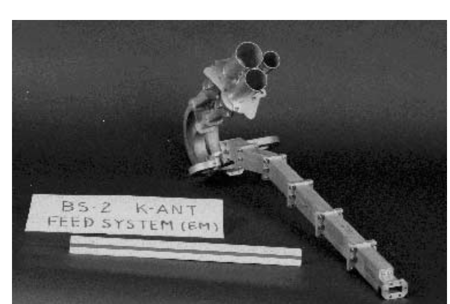

Fig. 6 Photograph of BS-2 feed.

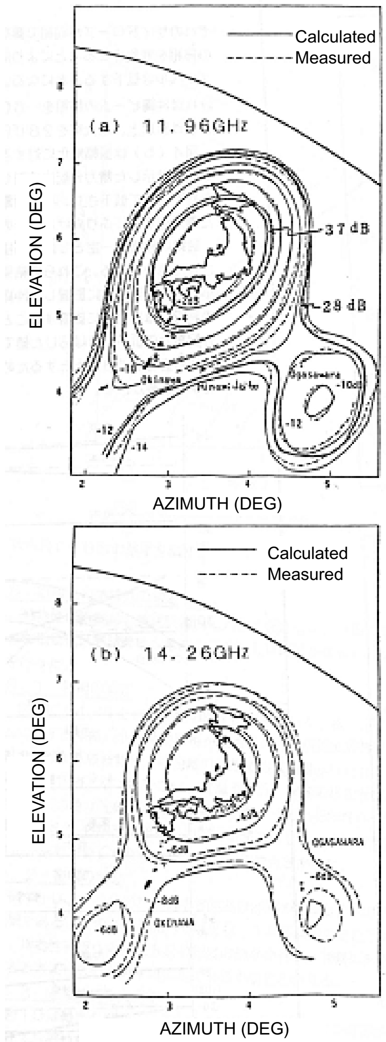

Fig. 7 BS-2 radiation patterns.

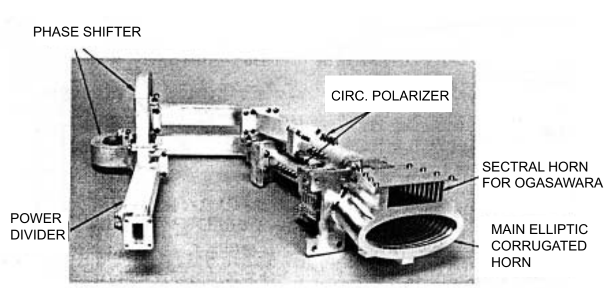

Fig. 8 Photograph of BS-3 feed.

3. Multibeam Antennas

Multibeam antennas are defined as antennas capable of creating a family of major lobes from a single nonmoving aperture, through use of a multiport feed [2]. A reflector-type multibeam antenna carries the primary radiator at the reflector focus, and the beam direction can be altered by changing the position of radiator around the focus. In the design of multibeam antenna, one of the most difficult problems to be solved is to obtain the high beam-to-beam isolation. In conventional antennas, the increase of scan angle causes the increase of sidelobe level and scan loss on account of aberration and increase of cross polarization level, so beam-to-beam isolation becomes lower. To solve this problem, front fed offset Cassegrain (FFOC) antenna was devised. Figure 9 shows a photograph of the FFOC antenna under test[8]. Main reflector is a paraboloid. Subreflector is a hyperboloid and concave viewing from the primary feed. The feed is located in side of the beam radiating direction from the main reflector. Figure 10 shows the calculated and measured gain reduction. The aperture diameter is 1.8m. The measured frequency is 20.1GHz. The gain reduction is less than 1.8 dB within 10 degrees(about 17 beam width). Also cross polarization level is measured and verified that the cross polarization component caused by the reflectors is very small.

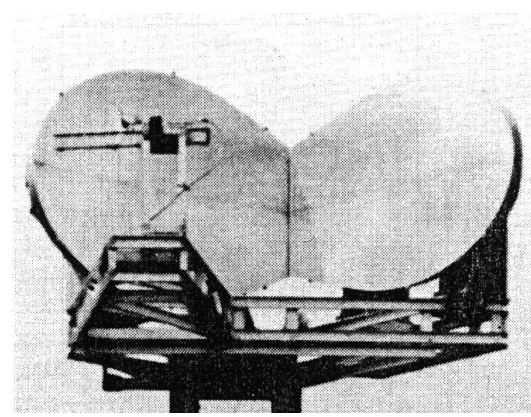

Fig. 9 Photograph of the FFOC antenna under test[8].

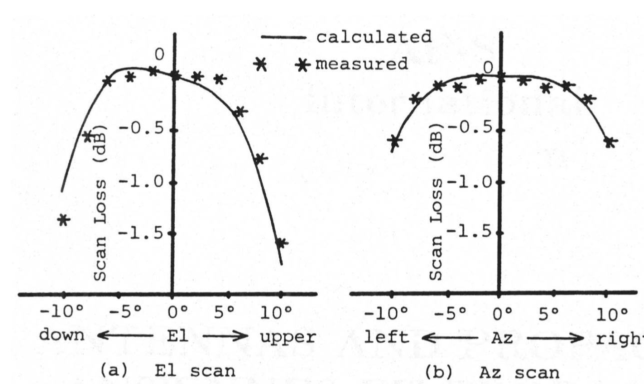

Fig. 10 Measured scan characteristics of gain[8].

Multibeam antennas were also studied and developed for broadcasting satellites in Japan. Figure 11 shows an example of beam allotment for the 22 GHz band satellite broadcasting. In this frequency band, the multibeam system is necessary because the attenuation loss due to rainfall is higher than other frequency bands. Also, the low sidelobe characteristic is required for frequency reuse. The multibeam antennas system which consists of an offset Cassegrain reflector and the novel feed horn system with a main horn and sub-horns was developed[9] to overcome the high gain and low sidelobe requirements. Figure 12 shows the front view of the feed horns. As shown in Fig. 13, the desired radiation patterns were realized by the engineering model. This antenna system launched by COMETS(Communications and Broadcasting Engineering Test Satellite) in 1998.

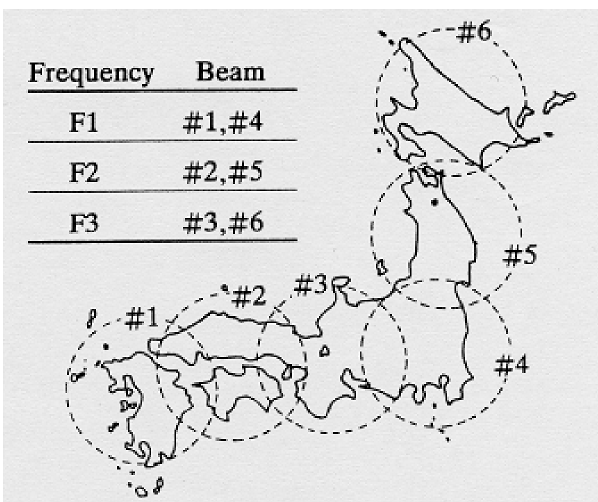

Fig. 11 Example of beam allotment for 22GHz band satellite broadcasting.

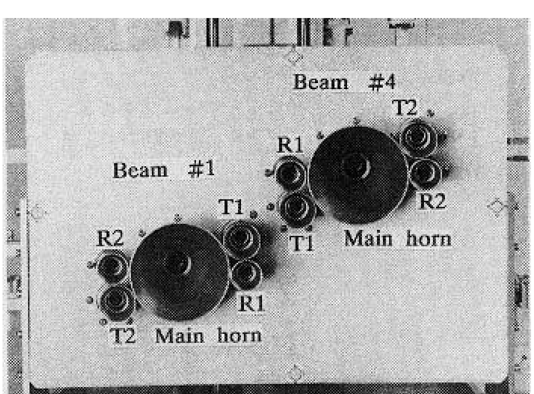

Fig. 12 Feed for COMETS.

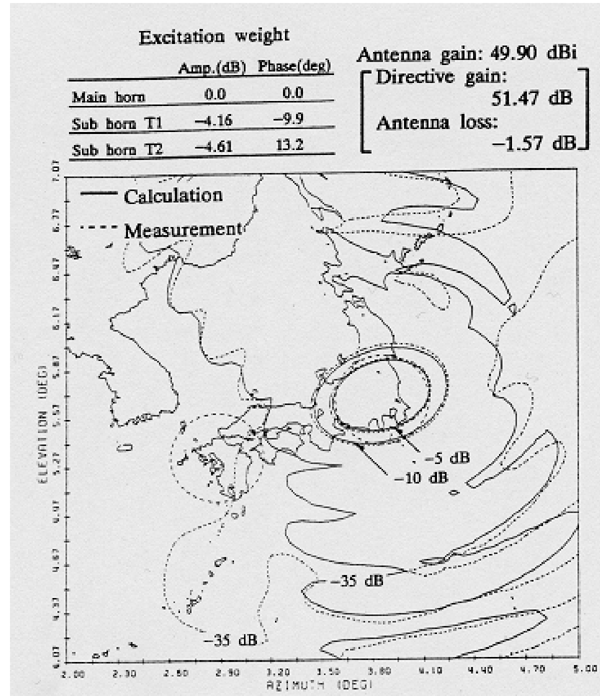

Fig. 13 Radiation pattern of COMETS antenna.

4. Shaped/Multibeam Antennas

Figure 14 shows a Ka band antenna for N-star[11]. N-star is a Japanese domestic commercial communication satellite, which takes over the CS-3. The Ka band antenna is an offset Gregorian antenna with 2.2 m diameter, fed by multi horns, and shares 20GHz band and 30GHz band using frequency selective surface (FSS), which is described later. In each band, the antenna is used for both shaped beams and multibeams in common by sharing beam forming network (BFN) for both beams [12].

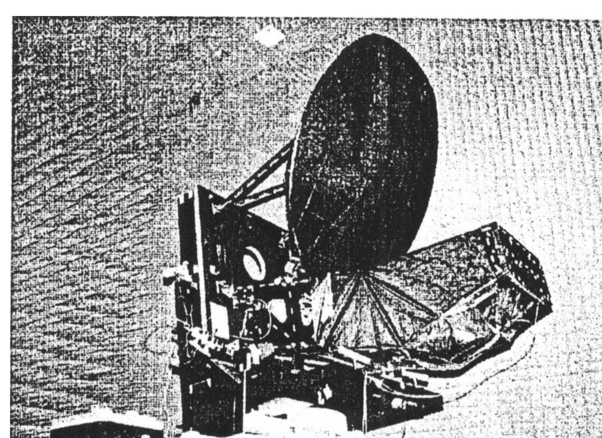

Fig. 14 The N-Star Ka-band antenna under test[12].

5. Reconfigurable Beam Antennas

Reconfigurable multi beam antennas radiate multiple contoured beams whose beam shapes can be changed according to the desired coverage shapes. Several types of the antennas have been studied, such as reflector antennas fed by multifeed horns, mesh reflector antennas and direct radiating array antennas.

A new reconfigurability concept proposed by INTELSAT provides a high reconfigurability without requiring more BFN components[13]. Figure 15 shows a definition based on the actual INTELSAT-VII C-band coverages. The antenna considered in this design consists of a single offset paraboloidal reflector whose aperture diameter is 2.44m, an array of 50 feed horns with polarizers and an associated reconfigurable BFN. To obtain the efficient and simple reconfigurable BFN, 3-subBFNs and a variable BFN configuration was selected for this system, as shown in Fig. 16. Figure 17 shows a picture of the developed reconfigurable BFN. This BFN can be operated in 4GHz frequency band with circular polarization. Figure 18 to 20 show measured radiation contours for each beam.

Reconfigurable beam antennas using a direct radiating array antenna (DRAA) have been studied[15], [16]. Figure 21 shows Ku-band DRAA experimental model with 64 array elements including 14 dummy elements. Figure 22 shows reconfigurable capability of DRAA (Excitation states and theoretical and measured reconfigurable performances.) The antenna has a low loss of less than 2dB in average and high sidelobe and polarization isolation of more than 27dB and 29dB, respectively.

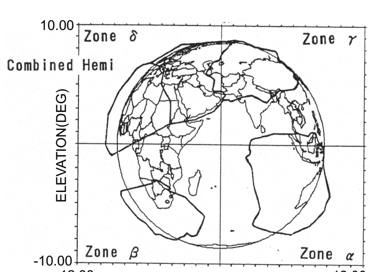

Fig. 15 Coverage definition[14].

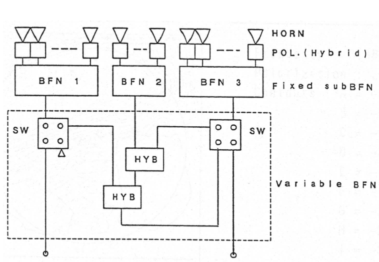

Fig. 16 Blockdiagram of reconfigurable BFN[14].

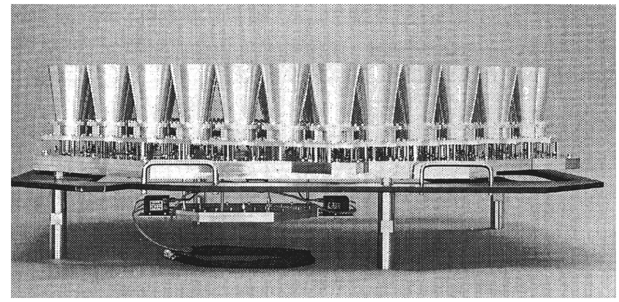

Fig. 17 Developed reconfigurable BFN[14].

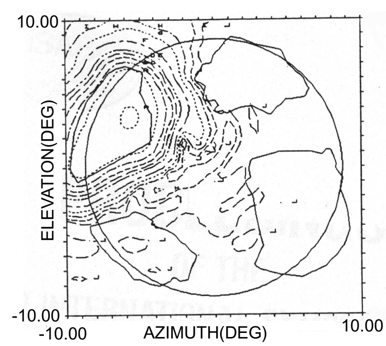

Fig. 18 Zone δ beam[14].

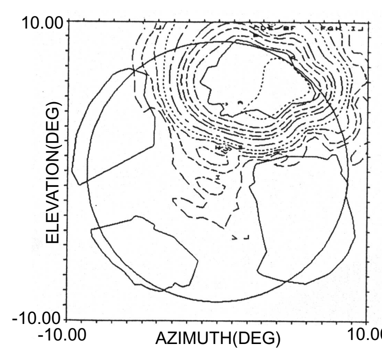

Fig. 19 Zone γ beam[14].

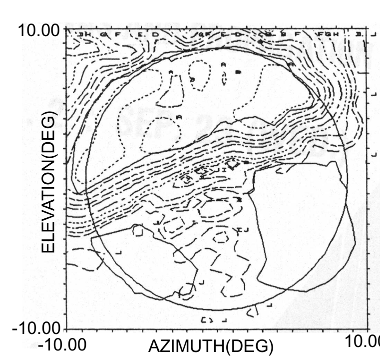

Fig. 20 Hemi beam[14].

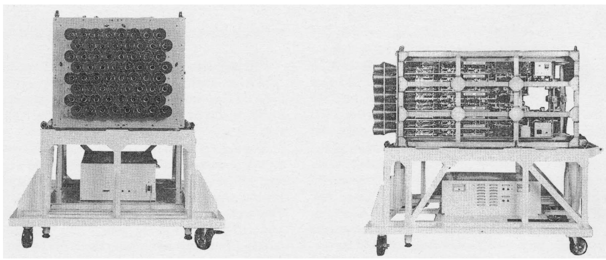

Fig. 21 DRAA experimental model[15].

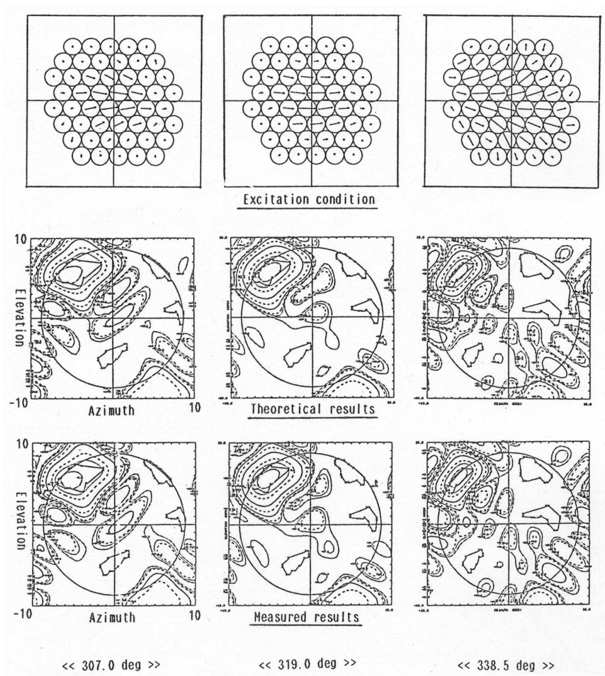

Fig. 22 Reconfigurable capability of DRAA (Excitation States and Theoretical and Measured Reconfigurable Performances)[15].

6. Frequency Selective Surface

Frequency selective surfaces (FSSs) or frequency selective reflectors (FSRs) comprise periodic arrays of patches or apertures in a conducting screen. They act as space diplexing to separate feeds in microwaves and optics. FSSs are widely used in satellite antennas in Japan, such as ETS-VI[10], [17], N-star[11], [12], ADEOS[18], DRTS and so on.

Figure 23 shows the experimental model for ADEOS-IOL (inter orbit link) antenna. The antenna is an axially symmetric Cassegrain antenna, sharing S/Ka band in common. Main reflector is a paraboloid of 1.35m diameter. Subreflector is a hyperboloid of 0.24m diameter employing a curved FSS, shown in Fig. 24. The FSS is designed to transmit S-band signals and reflect Ka-band signals. Resonant elements of the FSS are metallic ring patches with circumference of about 1 λ in the Ka-band. Figures 25 and 26 show radiation patterns of S-band and Ka-band, respectively. FSS losses are estimated theoretically. Losses in S-band and Ka-band are 0.07dB and 0.25dB, respectively.

Figure 27 shows the subreflector of Ka-band antenna for N-star, mentioned above[12]. The subreflector has a double-wall construction consisting of the front curved FSS and the rear solid reflector. The front reflector consists of 16,000 resonant elements on the surface so as to be transparent to 30GHz-band uplink signals and to reflect 20GHz-band downlink signals.

The quasi-periodic disposition of elements on the curved surface is made both in ADEOS and N-star subreflector by the novel method[20]. The methodology is based on the fact that a developable surface is mapped isometrically to a plane.

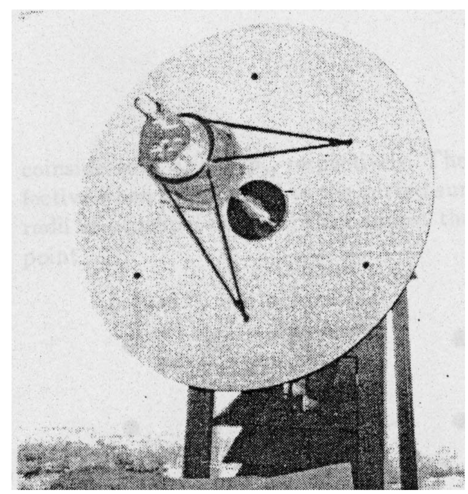

Fig. 23 Experimental model of S/Ka dual band antenna with curved FSR for ADEOS[18].

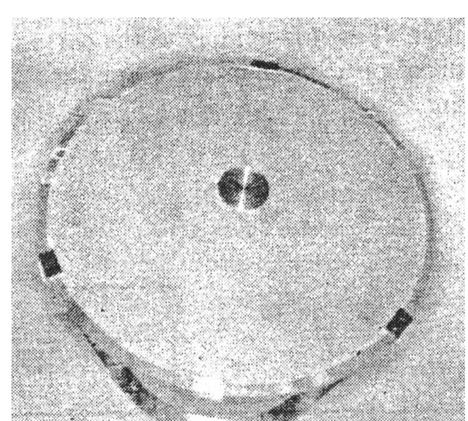

Fig. 24 Axially symmetric hyperboloidal FSR[18].

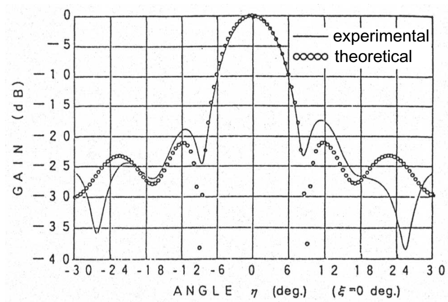

Fig. 25 S-band radiation pattern[18].

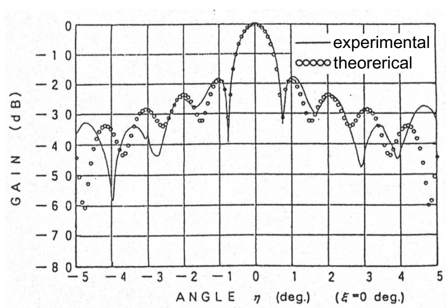

Fig. 26 Ka-band radiation pattern[18].

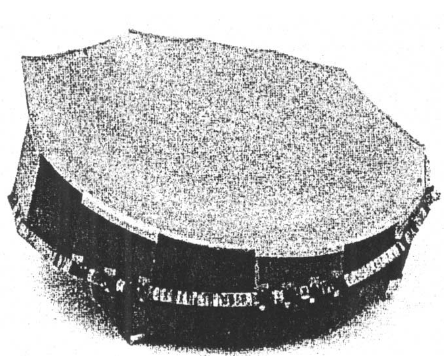

Fig. 27 Subreflector assembly of N-Star Ka-band antenna[12].

7. Gridded Reflector Antennas

Gridded reflector antennas are often applied to onboard antennas for communications satellites owing to their excellent cross polarization suppression characteristics to their frequency reuse capabilities. Polarization grids are arranged on a reflector surface to form a parallel-line pattern projected on an antenna aperture plane.

Figure 28 shows a photograph of the Superbird-C Ku-spot beam antenna[19]. The antenna is a dual overlapped reflector antenna and its diameter is 0.55m. Figure 29 shows the configuration of the antenna. The front reflector is composed of a sandwich honeycomb panel made of transparent material and polarization grids are patterned on its surface. The rear reflector is composed of a sandwich honeycomb panel made of reflecting material. Figure 30 shows measured radiation pattern of the antenna. Cross polarization level of under -40dB is achieved. Methodology of disposition of grids on the curved surface is also used [20].

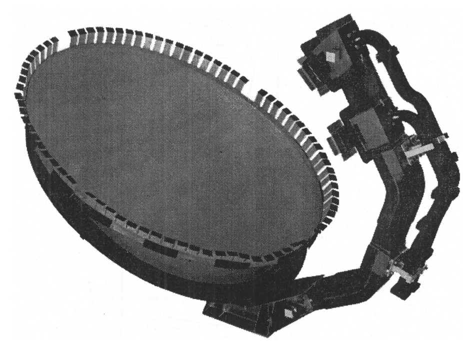

Fig. 28 Photograph of the Superbird-C Ku-spot beam antenna[19].

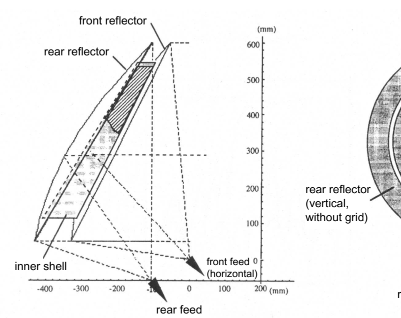

Fig. 29 Configuration of the antenna[19].

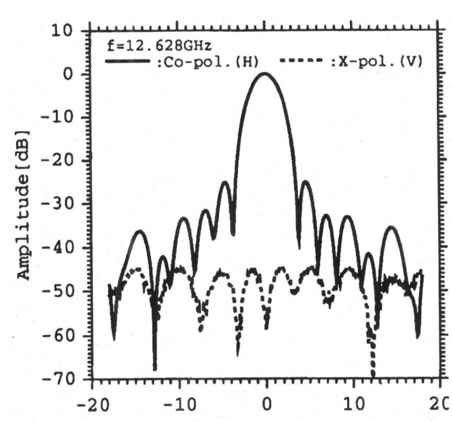

Fig. 30 Measured radiation pattern[19].

8. Large Deployable Antennas

Figure 31 shows the antenna structure of large deployable reflector antenna for space VLBI project[21]. A displaced axis Cassegrain antenna is adopted with a mesh reflector formed in tension truss concept. Diameter of the antenna is about 10m. The frequency bands used for the observation are 22, 5 and 1.6GHz. Figure 32 shows the antenna design parameters. The antenna is designed from the gain maximizing point of view by reducing the gain loss due to sub-reflector blockage. Figure 33 shows measured radiation pattern in orbit using 1.7GHz radiowave from GSO satellite, Himawari and a earth station, USDC[22].

Figure 34 shows an overview of modular mesh deployable antenna for satellite communication[23]. Design goal of the antenna diameter and the surface accuracy are 15m class and 0.24mmRMS, respectively. Figure 35 shows a basic module structure of the antenna. Bread board model of 4m deployable antenna module was fabricated and it is verified that 0.24mmRMS is achievable.

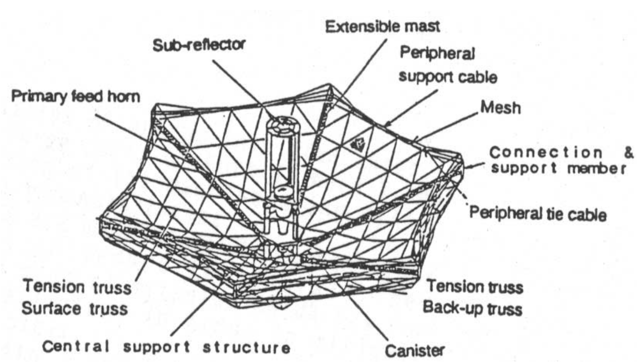

Fig. 31 Antenna structure for the space VLBI[21].

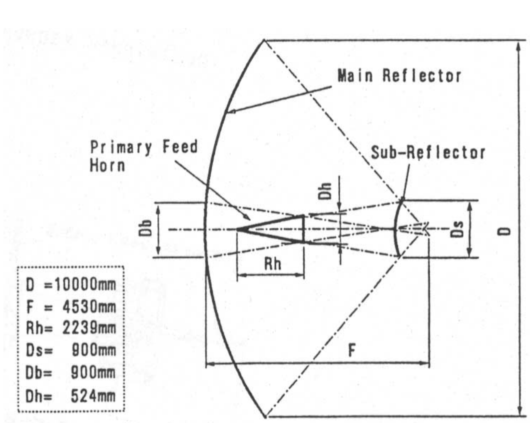

Fig. 32 Antenna design parameters[21].

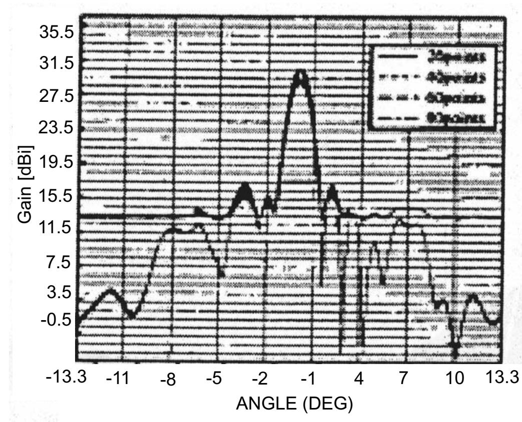

Fig. 33 Antenna radiation pattern (far-field, 1.7GHz)[22].

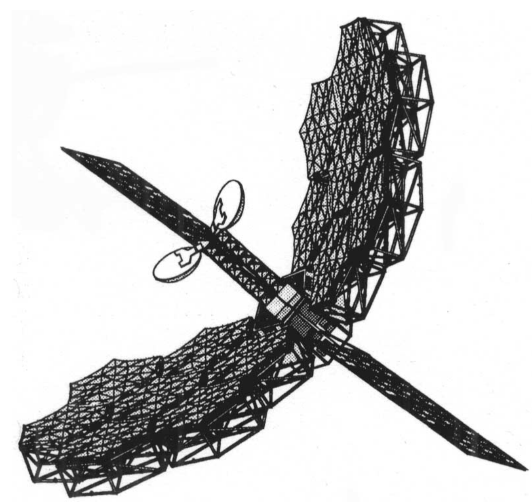

Fig. 34 Overview of modular mesh deployable antenna[23].

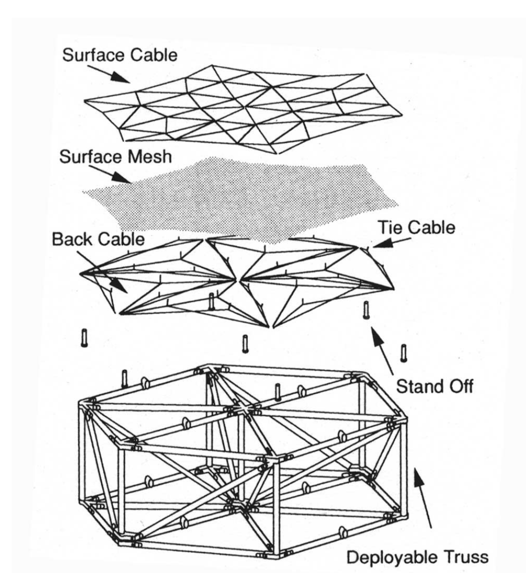

Fig. 35 Basic module structure[23].

9. Phased-Array-Fed Reflector Antennas

Phased array antennas are attractive for geostationary satellites because of their many advantages. In designing phased array antennas, the number of elements determines the complexity of the antenna and the beam forming network.

Figure 36 shows one of the configuration of the phased array antenna, which consists of a single reflector fed by active phased array. Figure 37 shows a manufactured array feed to confirm the feasibility or the phased-array-fed reflector antenna. The array feed is composed of 37 cavity-backed helical antennas for forming 19 beams. Diagonal length of the array feed, D_{a1} in Fig. 36 is 1.33 m and element spacing is 190 mm. Assuming that the reflector is an offset paraboloidal reflector with 10m diameter and 8m focal length, the array feed is placed one meter toward the reflector from the focal plane. The elements are aligned radially from the virtual center placed 2 m behind the array surface plane. Figure 38 shows measured array feed pattern. Measurement frequency is 2.5GHz. Figure 39 shows calculated secondary radiation pattern.

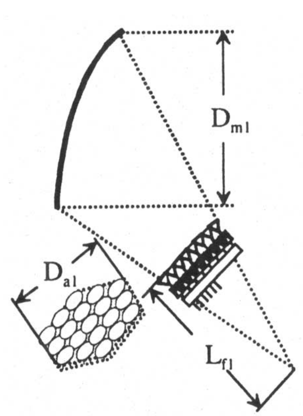

Fig. 36 Configuration of phased array antenna[24].

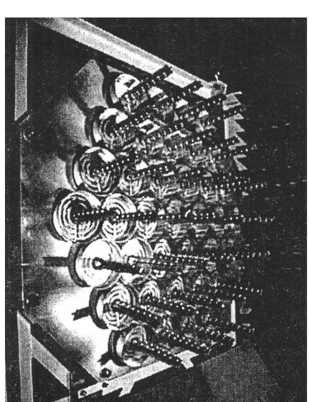

Fig. 37 Manufactured 37-element array feed[24].

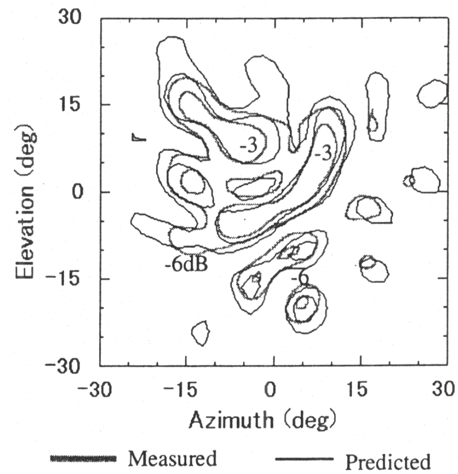

Fig. 38 Measured array feed pattern[24].

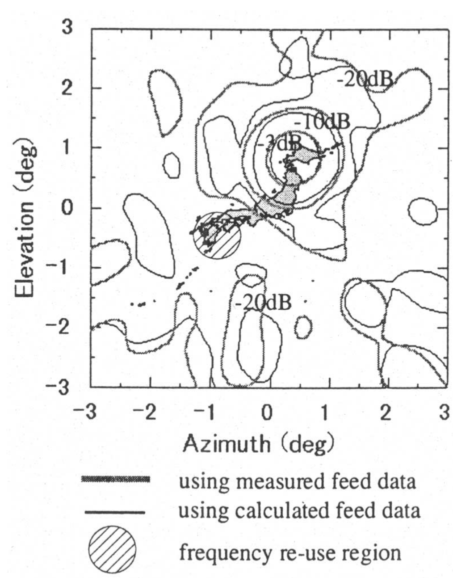

Fig. 39 Calculated secondary radiation pattern[24].

10. Conclusions

This paper has presented a historical review of the satellite onboard reflector antenna systems in Japan. From this review, Japan, in about two decades of vigorous R&D, has developed several original technologies in satellite onboard antennas and many antenna systems in this field have been made practicable. There will be continuous advances in space antenna technology for future applications in mobile satellite communications, satellite broadcasting, scientific observation or sensing and so on, based on much effort of space antenna engineers.

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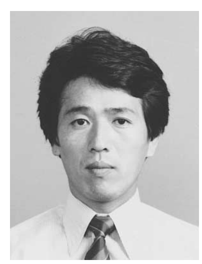

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