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A STUDY ON RADIATION CHARACTERISTICS OF LARGE DEPLOYABLE ANTENNAS FOR SPACE USE

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1. Introduction

There are needs of large satellite-borne antennas with a diameter over 10 meters for space-VLBI systems or mobile satellite communications systems. Such large antennas should be folded compact in a rocket vehicle in launching phase, and deployed on its operational orbit.

Several mechanisms for that purpose have been proposed so far(1), in which the reflector approximates a prototype antenna with a smooth surface. The mechanical error causes the error of field distribution on the aperture to degrade the radiation characteristics as an antenna.

This paper presents the conditions imposed on large deployable antennas by their mission applications, theoretically predicted characteristics and experimental results using a model antenna.

2. Requirements by mission application

Large deployable antennas for space use should satisfy the following conditions:

(1)Electrical conditions

1)Frequency band: VLBI systems prefer 22, 5 and 1.7GHz bands and mobile satellite communications systems are planned in 1.55 and 1.65GHz bands.

2)Polarization: choice of circular or linear polarization, and capability to use two orthogonal polarizations.

3)Gain: needs high aperture efficiency and low feeding loss.

4)Noise temperature: depends on wide angle sidelobes and the distribution of noise or interference sources in a visual angle in space.

(2)Mechanical conditions

1)Size in a folded state, 2)Weight, 3)Strength, 4)Stiffness and momentum of inertia.

(3)Thermal conditions

Electrical conditions will be discussed. A receiving system such as a space-VLBI system or an up-link of a mobile satellite communications system aims to maximize the G/T_{sys} ratio of an antenna. System noise temperature T_{sys} is expressed by Eq.(1).

$$T_{sys} = T_A + T_{LNA} \tag{1}$$

where T_A : antenna noise temperature, T_{LNA} : noise temperature of a low noise amplifier

Therefore, T_A is expected to be smaller than T_{LNA} which is typically about 20K for 1.6GHz band LNA cooled at 150K.

In the case to receive the radiation from a large heavenly body such as the sun or the earth albedo by wide angle sidelobes, T_A is expressed by Eq.(2), assuming that the brightness temperature T_b is constant over the disc, and that the antenna power gain changes periodically with its peak value of G_p in the solid angle $\Delta\Omega$ for the disc.

$$T_A = 0.5 G_p T_b \Delta\Omega / 4\pi \tag{2}$$

As for the sun, $\Delta\Omega = 6.8 \times 10^{-5}$ sterad. and $T_b = 80000K$ at 1.6GHz. So, -20dB sidelobes of a 10 meter diameter antenna with aperture efficiency of 50% give T_A of 30K. It is, therefore, desirable to suppress wide angle sidelobes within the visual angle to a lower level than -20dB.

In a mobile satellite communications system, purposes to use a large antenna are to realize high flux density on the ground and to divide the service area by many sharp beams without mutual interferences. Therefore, gain and sidelobes around several degrees are important characteristics.

3. Analysis of radiation characteristics

Radiation characteristics are mainly determined by (a)field distribution on a reflector aperture, (b)spillovers from a subreflector and a main reflector, (c)blockages by a horn and a subreflector, (d)scattering by struts, and (e)reflection of mesh. This paper analyzes the effects of factor (a), based on the calculation method of Ref.(2).

A reflector composed of triangular facets to approximate a prototype paraboloidal surface as shown in Fig.1(3) is investigated as an example. The radiated field $E(\phi, \psi)$ in the far field from the aperture is expressed by the following Fraunhofer equation.

$$E(\phi, \psi) = (4\pi / \lambda^2 C) \int\int_S e(r, \theta) \exp j[kr \sin\phi \cos(\theta - \psi) - \Delta p] r dr d\theta \tag{3}$$

where λ : wavelength, k : wavenumber, $C = \int\int_S |e(r, \theta)|^2 r dr d\theta$, Δp : phase due to mechanical error

The field on the aperture is supposed that $e_y(r, \theta) = J_0(vr)$ neglecting the cross polar component, and $v=2.4$. The aperture diameter and the frequency are the same values as the model antenna.

Figure 2 shows the gain dependence on the division number which affects mechanical reflector error. D and F represent the diameter and focal length of the reflector, respectivily. Increasing the number N, the gain rapidly approaches that of the prototype antenna with hexagonal aperture. N of 7 is sufficient division to give the gain degradation less than 0.2dB.

The wide angle radiation patterns are shown by their envelopes in Fig.3 by thick lines. The level in ϕ =90deg. direction is higher than that in ϕ =0deg. This fact is caused by the difference of the reflector contours or edge tapers.

The curve for ϕ =0deg. shows peaks around the angles of (23 × integer deg.), which correspond to grating lobes with a period of D/4N. The curve for ϕ =90deg. has grating lobes corresponding to a period of $\sqrt{3}D/4N$. These values of the periods mean the averaged error distribution.

4. Experimental results using a model antenna

Figure 4 shows a polyhedron-approximated antenna under test. The prototype antenna is a shaped Cassegrain antenna with a diameter of 600mm and a focal length of 150mm. The diameter of a subreflector is 42mm, and a primary radiator is a conical horn with an aperture diameter of 22mm.

The approximated reflector surface was formed by attaching triangular facets of brass onto the prototype reflector. The facets projected on the reflector aperture are identical regular triangles of 60mm side length which divide the reflector radius by 5.

The measurement was carried out in an unechoic chamber using a defocusing technique to satisfy the far field condition. The frequency was 25.25GHz to simulate a 10 meter diameter antenna at 1.6GHz.

Gain measurement results are summarized in Table 1 in comparison with theoretical results, both relative to the gains of the hexagonal aperture antenna which has a smooth surface surrounded by radiowave absorber to shape the contour as shown in Fig.4. It is reasonably verified that the adopted calculation method is valid to explain the experimental results and the assumption of field distribution made for calculation was adequate.

Figure 5 shows wide angle radiation patterns when the electric vector lies between opposite vertexes of the hexagonal aperture. The spillover and blockage effects are recognized which depend on polarization direction. And peaks around 23deg. or 13 and 26deg. are significant in Fig.5(a) or (b), respectively. By other experiments, these peaks were shown to be dependent on the orientation of the hexagonal aperture but not on the polarization. The angles and levels of the peaks coincide with the theoretical results shown in Fig.3.

5. Conclusions

(1) The investigation of system performances shows that noise temperature due to wide angle sidelobes could be a fatal parameter together with gain. Rough estimation of wide angle sidelobe specification gives the value of -20dB relative to the boresight for a 10m diameter antenna at 1.6GHz.

(2) The validity of calculation method is verified by the experiment using a model antenna.

(3) Gain degradation of 10 meter diameter antenna at 1.6GHz due to mechanical error can be small enough if division number N is larger than 7.

(4) Grating lobes are apt to be conspicuous due to periodic error of a reflector.

Acknowledgement

The authors would like to thank Professor K.Miura for helpful suggestions on tension-truss antennas.

References

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(2)T.Takano and M.Ui, "A study on reflector error of large deployable antennas and its effects on radiation characteristics", Trans. of Inst. of Electr., Information and Comm. Engineers, vol.J71-B, no.6, pp.764-771, 1988. (in Japanese)

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Table 1. Comparison of gains

antenna type	prototype	hexagonal aperture	model antenna
experimental value	+0.6dB	0dB	-1.0dB
theoretical value	+0.3dB	0dB	-0.7dB

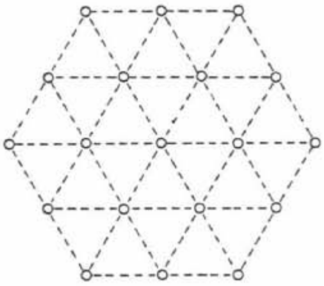


Fig.1 Tension-truss reflector.
o shows nodes on a prototype antenna.

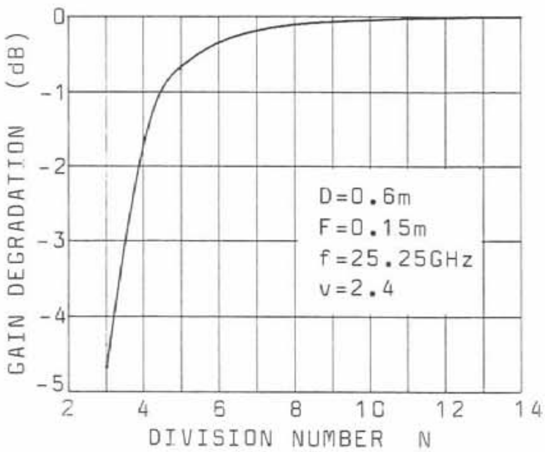


Fig.2 Antenna gain dependence on division number.

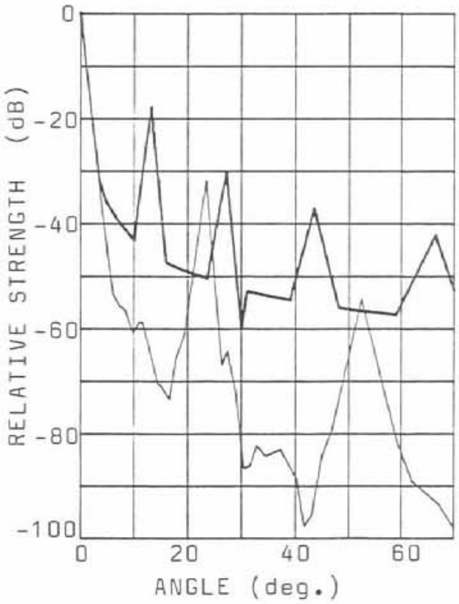


Fig.3 Computational results of wide angle radiation pattern.
——— between opposite vertexes.
——— between opposite sides.

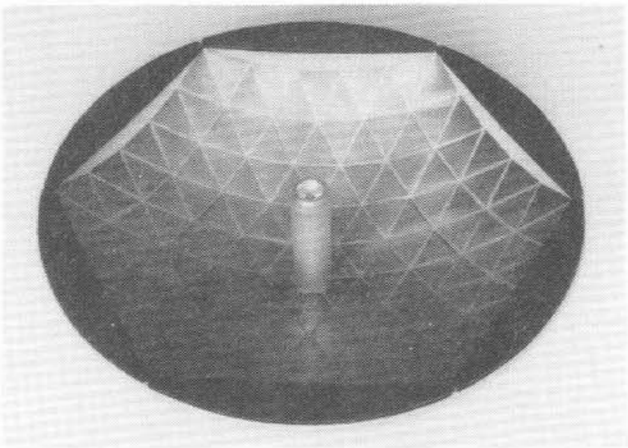
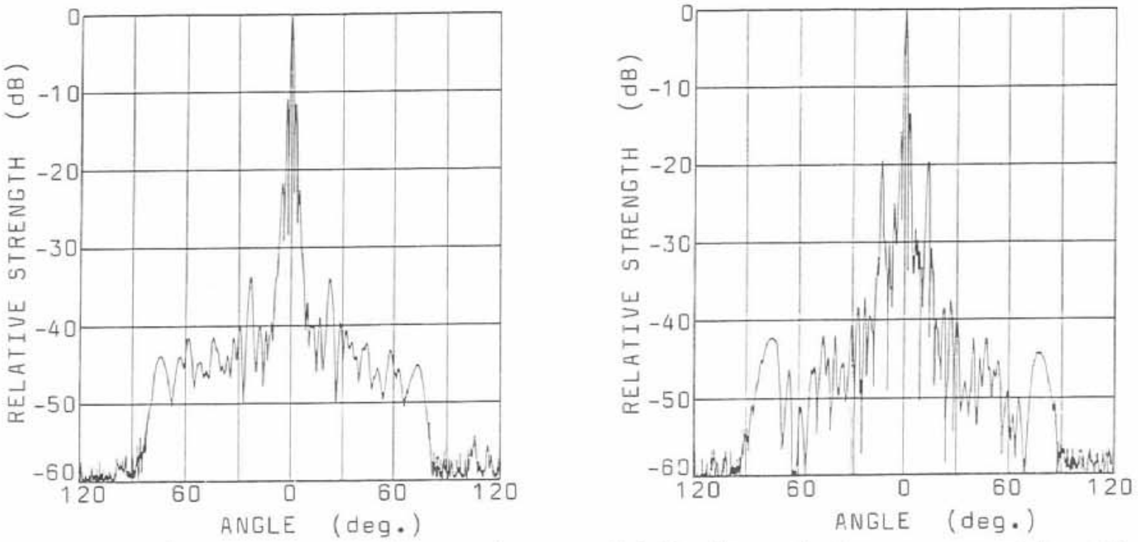


Fig.4 Outlook of the model antenna.



(a) E-plane, between opposite vertexes (b) H-plane, between opposite sides

Fig.5 Experimental results of wide angle radiation pattern.