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PATTERN DEGRADATION DUE TO SATELLITE ANTENNA DEFORMATION IN SPACE ORBIT

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1. Introduction

It is a world wide tendency to establish a multi beam communication technology in the 30/20 GHz bands. To construct a large capacity satellite communication system, the on-board antenna must satisfy requirements of frequency reuse and mass/structure properties. The electrical design goal of frequency reuse is to utilize the same frequency for every second beam in the same polarization. For sidelobe suppression, it is efficient to control the antenna aperture field distribution. When the antenna reflector is illuminated by a 9-horn cluster, the sidelobe can be more than 40dB below the main lobe peak (Ref.1). However, this property must be satisfied not in a rigid structure in a terrestrial environment but in a space environment for continuous operation.

In mechanical design of the on-board antenna, it is necessary to eliminate structural members and thermal control materials. However, eliminating these materials will tend to distort the reflector surface because of decreased stiffness and large temperature distribution. It is important to present allowable mechanical and thermal distortion which satisfy electrical specifications.

This paper clarifies requirements for mechanical and thermal distortion from the point of view of sidelobe level conditions. As for distortion, vibration during satellite maneuvering and illumination by solar rays are considered. Although electrical properties are evaluated in a simple two-dimensional model, the results are available as a first order approximation.

2. Antenna structure and deformation

The form of reflector distortion is closely connected with reflector structure. The two kinds of reflector structures taken into consideration are shown in Fig.1. The sandwich shell structure is the most popular one for space use because of its mass and structure properties. However, large diameter reflectors are more difficult to manufacture accurately than smaller ones. It will require additional frames with additional weight to compensate the distortion. On the other hand, although the truss structure antenna has not been used much in space, it has the advantage that the reflector surface can be controlled by adjusting the length of struts which connect the reflector skin and the truss. As an object of investigation, we have considered an offset paraboloidal reflecor which has its lower edge tightly connected to the satellite.

In general, the vibration mode of a cantilever beam can be estimated. As an antenna reflector is seen to be a surface which is fixed at a certain point, its vibration property is presented as that of a cantilever in a first order approximation. The dominant deformation caused by vibration has the approximate form of a quadratic curve. Furthermore, higher order deformations, except the dominant one, are ignored in assuming that the deformation amount decreases rapidly with the order of the mode.

The distortion caused by thermal expansion has many forms according to the solar ray incident direction. When the reflector surface of the sandwich shell structure is uniformly illuminated by solar rays and temperature differences between the front and rear occur, the reflector also reveals a quadratic warp like that of a bimetal (Ref.2). This deformation is treated in the same manner as that by vibration. In the case of truss structure, if there are temperature differences between the truss and the skin, the skin swells with the period of the supporting struts. Thus, the skin of truss structure deforms with a shorter period than that of sandwich shell.

3. Radiation pattern consideration

To simplify the problem, we restrict the calculation to the elevation pattern of an offset paraboloid reflector antenna. This restriction leads us to a two-dimensional model. The radiation pattern with a phase error on the aperture is evaluated in the following equation (Ref.3):

$$E(u)=\int_{-1}^{1} g(x)\exp(jf(x)+jux)dx \qquad (1)$$

where x is the radial distance normalized by the aperture radius, $u=\pi D\sin(\Theta)/\lambda$, Θ the angle from the boresight, g(x) and f(x) the amplitude and phase error distributions on the aperture. Function g(x) should be selected to produce a low sidelobe level. So, we select the following functions:

$$g(x)=1+2a\cos(\pi x) \quad ; a=0.4 \qquad (2)$$

This function generates a sidelobe of about -40dB (Ref.4). This distribution is almost entirely achieved by cluster horn feed (Ref.5). Phase error, caused by cluster feed excitation and by manufacturing error containing surface roughness, is ignored to clarify the effect of reflector deformation in space.

3.1 Quadratic deformation

Dominant vibration and thermal deformations of a sandwich shell structure yield the quadratic deformation approximated as shown in Fig.2. The deformed reflector surface is approximated in the following equations:

$$\rho'=\rho - \delta q(1+ \theta/\theta a)^2 /4 \quad ; \rho =2f/ (1+\cos(\theta +\theta o)) \qquad (3)$$

where ρ and ρ' are distances between the focus and the reflector surface before and after deformation, respectively, δq is the amount of deformation at the top of the reflector, f the focal length, θ the angle from offset axis, θo the offset angle, θa half of the angular aperture. Phase error Φ on the aperture is indicated by Eq.(4):

$$\Phi =k(\rho- \rho') (1+\cos(\theta+ \theta o)) \qquad (4)$$

where $k=2\pi/\lambda$. In calculating Eq.(1), Φ is expanded into a polynomial of θ and then terms of the constant and θ are excluded, because these affect only beam deviation. In an actual satellite system, these deviations are absorbed by the antenna pointing control system.

Calculated radiation patterns for $\theta o= \theta a=26.6°$ (f/D=1) and δq of 0, 0.13λ, 0.27λ, 0.4λ are shown in Fig.3. The figure shows that this type of deformation degrades the pattern of the angular region from the main lobe edge to the second sidelobe. Succeeding main beams are also plotted with a cross over of about -3dB as shown in Fig.3. When frequency reuse is operated in beam #0 and beams #2~ #5 (Ref.6), the sidelobe level of beam #0 must be suppressed in the region of beams #2~ #5 (low sidelobe level required region). This region is presented by $u= 2\pi\sim 22\pi/3$ because a beam width of -3dB is shown by $u=4\pi/3$ (Ref.4). The maximum undesired signal level in the low sidelobe level required region for δq is shown in Fig.4. If suppression by -35dB is required, it is seen that the maximum δq must be less than 0.2λ.

3.2 Periodic deformation

Truss structure thermal deformation is illustrated in Fig.5. The deformed reflector surface is formulated by the following equation:

$$\rho'=\rho - \delta t(1 \pm\cos((n-1)\pi\theta/\theta a))/2 \qquad (5)$$

where n is the number of struts and ± corresponds to the even and odd of n. The phase error on the aperture is given by Eq.(4). Radiation patterns obtained by the integration of Eq.(1) for δt of 0.033λ and four cases of n=7~10 are shown in Fig.6 with a dotted pattern for no phase error. Even with small δt, these patterns reveal strong grating lobes positioned according to the number of n. Radiation patterns for n=8 and four δt of 0, 0.033λ, 0.0067λ, 0.0033λ are shown in Fig.7. The angular position of the grating lobe is not changed with δt. Undesired signal levels in the low sidelobe level required region are plotted in Fig.8 for n and δt. When specifications require sidelobes of -35dB, there are two approaches: one is to keep δt within 0.0067λ, and the other is to select n to be more than 10. However, it should be noticed that δt also affects main lobe gain reduction. When n is 10 and δt is 0.033λ, 0.067λ, 0.13λ, the gain is reduced to 0.025, 0.1 and 0.4dB respectively. Even when a large n is selected, δt should be kept within 0.067λ.

4. Conclusion

The effects of mechanical and thermal deformation are calculated to determine the allowable deformation for a multi beam antenna. This is done by numerical analysis using a simplified two-dimensional model of an on-board antenna.

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References

(1) Y. Yamada and K. Kagoshima: IEEE AP-S Int. Symp., APS-13-10, p.498,1984.
(2) K. Oohata: Proc. 28th Space Sciences and Tech. Conf., 2C15, Oct., 1983.
(3) S. Silver, "Microwave Antenna Theory and Design", Dover.
(4) T. Kobayashi and K. Kagoshima: Paper Tech. Group on AP, IECE Jpn., A.P84-7, April 1984.
(5) K. Kagoshima, Y. Itami and Y. Yamada: Paper Tech. Group on AP, IECE Jpn., A.P83-66, Sep. 1983.
(6) I. Ohtomo, K. Ueno and T. Yasaka: Proc. 14th Int. Symp. on Space Tech. and Science, p.893, 1984.

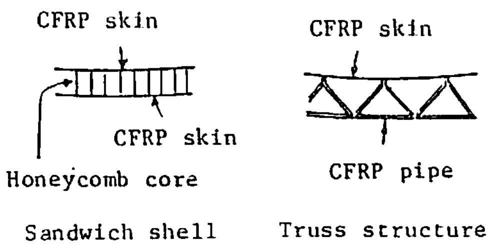

Fig.1 Reflector structures (cross section)

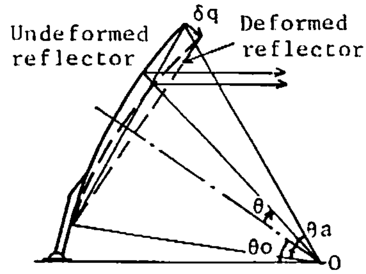

Fig.2 Quadratic reflector deformation

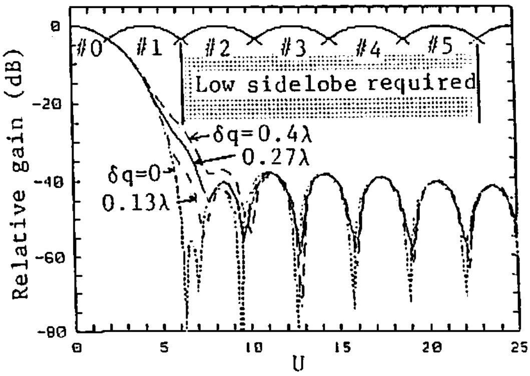

Fig.3 Radiation patterns with quadratic reflector deformatin

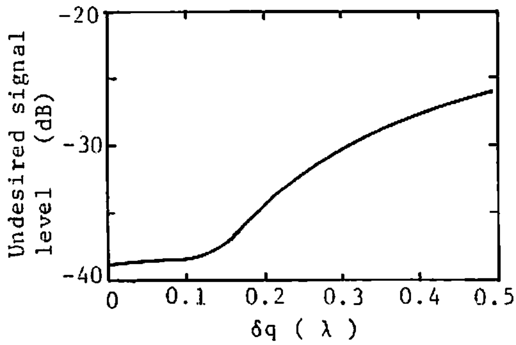

Fig.4 Undesired signal level versus maximum quadratic deformation

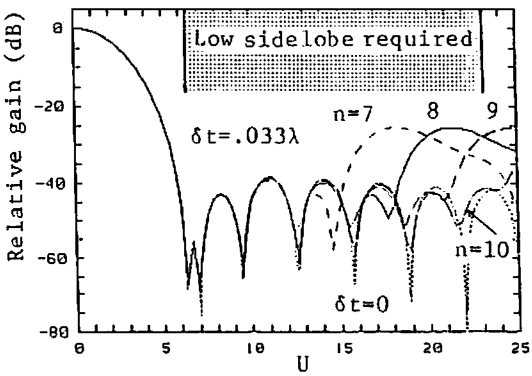

Fig.6 Radiation patterns with periodic deformation for n=7 ~ 10

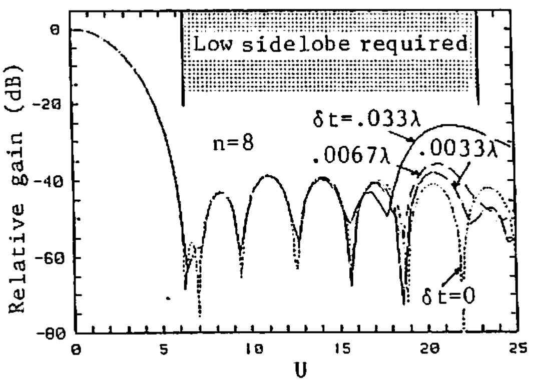

Fig.7 Radiation patterns with periodic deformation for δt= 0~ 0.033λ

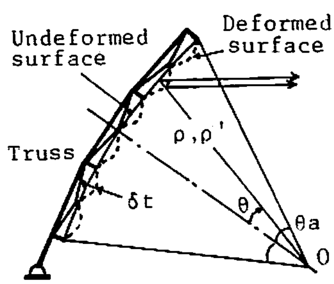

Fig.5 Periodic reflector deformation

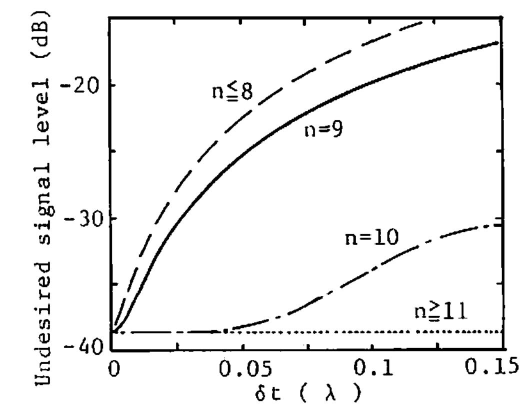

Fig.8 Undesired signal level versus maximum periodic deformation