Characteristics of an Ultra-Large Antenna with Hexagonal Element Apertures

Yoji MURAO Tadashi TAKANO

Institute of Space and Astronautical Science email:murao@malts.radionet.isas.ac.jp

1 Introduction

Antennas with a diameter larger than 100m, which needs a new construction method, have been discussed for microwave power transmission in space^[1]. An array antenna with circular element apertures of about 10m in diameter was formerly reported by the authors^[2]. This type of array antenna suffers grating lobes caused by the periodicity of the element aperture allocation, and has difficulty in mechanical steering of the main beam. This paper presents the numerical analisis of an array antenna of 100m in diameter whose element is a regular hexagonal aperture^[3] with a diameter of approximately 10m. The study to steer the main beam by phasing will be also described.

2 Structure of the proposed antenna

The structure of the antenna composed of 61 regular hexagonal apertures is shown in Fig.1. The element apertures are identical and placed on the vertices of the regular triangles inside the outer circle in the way that the sides of the hexagons are parallel to each other. In the following analysis, the radius of the outer circle is fixed to be 50m, and the frequency is 2.45GHz.

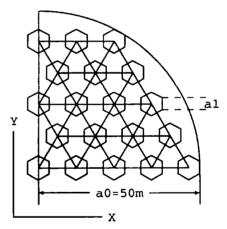


Figure 1: Structure of the antenna with hexagonal apertures (1st quadrant)

3 Expression of the far field

The far field diffraction pattern of an aperture antenna is given by

$$U_{P}(\theta,\phi) = \int_{A} F(\xi,\zeta) \exp(jk\sin\theta (\xi\cos\phi + \zeta\sin\phi)) d\xi d\zeta$$
(1)

where A: the aperture area, F: the field over the aperture, and k: propagation constant. The gain function is

$$G_M = \frac{4\pi}{\lambda^2} \frac{|U_P|^2}{\int_A |F(\xi,\zeta)|^2 d\xi d\zeta}$$
 (2)

where λ is the wavelength of the beam. For an array antenna whose element apertures are identical, the terms dependent on the allocation of element apertures can be extracted from the function U_P . Therefore, U_P is expressed by the product of the single antenna pattern and the remaining

term as follows:

$$U_{P,total} = f(\theta, \phi) U_{P,\epsilon lement}$$
 (3)

where $f(\theta, \phi)$ is the function called array factor which depends on the arrangement of the element antennas, and $U_{P,element}$ is the diffraction pattern of a single element antenna.

The diffraction pattern of a hexagonal aperture is given by

$$\begin{split} U_{P,hexagonal}\left(\theta,\phi\right) \\ &= \frac{12k_x^2}{k_y(3k_x^2 - k_y^2)} \left[\frac{\sin\left(k_x \frac{\sqrt{3}}{2} a_1\right) \sin\left(k_y \frac{a_1}{2}\right)}{k_x} + \frac{k_y}{\sqrt{3}k_x^2} \left\{ \cos\left(k_y a_1\right) - \cos\left(k_x \frac{\sqrt{3}}{2} a_1\right) \cos\left(k_y \frac{a_1}{2}\right) \right\} \right] \end{split}$$

where $k_x = k \sin \theta \cos \phi$, and $k_y = k \sin \theta \sin \phi$. The array factor $f(\theta, \phi)$ for this antenna is given by

$$f(\theta, \phi) = 1 + 2\sum_{i=1}^{4} \cos(ilk \sin\theta \cos\phi)$$
$$+4\cos\left(\frac{\sqrt{3}}{2}lk \sin\theta \sin\phi\right)$$

$$\cdot \sum_{i=1}^{4} \cos \left(\frac{2i-1}{2} lk \sin \theta \cos \phi \right)
+2 \cos \left(\sqrt{3} lk \sin \theta \sin \phi \right)
\cdot \left(1 + 2 \sum_{i=1}^{3} \cos \left(ilk \sin \theta \cos \phi \right) \right)
+4 \cos \left(\frac{3\sqrt{3}}{2} lk \sin \theta \sin \phi \right)
\cdot \sum_{i=1}^{3} \cos \left(\frac{2i-1}{2} lk \sin \theta \cos \phi \right)
+2 \cos \left(2\sqrt{3} lk \sin \theta \sin \phi \right)
\cdot \left(1 + 2 \sum_{i=1}^{2} \cos \left(ilk \sin \theta \cos \phi \right) \right)$$

where $l = (50 - a_1)/4$, and the gain function is

$$G_{total} = \frac{4\pi}{\lambda^2} \frac{\left(f(\theta, \phi) U_{P,hexaganat}\right)^2}{61 \frac{3\sqrt{3}\sigma_1^2}{2}}.$$
 (6)

4 Numerical analysis

The diffraction pattern of the antenna with the in-phased elements is shown in Fig.2. The element size a_1 is 5.56m. The

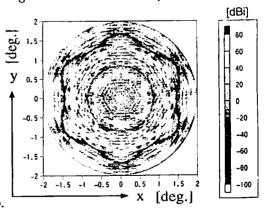


Figure 2: Radiation pattern $(a_1 = 5.56m)$

main beam, the highest level, is at the center. Some of the nulls form two hexagons in this angle range, the vertices of which

lie at 0.9deg, and 1.6deg, from the center, respectively. Comparatively higher points lie in lines from the center to the middle points of the sides or the vertices of the hexagons.

The two thick curves in Fig.3 show the diffraction pattern in X-direction and Y-direction. The antenna gain is 65dBi. In the X-scan the grating lobes are seen in the vicinity of 0.6deg, and 1.2deg, which will be called GL X1 and X2, respectively, in the later sentences. The first grating lobe in the Y-scan, which will be called GL Y, is seen at 0.7deg..

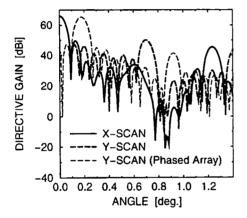


Figure 3: Radiation pattern $(a_1=5.56m)$

The directive gain of the main beam, the 1st sidelobes, and the grating lobes change according to a_1 . Figure 4 shows the results: (1)The main beam level increases in accordance with a_1 . (2)When $a_1 \leq 5.6m$, GL Y is greater than the 1st sidelobe. (3)One of the zeros of the single antenna pattern causes the minimum value of GL X2 in the vicinity of $a_1=3.9m$. (4)The difference in the element apertures arrangement in X-direction and Y-direction causes the different grating lobes.

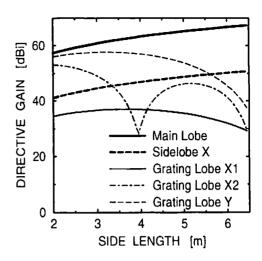


Figure 4: Directive gain vs. side length of a hexagonal element aperture

In the case of an array antenna with circular element apertures, the directive gain of those lobes is shown in Fig.5^[1]. Note that " a_1 " of the circular element is the radius of the element. Therefore, when the elements are allocated without any gap between them, a_1 in Fig.5 takes the value of 5.56m while a_1 of the hexagonal element, in Fig.4, is 6.42m. The side

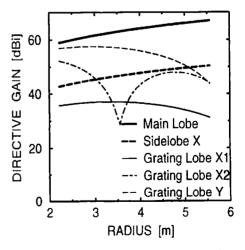


Figure 5: Directive gain vs. radius of a circular element aperture

lobes of the antenna with hexagonal apertures decreases more drastically with a larger element size than those of the antenna with circular apertures.

5 Beam steering by phasing

If the element apertures are fed with phase difference between adjacent ones, the beam may be steered. The thin curve in Fig.3 shows the pattern of the antenna, when the adjacent apertures have a phase difference of 90deg. in Y-direction. The main beam is shifted by approximately 0.2deg. from that of in-phase feeding. Figure 6 shows the direction of the main beam versus the phase difference between the two adjacent element apertures. The direction of the main beam changes linearly from 0deg. to 0.35deg., by 180deg. phase difference.

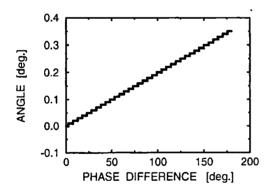


Figure 6: Angle of the main beam vs. phase difference

The directive gain of the steered antenna versus the phase difference is shown in Fig.7. Because the gain of the element aperture gets lower as the diffraction angle increases, the total gain of the shifted main beam decreases according to

the phase difference or the steering angle.

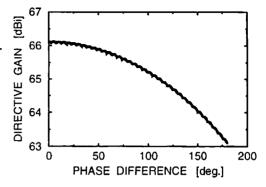


Figure 7: Directive gain vs. phase difference

6 Conclusion

The aperture array antenna of the fixed radius of 50m with hexagonal element apertures is proposed and analysed. The grating lobes can be made smaller than the first sidelobes when the side length of the element aperture is larger than 5.6m, which means 1.5m space between the elements. By phasing the main beam direction can be changed by 0.1deg, with the penalty of the gain decrease of 0.2dB.

References

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