

Parametric Analysis of the Radiation Characteristics of a Multiple-Folded Phased Array Antenna

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1. Introduction

A high gain antenna with a large aperture is required on a satellite for satellite communications, remote sensing, microwave power transmission, or scientific exploration. An important problem is how to obtain a large aperture in an orbit while being folded small in a rocket in a launch stage. There have been proposed several schemes to fold and deploy large parabolas [1] [2]. The tensioned truss antenna was launched in orbit [3]. In order to achieve even smaller folded volume, however, parabola antennas have difficulties due to the necessity of three-dimensional structure and mechanical stiffness.

To solve the problems, a phased array antenna (PAA) with flat panel structure may be a good candidate. We proposed a multiple- folding (MF) scheme to realize a significant improvement of the folding ratio, together with the method to compensate the phase discrepancy between panels by phasing [4]. The previous paper described the basic configuration of MF-PAA, and the analysis of principal characteristics and application forms.

In this paper, we generalize the concept of MF-PAA. The characteristics are analyzed for various values of step size. An antenna composed of nine panels with actual steps is simulated so that more realistic estimation will be possible.

2. Deduction of the radiation patterns from a planar array antenna

The proposed scheme is shown in Fig. 1(a) and (b). The folded state is a superimposition of nine panels, as shown in the figure (a). The deployed state is shown in the figure (b). Accordingly, the deployed panels are not in a single plane, but have level steps between the adjacent panels. The level difference between panels ranges from zero at smallest to eight thicknesses at largest in this case.

We assume that the radiation pattern is expressed in the form of variable separation, as follows:

$$f_t(\theta_x, \theta_y) = f_x(\theta_x) \times f_y(\theta_y). \quad (1)$$

The radiation pattern in x-direction $f_x(\theta_x)$ is the superposition of three rows ($i = 1, 3$) which are composed of three panels in x-direction, respectively. Therefore, we obtain,

$$f_x(\theta_x) = \sum_{i=1}^3 f_{xi}(\theta_x). \quad (2)$$

Each panel has four radiating elements in this case. The $f_{xi}(\theta_x)$ is expressed by the product of an element radiation pattern $f_{xi}^e(\theta_x)$ and the array factor $f_{xi}^a(\theta_x)$, as follows:

$$f_{xi}(\theta_x) = f_{xi}^e(\theta_x) f_{xi}^a(\theta_x). \quad (3)$$

The $f_{xi}^e(\theta_x)$ depends on the kind of the element. And,

$$f_{xi}^a = \sum_{na-1}^2 \exp(jknd(\sin\theta - \sin\theta_0)) \times \exp(j\phi) \quad (4)$$

where k is a wave number which is given by $2\pi/\lambda$, and λ is a wavelength, d is the element spacing, θ_0 is the desired beam direction, and ϕ is the compensated phase.

The $f_y(\theta_y)$ can be formulated in the same way as described above for $f_x(\theta_x)$.

3. Simulation Model of the Antenna

As the first step, two panels are considered, as shown in Fig. 2 in the side view in z-x plane. The elements are assumed infinitesimal dipoles located a quarter wavelength above the reflector. Radiating elements are installed at the i -th point A_i on the panel surface. The level difference between panels is s . The radiated wave to the angle θ from the normal direction is considered.

The complex radiated field f_i is described by the superposition of the components of the wave packets No.1 to No.4. With the desired beam angle θ_0 , the field is expressed as follows:

$$f_i = a \left[\sum_{n=1}^2 \exp(jk(n-1)d(\sin\theta - \sin\theta_0)) + \sum_{n=3}^4 \exp(jk(n-1)d(\sin\theta - \sin\theta_0)) \times \exp(-jks(\cos\theta - \cos\theta_0)) \right] \quad (5)$$

where a is an element excitation coefficient assuming a constant value for all elements.

The panel thickness is 4 mm. The frequency is 18.8 GHz. The level difference between panels is assumed equal to the panel thickness, which is $\lambda/4$ in this case. The reflectors on the panels are a thin rectangle with the size of $\lambda \times \lambda$. The separation d is a half wavelength.

The radiation pattern from this configuration is analyzed for various values of s , while keeping θ_0 constant, 30 deg. The FD-TD simulator was used.

At the second step, the radiation pattern from MF-PAA with nine panels shown in Fig. 1 is analyzed. Taking a reference to the center panel in Fig. 1, the panel levels are as follows: 0 mm (2), 4 mm (1), 16 mm (1), 20 mm (2), 28 mm (1), and 32 mm (2). The figures in brackets mean the number of correspondent panels.

4. Simulation Results

4.1 Pattern change according to step size

The computed radiation power patterns $|f_i|^2$ in the cases with and without phase compensation are shown and compared in Fig. 3. The step is 8mm or a half wavelength which causes most severe effects. Without the phase compensation, the pattern expressed by thin solid lines has the null at the desired angle of 30 deg. With the phase compensation by Eq. (5), the pattern is improved as shown by the thick solid line. The main beam is directed to the desired angle.

Fig. 3 also includes the pattern for a flat array antenna of the same elements and same location on the reflector as a reference. The compensated patterns are almost the same as the reference pattern. But the main beam in the minus angle is slightly lower than the reference. The peak directions of the compensated beam are slightly different from the desired angle as well as the reference. The side-lobes are -7dB and -5dB for the plus and minus scan angle, respectively, and are both higher than the reference by about 4dB.

Fig. 4 shows the case with a step of 4 mm or a quarter wavelengths. The effects are not as severe as the case shown in Fig. 3.

All data taken for various values are summarized in Fig. 5. The gain is kept almost constant and the same as the reference. The case in the minus angle scan, however, shows gradual degradation up to 3 dB due to blocking effect by the step. Without compensation, the gain drastically decreased due to phase deterioration by the step.

4.2 Radiation pattern from the entire array antenna

The calculated pattern of the array antenna is shown in Fig. 6. The azimuth angle ϕ is the same as the analyses of two panels. For $\phi = 0$ deg, the directivity is 19 dBi which is -1 dB relative to that of the reference antenna. The direction of the main lobe is slightly inward to the desired angle 30 deg. The highest side-lobe is 1 dB lower than that of the reference.

for $\phi = 180$ deg, the directivity is 18.5 dBi which is -1.5 dB relative to that of the reference. The direction of the main lobe is slightly inward to the desired angle -30 deg. The highest side-lobe is -1 dB lower than that of the reference.

5. Conclusions

The analysis results show that a step between two panels can be compensated by the proposed method in the case of 30deg beam shift. Blocking effect due to a higher step, however, deteriorates the antenna characteristics for a large step of $\lambda/2$.

The entire array antenna in multiple- folding scheme has excellent characteristics which are almost the same as a flat array antenna on a single plane. From these facts, the availability of MF-PAA is confirmed. As the blocking effect is significant, large step should be avoided in the design of panels and folding scheme, especially for antennas with a small number of elements.

References

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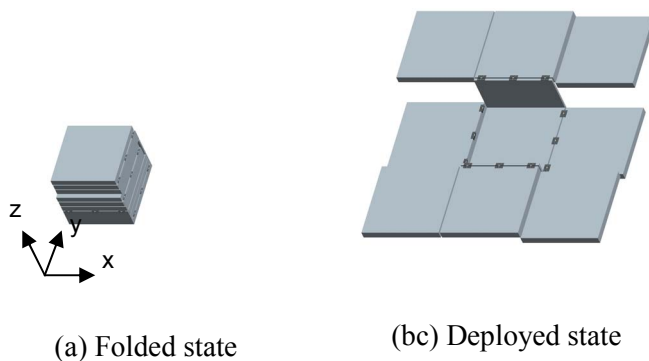


Fig. 1 the proposed array antenna with nine panels in two states.

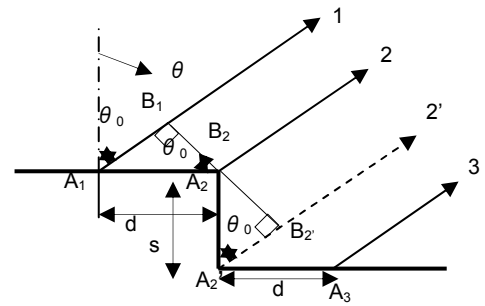
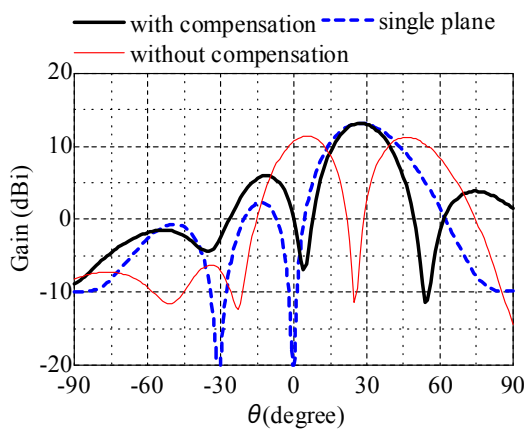
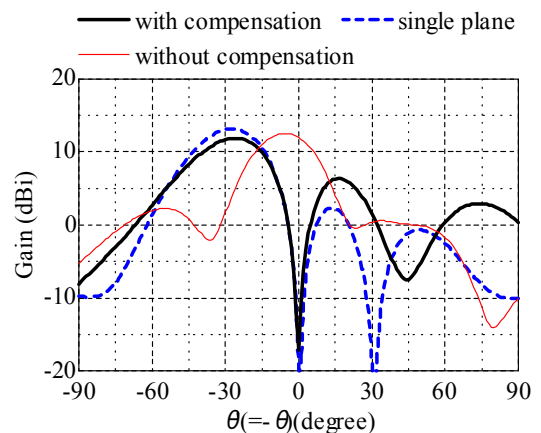


Fig. 2 Phase variation due to a step between panels.

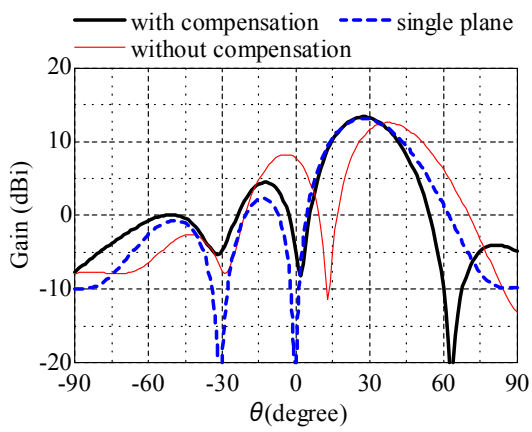


(a) $\phi = 0$ deg

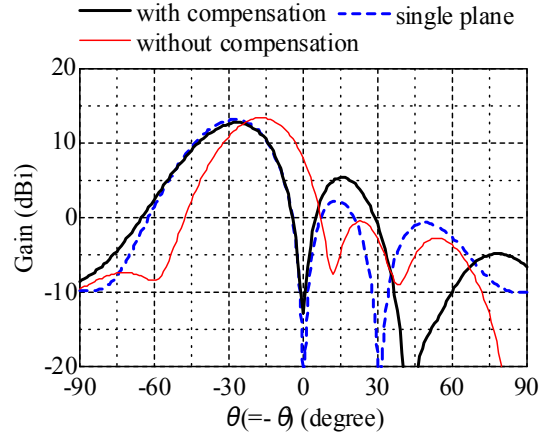


(b) $\phi = 180$ deg

Fig. 3 Radiation patterns from two panels (step= $\lambda/2$)

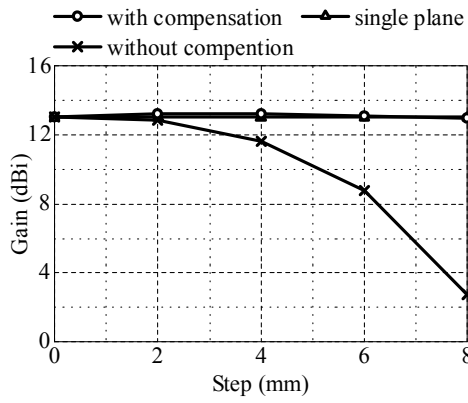


(a) $\phi = 0$ deg

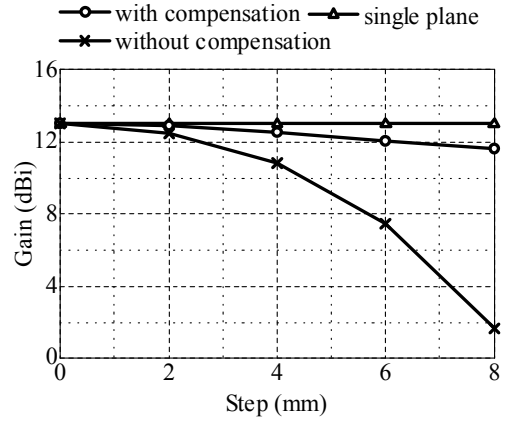


(b) $\phi = 180$ deg

Fig. 4 Radiation patterns from two panels (step= $\lambda/4$)

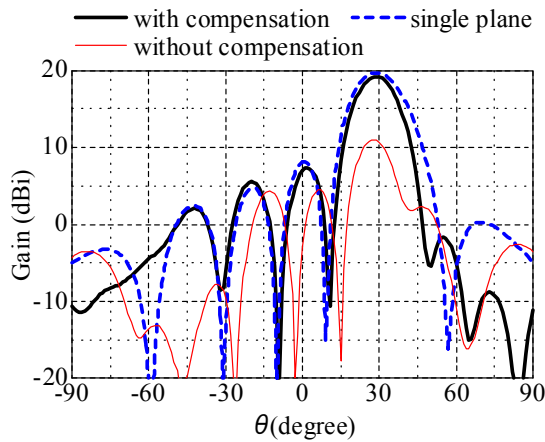


(a) $\phi = 0$ deg

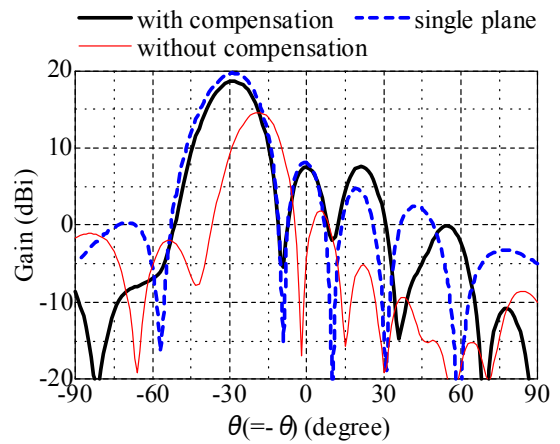


(b) $\phi = 180$ deg

Fig. 5 Dependence of the gain on the step for two panels.



(a) $\phi = 0$ deg



(b) $\phi = 180$ deg

Fig. 6 Radiation patterns from the entire array antenna with nine panels.