Novel Phased Array Antenna in a Multiple Folding Scheme and its Application to a Satellite

#Tadashi Takano [1], Hiroyuki Hosono [1], Kenji Saegusa [1],
Yasuyuki Miyazaki [2], Kenji Uchiyama [2], and Yuta Araki [2]
1 Department of Electronic and Computer Science
2 Department of Aerospace Engineering
Nihon University
7-24-1 Narashino-dai, Funabashi, 274-8501 Japan
takano@ecs.cst.nihon-u.ac.jp

Abstract

This paper proposes a high- gain array antenna in a novel multiple folding scheme of panels. The phase of array elements is deteriorated due to the mechanical steps between panels, but is compensated by additional phasing to the driving field. The numerical simulation shows the availability of the proposed schemes. Its application to a remote sensing satellite is presented.

Keywords : Phased array antenna, Deploy, Multiple folding, Panel steps, Phase compensation, Application, Remote sensing.

1. Introduction

A mission of satellite communications, remote sensing, microwave power transmission, or some scientific exploration requires a high gain antenna (HGA) with a large aperture on a satellite. An important problem is how to obtain a large aperture in an orbit while being folded small in a rocket in a launch stage. Moreover, an HGA is required particular functions in some missions. For example, remote sensing and radars needs the scanning antenna beam. Satellite communications use a shaped beam or multiple beams to accomplish an efficient communication network.

There have been proposed several schemes to fold and deploy large parabolas [1] [2]. The folding ratio, which is defined by the ratio of the folded volume to the deployed aperture area, is 0.5λ in the case of the tensioned truss antenna [3]. In order to achieve a smaller ratio, parabola antennas have difficulties due to the necessity of three-dimensional structure and mechanical stiffness. On the other hand, an array antenna with flat panel structure may be a good candidate to lessen the folded volume. However, if a panel is simply overlapped on another panel, the folding ratio is limited to a large value.

We propose a multiple folding scheme to realize a significant improvement of the folding ratio. An aperture is divided into panels, and the panels are folded in a multiple scheme. In the deployed state, however, adjacent panels have steps between panels as each panel has a finite thickness. Accordingly, the radiated waves suffer from significant discrepancy of phase distribution on the aperture.

Then, we make another proposal to compensate the phase discrepancy by electrical means. If we scan the beam, however, the compensation should depend on the scanning angle. In other words, the compensation should be accomplished dynamically. This phase compensation is also effective to keep the accurate phase distribution on the aperture against panel deformation.

The resultant proposed antenna is a phased array antenna (PAA) in multiple folding (MF) scheme, and is called MF-PAA in the subsequent section. We study the features of MF-PAA for applications to space activities, especially a remote sensing satellite.

This paper first explains the proposed folding scheme and antenna structure. Next, the phase compensation method is presented with numerical simulation data. Finally, the comparison with a parabolic reflector antenna and possible application to a satellite will be given.

2. Concept of a Phased Array Antenna in a Multiple Folding Scheme

An antenna aperture with nine panels is schematically shown in Fig. 1(a). Each panel is a rectangular plate with sides of a and b, and a thickness of t. Therefore, the total aperture is 3a x 3b. Radiating elements are installed on the panels. The problem is how to fold the panels in simple and systematic manners avoiding mechanical interferences.

The proposed scheme is shown in Fig. 1(b) and (c). The folded state is a superimposition of nine panels, as shown in the figure (b), three panels of which compose a pile of a deployment unit. In the first deploying process, the upper most pile is push up in y-direction, and its two outside panels are deployed in x-direction. Then, the second pile is deployed in the same way as the first pile. Finally, nine panels are deployed, as shown in the figure (c).

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.

3. Phase Compensation method and the Radiation Simulation Result

A step between two panels is shown in the perpendicular plane to the step line in Fig. 2. Radiating elements are installed at the i-th point A_i on the panel surface with a constant spacing d. The level difference between panels is denoted by s. The radiated wave is directed to the angle θ from the normal direction.

The wave packets No.1 and No3 have longer paths than No.2 by A_1B_1, and by - A_1B_1 + $A_{2'}B_{2'}$, respectively. Each term is given by

$$A_1B_1 = d\sin\theta, \text{ and } A_{2'}B_{2'} = s\cos\theta. \quad (1)$$

Therefore, the wave packets No.1 and No.3 have the resultant phase retardation to No.2.

The complex radiated field ft is described by the superposition of the components of the wave packets No.1 to No.3. If we want to shift the beam to the angle θ_0, the phase exponent of each team should be compensated to be zero at $\theta = \theta_0$. Therefore, the resultant field is expressed by

$$f_t = \sum_{n-1} \exp(-jk(n-1)d(\sin\theta - \sin\theta_0)) + \sum_{n-1} \exp(jknd(\sin\theta - \sin\theta_0)) \times \exp(-jks(\cos\theta - \cos\theta_0)), \quad (2)$$

where k is a wave number which is given by $2\pi/\lambda$, and λ is a wavelength. Here, we assume isotropic radiation from each element so that Eq. (2) actually represents an array factor.

This phase compensation can be accomplished dynamically according to the angle θ_0. The beam shift in the plane parallel to the step line can be realized by the conventional phase compensation in the same way as a flat PAA.

Next, we compute and compare the radiation power patterns $|f_t|^2$ in the cases with and without phase compensation. We assume that the elements are five on a panel with spacing d =λ/2, the frequency is 18.8 GHz, and the panel thickness is 8 mm. The level difference between panels is assumed equal to the panel thickness, which is λ/2 in this case. The simulation is carried out in two cases of θ_0 = 0, 20 deg. (0.35 rad.).

The results of $|f_t|^2$ are shown in Fig. 3. The radiated pattern without the phase compensation is expressed by broken lines. With the desired angle θ_0 = 0 deg., the pattern has the null at the boresight because the panel step corresponds to the phase difference of π. If we compensate the phase difference by Eq. (2), the pattern is changed as shown by the solid line. The beam points 0 deg. with the peak height of 100 which is equal to the radiated power of 10 elements with a unity power.

Trying to shift the beam to θ_0 = 20 deg. by compensating only the phase of $kd\sin\theta_0$, the power level at 20 deg. is null, in vain. However, by additionally compensating the phase of $ks\cos\theta_0$, the peak is shifted to 20 deg. with the power of almost 100.

4. Application to a Satellite in Comparison with a Parabola Antenna

As an HGA, the proposed MF-PAA and a conventional parabolic reflector antenna are compared in Table 1. MF-PAA is advantageous in mechanical folding, beam scanning and aperture efficiency, but has demerits in the weight, frequency characteristics, and electric power. Some of the demerits are being solved by partial drive technique [4] [5].

The final appearance of MF-PAA is shown in Fig. 4 with partial drive technique. The antenna is composed of panels, each of which has a number of radiating elements. Therefore, a panel itself has functions of a smaller antenna so that a large antenna can be made by assembling a desired number of panels. Also, a small design change may be acceptable even in the system development phase. These points are not available in a parabolic reflector antenna which is a single complete unit of an antenna.

As for antenna functions, MF-PAA can afford the gain change, beam scanning, multiple beams, and beam shaping. On the other hand, in a parabola antenna, these functions are realized by moving a horn or switching horns, which is much slower in response than MF-PAA.

An HGA is so large to occupy a whole side of a satellite body. However, MF-PAA may be attached to another side of the satellite and deployed facing to the same direction as the other HGA. MF-PAA has a great advantage of wide beam scan, but supports only one frequency.

Considering these features, a remote sensing satellite may benefit from the MF-PAA. The whole satellite configuration is shown in Fig. 8. A solar cell paddle should point to the sun so that the normal direction is different from those of two HGAs.

5. Conclusions

By the proposed scheme of multiple folding, the antenna with nine panels can be folded into the 1/9 of the antenna aperture and the total thickness of 9 panels.

The phase deterioration due to steps between panels can be compensated according to the desired beam direction by the proposed method. Accordingly, the radiation pattern and gain are almost restored to those of a flat array antenna.

We studied the application of the antenna to a remote sensing satellite, and showed a possible configuration and advantages in comparison with a parabola antenna.

References

[1] R.E.Freeland, N.F.Garcia and H.Iwamoto: "Wrap-rib antenna technology development", NASA CP-2368, pp.139-166 (Dec.1984).

[2] T.G.Campbell, D.H.Butler, K.Belvin and B.B.Allen: "Development of the 15-meter hoop/column antenna system", NASA CP-2368, pp.167-212 (Dec.1984).

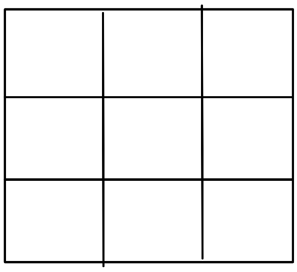
[3] T. Takano et al., “Deployable Antenna With 10-m Maximum Diameter for Space Use”, IEEE Transactions on Antennas and Propagation, Vol.52, No.1, pp.2-11, 2004.

[4] M. Okumura et al., “Theoretical and Experimental Study on a Partially Driven Array Antenna with Simplified Dipole Elements”, IET Microwaves, Antennas & Propagation, Vol.2, No.7, pp696-703, March 2008.

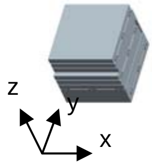
[5] T. Takano, T. Imura and M. Okumura, "Experimental Study of a Partially Driven Array Antenna with a Reflector", ISAP2010, 43, Macao, November 2010.

Table 1 Multiple folding phased array antenna (MF-PAA) versus parabola antenna

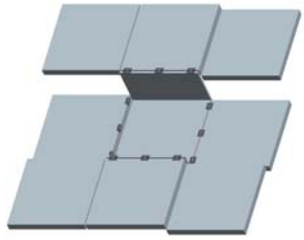
Items	MF-PAA	Parabola antenna
Folding capability	excellent, large folding ratio, flexible.	poor, special folding technique
Weight	heavy	light
Frequency	one frequency	two frequencies are possible.
Band width	narrow, about 3%	wide, about 15%
Beam scanning	< 22 deg.	< 5(λ /D) rad.
Aperture efficiency	< 100%	< 50%
Feeding loss	with gain using amplifiers	0 dB from the horn input
Electric power	amplifiers, phase shifters	horn driving motors



(a) Deployed aperture in plan view.



(b) Folded state



(c) Deployed state

Fig. 1 Deploying sequence of the proposed array antenna with nine panels.

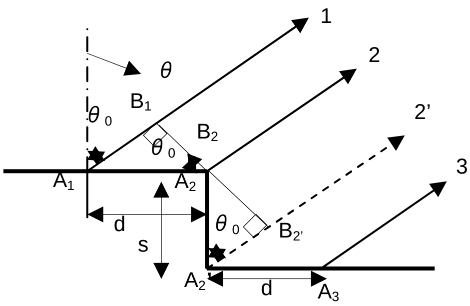
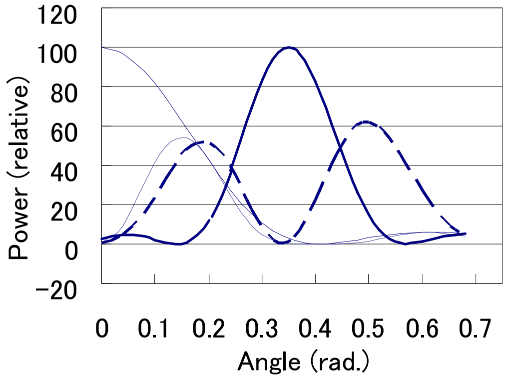


Fig. 2 Phase variation due to a step between panels.



———— with compensation
– – – – – – without compensation
Thin lines and thick lines are for θ_0 = 0 and 20 deg., respectively.
Fig. 3 Computed radiation patterns.

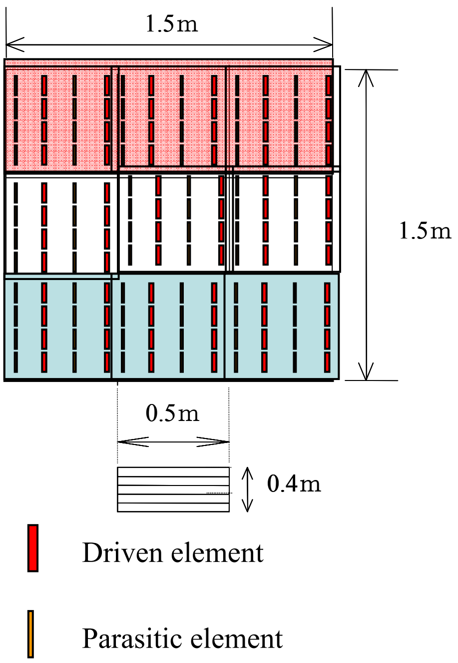
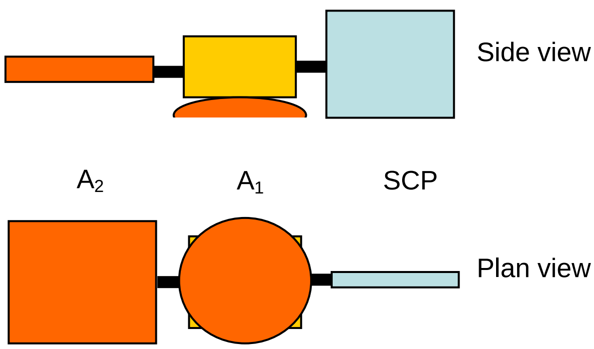


Fig. 4 Configuration of the proposed antenna with element dipoles in partial drive concept.



A1: Communication antenna: parabola, T and R, Two frequencies in X-band.
A2: Radiometer antenna: MF-PAA, R only, 18.8 GHz.
SCP: Solar cell paddle: MF scheme structure.

Fig. 5 Application of the proposed antenna to a remote sensing satellite.