BEAM POINTING METHOD IN A DEPLOYABLE PHASED ARRAY ANTENNA FOR SPACE USE

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1 Introduction

In a phased array antenna, the excitation phase is the most important factor. For the case when the observation point coincides with the point towards which the beam should be directed, the method for determining the excitation phase is presented in reference [1]. In this case, deflection of the main beam due to a change of the satellite attitude or distortion of the antenna surface can be corrected. However, in an antenna in which the shape of the main beam has to be maintained, the observation point should be placed apart from the main beam region. In this paper, we investigate the necessary number of observation points to correct main beam deflection and present a method that makes it possible not only to correct the deflection of the main beam but also to measure displacement of relative element positions.

2 Theory

When the shape of the main beam has to be maintained in an antenna, like the one for a Solar Power Satellite (SPS) [2], the observation point should be placed apart from the main beam region such as shown in Figure 1. Here, an array antenna consisting of M elements is assumed as the antenna under test (AUT) which is on the satellite. The point of the standard element on the AUT is assumed as the origin of the coordinates in this scheme and Z-axis is assumed in the direction towards which the beam should be directed. Here, the relative position of the element antenna of AUT is $\mathbf{r}_m$ and the unit vector of observation point #n from the origin $\mathbf{v}_n$ is assumed to be known. The excitation phase of each element can be determined by applying Rotating-element Electric-field Vector (REV) method[3] at each observation point. This is a method to determine amplitude and phase values of the electrical field vector radiated from each element antenna of a phased array antenna under operation.

The observation point in the direction $\mathbf{v}_n$ is denoted as #n. When the REV method is carried out at the observation point #n, the relative amplitude $E_{n,m}$ and phase $\phi_{n,m}$ of the #m-th element are measured. $E_{n,m}$ and $\phi_{n,m}$ are expressed as:

$$E_{n,m}e^{j\phi_{n,m}} = \frac{E_m}{E_{0n}}e^{j\Phi_m}\frac{e^{-jkr_{n,m}}}{r_{n,m}}e^{-jP_{0,n}}, (m = 1 \ to \ M) \qquad (1)$$

E_m and Φ_m are the amplitude and phase of the element antenna #m, $E_{0,n}$ and $P_{0,n}$ are those of the initial composite field at observation point #n, k is the wave number and $r_{n,m}$ is the distance between the element antenna #m of the AUT and observation point #n. Using the phase component in this equation in case of far field approximation ($r_{n,m} >> |\mathbf{r}_m|$) we have,

$$\phi'_{n,m} = \Phi'_m + k \cdot (r_m \cdot v_n) \qquad (2)$$

Here the phase is normalized by that of the standard element #1 which is $\phi'_{n,m} = \phi_{n,m} - \phi_{n,1}$ and $\Phi'_m = \Phi_m - \Phi_1$, and $\mathbf{r}_m$ is the vector pointing towards the element #m.

(1) When observing in the main beam direction, such as in reference [1], in order to determine the optimum excitation phase, REV method can be applied at the observation point indicated n=0 in Fig.1 which is the position to which the beam should be directed.

(2) When observation point is placed apart from the main beam direction, such as in SPS, REV method is applied at the observation point #n ($n \neq 0$). As from equation (2), $-\phi'_{0,m}$ is the excitation phase for beam direction. The relation is expressed by the following equation:

$$\phi'_{n,m} - \phi'_{0,m} = kr_m \cdot (v_n - v_0) \qquad (3)$$

where $\mathbf{v}_0$ is the unit vector pointing in +z direction.

When the antenna structure is distorted and difference in element position arises, the position vector is expressed as:

$$r_m = r_{m0} + \Delta r_m$$
$$= (x_{m0} + x_m, y_{m0} + y_m, z_{m0} + z_m) \qquad (4)$$

where $\Delta \mathbf{r}_m$ is the displacement of the element antenna #m and $\mathbf{r}_{m0}$ is the initial relative position of the element antenna. Accordingly, eq.(3) becomes as follows:

$$\phi'_{0,m} = \phi'_{n,m} - k(r_{m0} + \Delta r_m) \cdot (v_n - v_0) \qquad (5)$$

Now, we consider two cases when (i) $k \cdot \Delta \mathbf{r}_m \cdot (\mathbf{v}_n - \mathbf{v}_0)$ is negligibly small and when (ii) $k \cdot \Delta \mathbf{r}_m \cdot (\mathbf{v}_n - \mathbf{v}_0)$ needs to be considered.

(i) If $k \cdot \Delta \mathbf{r}_m \cdot (\mathbf{v}_n - \mathbf{v}_0)$ is small enough, eq.(5) becomes as follows:

$$\phi'_{0,m} = \phi'_{n,m} - kr_{m0} \cdot (v_n - v_0) \qquad (6)$$

Terms in the right hand side are known and $\phi'_{0,m}$ can be determined from this equation, and in this case, only one observation point is sufficient.

(ii) When the distance between the AUT and the observation point is not far enough, the first case cannot be applied. In this case, eq.(5) is transformed as follows:

$$\phi'_{n,m} - \phi'_{0,m} = A_{n,m} + B_{n1}x_m + B_{n2}y_m + B_{n3}z_m \qquad (7)$$

where,

$$A_{n,m} = k\mathbf{r}_{m0} \cdot (\mathbf{v}_n - \mathbf{v}_0) \quad , \quad B_{n2} = k \sin\theta_n \sin\phi_n$$
$$B_{n1} = k \sin\theta_n \cos\phi_n \quad , \quad B_{n3} = k(\cos\theta_n - 1)$$

This is an equation composed of four unknowns, which are $\phi'_{0,m}, x_m, y_m$ and z_m (other terms are known values). By using four observation points, simultaneous equations can be derived from the above relations and the excitation phase $-\phi'_{0,m}$ and the displacement of element antennas could be derived.

3 Experiment

Here, the result of an experiment detecting the position of the element antenna is shown. Figure 2 shows the measuring system of this experiment. The frequency is 11.85GHz and 8-element array antenna is used as the AUT. The antenna is measured from four receiving points using REV method. Figure 3 shows the radiation pattern comparing the one obtained by this method with the one obtained by observing in the main beam direction. A good agreement between the two can be seen from these results. Figure 4 shows the calculated results of the displacement of element positions.

4 Summary

We have investigated the necessary number of observation points in cases when the observation point is placed apart from the main beam region such as in an SPS, and have examined the case when the distortion is negligibly small and the case when the distortion should be considered. As a result, it was confirmed that when the distortion is small, one observation point is sufficient to correct main beam deflection. When the distortion is large, by using four observation points, not only deflection of the main beam can be corrected but also displacement of relative element positions can be measured.

The element positions are determined by measuring the phase of each element antenna from multiple receiving points using REV method. The effectiveness of this method was experimentally confirmed.

References

[1] T.Katagi, Y.Konishi, Y.Tamai and Y.Iida : "A Large Deployable Active Phased Array Antenna for Satellite Use", Proc.15th International Comm. Sat. Sys. Conf., AIAA-94-1070, pp.1075-1084 (February 1994).

[2] H.Matsumoto : "Microwave Power Transmission from Space and Related Nonlinear Plasma Effects", Radio Science Bulletin No.273, pp.11-35, (June 1995).

[3] S.Mano and T.Katagi : "A Method for Measuring Amplitude and Phase of Each Radiating Element of a Phased Array Antenna", Electronics and Communications in Japan, Vol.65-B, No.5, pp.58-64 (May 1982).

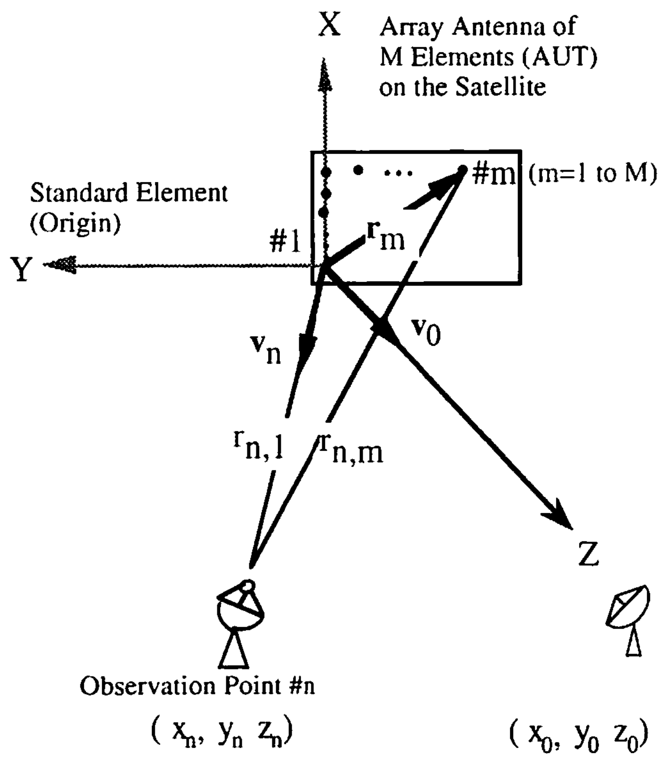

Fig.1 Satellite Antenna Measuring Scheme

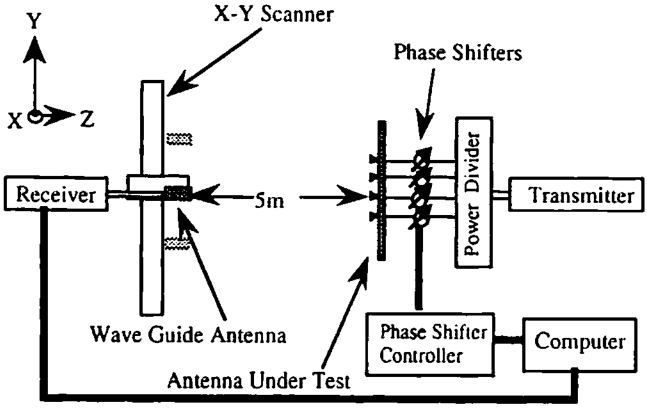

Fig.2 Measurement Structure

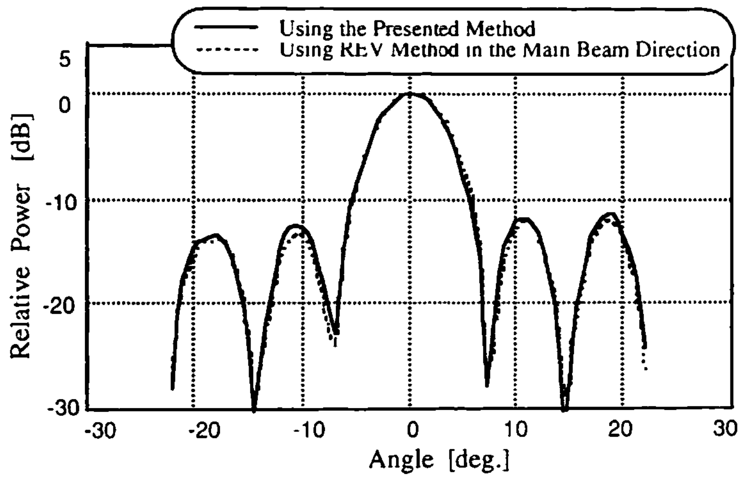

Fig.3 Antenna Pattern after Phase Control

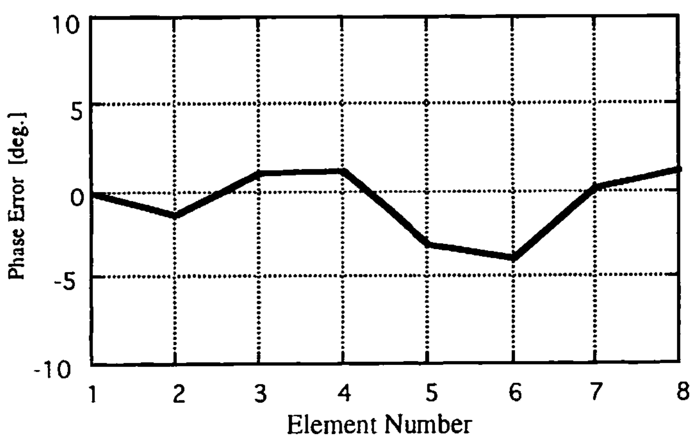

Fig.4 Phase Error of each Element