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Estimation of Directivity on Array Antennas by Using 1D Electric Current Distribution

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***Abstract* - We estimate a radiation pattern of a linear array antenna from 1D electric current distribution by approximating the antenna's radiation directivity by a series of small dipole elements and calculating the sum of radiations from them. As a result, we confirm that the estimation on the dipole array antenna is accurate and good pattern on the patch array antenna is obtained by removing the effect of the edges of the ground plane of the antenna. We also show that estimation results are obtained in high accuracy by setting the sampling interval $l \leqq \lambda/28$ on the all antennas under test.**

***Index Terms* — Directivity estimation, electric current distribution, linear array antenna, small dipole element.**

I. Introduction

As the number of base station for a mobile phone is increasing, we need to evaluate the performance of a base station antenna quickly. In particular, the radiation directivity of the antenna is one of the major characteristics in the evaluation. However, a sufficient long distance is necessary to measure an antenna with a narrow beam radiation in the vertical plane. In this case, a huge anechoic chamber, an open site, a compact range [1], a near-field measurement [2],[3] and so on are used for the measurement. These methods have the problems in saving a space, weather condition, the cost and long measurement time of near field scanning. These problems should be solved to realize a simple and quick directivity measurement.

To overcome these difficulties, we propose the estimation method of the radiation directivity on a linear array antenna by using the one-dimensional (1D) current distribution. The method can save substantial measurement time because of a very simple linear scanning. Although several companies already estimate the directivity from the current distribution on the antenna, we aim to make the measurement easier and clarify measurement conditions for more accurate estimation.

In this paper, we verify the validity of the estimation method by simulations on some array antennas. Furthermore, we discuss the conditions to obtain high accuracy results.

II. Directivity Estimation Method

Here, we propose the directivity estimation method. First, we assume that the antenna under test (AUT) is a series of small dipole elements and an electric current equal to the current distribution is flowing on each dipole element. Next, we calculate the sum of radiations from the dipole elements. This relation is shown by the following equations,

$$\mathrm{E}_r[1\times m] = \mathrm{G}_r[m\times n]\, J[n\times 1] \tag{1}$$

$$\mathrm{E}_\theta[1\times m] = \mathrm{G}_\theta[m\times n]\, J[n\times 1] \tag{2}$$

where J and E show an electric current vector and an electric field vector, and m and n are the number of the estimated electric field data and the electric current on the AUT. In the spherical coordinate system, each component of G is shown by the following equations based on the theory of a radiation from a small dipole element [4] :

$$G_{r,ij} = \frac{\eta_0 l k^2 \cos\theta e^{-jkR_{ijn}}}{2\pi}\left\{\frac{1}{(kR_{ij})^2} - j\frac{1}{(kR_{ij})^3}\right\} \tag{3}$$

$$G_{\theta,ij} = \frac{\eta_0 l k^2 \sin\theta e^{-jkR_{ij}}}{4\pi}\left\{j\frac{1}{kR_{ij}} + \frac{1}{(kR_{ij})^2} - j\frac{1}{(kR_{ij})^3}\right\} \tag{4}$$

Here, η_0 is the characteristic impedance, k is the wavenumber, and l is the sampling interval equal to the length of the small dipole element. and R_{ij} is the distance between a position of the i-th electric current and one of the j-th electric field ($i = 1, 2,\ldots, m,\ j = 1, 2,\ldots, n$).

III. Estimation Result

We estimate a directivity of the AUT by using the method described above. The current distribution and a theoretical directivity are derived by the electromagnetic simulator FEKO [5]. The AUTs are an 8-element linear dipole array (LDA) and a linear patch array (LPA) antenna. A testing frequency is 3 GHz. We evaluate the estimation accuracy by using ΔG defined in the following equation,

$$\Delta G = Gain(FEKO) - Gain(Est.)\quad [dBi] \tag{5}$$

where the first- and the second- term show the theoretical- and the estimated- gain of the AUT. In this paper, we obtain the directivity and gain in only the vertical plane. Therefore, it is assumed that the directivity in ϕ is omni-directional.

We show estimation results and the ΔG in Figs. 1, 2 and Table I, respectively. In these figures, results obtained by changing the sampling interval l and using the current data at its feeding points are shown. The interval l has the relationship $N_z = D/l$, where N_z is a number of z-directional division and D is the maximum size of the AUT. For the LDA, the estimated directivities substantially correspond to the theoretical value regardless of l. In addition, the estimation from the current on only the feeding points has a sufficient accuracy. The ΔG less than 0.06 dBi in Table I shows high accuracy. For the LPA, the estimation result is better when $l = \lambda/16$ than when $l = \lambda/8$. We confirm this fact from the ΔG. However, estimation accuracy is about 0.7 dBi higher in ΔG than the LDA's one. This is due to the difference in their structure since the LDA has a 1D structure along the z-axis and the LPA has a 2D structure along x- and z-axis, and the second is the effect of the ground plane edge current of the LPA. When we change the scanning area not to include the edges, more accurate result is obtain shown in Fig. 3 and $\Delta G = 0.346$ dBi. In this figure, 'w/ G' and 'w/o G' mean that the estimated directivity includes and doesn't include the edge effects of the ground plane respectively. Therefore we can estimate the directivity that almost agrees with the theoretical value by removing the effect of the edges.

We show the relationship between the ΔG and l in Fig. 4. Here, we add an 4-element LDA and LPA to the AUTs. The ΔG on the LDAs is almost zero when $l \leqq \lambda/8$, and that of the 4- and 8-elment LPA converges to about 0.36 dBi for $l \leqq \lambda/28$ and about 0.75 dBi for $l \leqq \lambda/16$. Therefore we define $l \leqq \lambda/28$ so that it is much shorter than the wavelength if the structure is complicated compared to a dipole antenna because the AUT is approximated by the 'small' dipole elements in our estimation method.

TABLE I Accuracy evaluation by ΔG

l	LDA	LPA
$\lambda/16$	0.011	0.752
$\lambda/8$	0.040	0.782
Feed	0.056	-0.259

Unit [dBi]

IV. Conclusion

In this paper, we estimated the radiation directivity in the vertical plane by using 1D electric current distribution. As a result, we confirmed that the estimated directivity of the LDA is accurate and good pattern on the LPA is obtained by removing the edge effects of the ground plane of the antenna. Moreover, it was shown that high accuracy was obtained for LDA and LPA when the sampling interval $l \leqq \lambda/28$.

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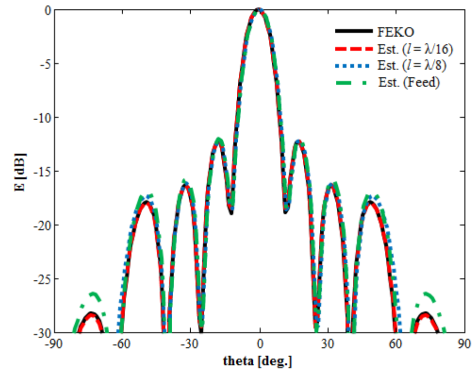

Fig. 1. Radiation directivity of 8-element LDA

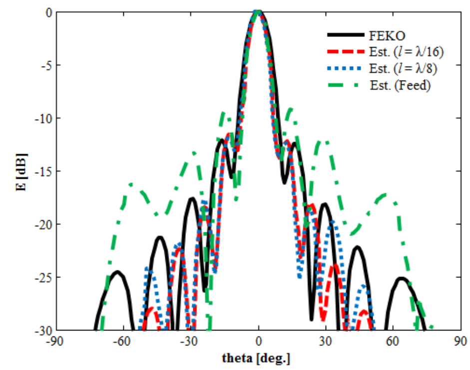

Fig. 2. Radiation directivity of 8-element LPA

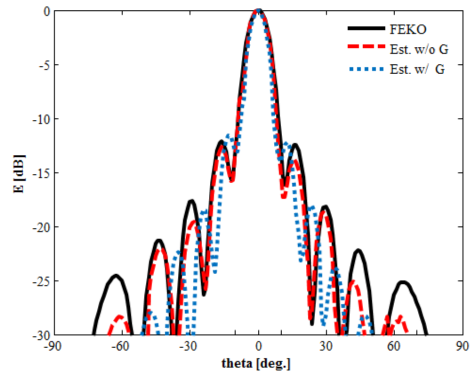

Fig. 3. Radiation directivity w/ and w/o the effect of the ground plane

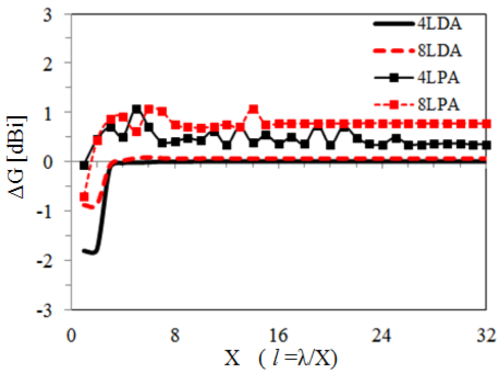

Fig. 4. Relationship between ΔG and the sampling interval l