B—1—5 ANALYSIS OF MULTIPATH PROPAGATION BY A SMALL ANTENNA

Kazuaki TAKAO and Keiich SAKURAI*
Department of Electrical Engineering, Kyoto University, Kyoto, JAPAN

Summary: A method of determining precise angles of arrival of multipath propagation is presented. Neither large space nor large-scale antenna is required but a small antenna(an example of a half-wavelength dipole is shown here) is sufficient, which is a favorable feature for outdoor, on-the-spot diagnosis of receiving difficulties.

Introduction: Recently, troubles of radio reception due to multipath propagation has been a serious problem in mobile communication and TV broadcasting. In order to analyze such field structure, the specific parameters of the incoming waves, i.e., intensity, phase and direction must be measured. As for the angular resolution, even a multi-element Yagi-Uda antenna cannot produce a sufficiently narrow beamwidth, and application of aperture synthesis has been sometimes tried.

These measurements, however, require a large aperture, real or effective, so that the following drawbacks will arise; (1) Such large space cannot always be guaranteed, especially in urban areas, (2) The apparatus becomes too large and heavy for mobile measurement, and (3) Their principle of performance is vulnerable where the correlation distance is very small as in a complicated field. These are the motives to investigate the possibility of achieving a high resolution with a small antenna and space.

Principle: Fig.1 shows a half-wavelength dipole antenna which is supported at its center and rotated with an arm of length r. Both the antenna and arm are in the horizontal plane throughout the rotation around the center O, the other end of the arm. The angle Φ between the antenna and arm is a critical parameter and should be chosen as discussed later. We assume that the number of incoming waves is finite, and that all of them are horizontally polarized plane waves. A representative wave is shown in the figure, where k is the wave number, $2\pi/\lambda$ with λ as the wavelength.

The directional characteristics of this antenna system is given by,

$$d(\theta,\phi) = \sin(\phi + \Phi) \exp(jkr \sin\theta \cos\phi)$$
$$= -j/2\, (e^{j\phi}e^{j\Phi} - e^{-j\phi}e^{-j\Phi}) \sum_{-\infty}^{\infty} J_n(kr \sin\theta)\, j^n e^{jn\phi} \qquad (1)$$

This $d(\theta,\phi)$ is a periodic function of ϕ with the period of 2π, and its Fourier series expansion has

$$D_n(\theta) = -1/2\, \{e^{j\Phi} J_{n-1}(kr \sin\theta) + e^{-j\Phi} J_{n+1}(kr \sin\theta)\}\, j^n$$
$$n = 0, \pm 1, \pm 2, \ldots\ldots \qquad (2)$$

as its n-th order component. Let us assume that the number of incoming waves is L and the i-th wave has a complex amplitude A_i and angle of arrival (θ_i,ϕ_i), then the source distribution $b(\theta,\phi)$ is given by

$$b(\theta,\phi) = \sum_{i=1}^{L} A_i\, \delta(\theta-\theta_i)\, \delta(\phi-\phi_i) \qquad (3)$$

The output complex voltage $v(\phi)$ when the antenna is rotated by angle ϕ is

$$v(\phi) = \sum_{i=1}^{L} A_i \, d(\theta_i, \phi-\phi_i)$$

$$= \sum_{n=-\infty}^{\infty} \sum_{i=1}^{L} A_i \, D_n(\theta_i) \, e^{jn(\phi-\phi_i)} \quad (4)$$

The n-th order component of the Fourier series of $v(\phi)$ is given by

$$V(n) = \sum_{i=1}^{L} A_i \, D_n(\theta_i) \, e^{-jn\phi_i} \quad (5)$$

Now, the Fourier component of the source distribution $b(\phi)$ is given by

$$B(n) = V(n)/D_n(90°) = \sum_{i=i}^{L} A_i \, \{D_n(\theta_i)/D_n(90°)\} \, e^{-jn\phi_i}$$

$$= \sum_{i=1}^{L} A_i \, q_i \, e^{-jn\phi_i} \quad (6)$$

where

$$q_i = D(\theta_i)/D_n(90°) \quad (7)$$

$V(n)$ and $D_n(90°)$ are derivable from measured quantities, but q_i cannot be determined since θ_i's are unknown at this stage. If q_i does not depend on θ_i and can be treated as constant, (6) will reduce to a set of simple simultaneous equations with $n = 0, \pm 1, \pm 2, \ldots..$

We now go back to (2) to investigate $D_n(\theta)$. From practical viewpoint, the range $\theta = 90° \pm 40°$ is considered. For the cases of $r = \lambda/4$ and $\lambda/2$, $D_n(\theta)$'s are calculated for $n = 0 \sim 3$ and $n = 0 \sim 5$, respectively. The results are shown in Fig.2. In this figure, two kinds of symmetricity, one around $\theta = 90°$ and the other around $n = 0$ are taken into consideration and the redundant parts are omitted. The examination of the figure concludes the choice of $\Phi = 30°$ will best allow the approximation of q_i of (7) as unity. With this Φ, we get

$$B(n) = \sum_{i=1}^{L} A_i (e^{-j\phi_i})^n, \qquad n = 0, \pm 1, \pm 2, \ldots.. \quad (8)$$

In our case, (8) does not contain large enough higher-order components. So, we utilize the lower-order components($n = -N \sim N$; with $N \geq L$) and apply Prony's method[1] to solve (8) and obtain A_i's and ϕ_i's.

If θ_i's need to be known, an additional measurement of $v(\phi)$ must be done with a different height of the arm-dipole plane. If two waves are coming from the same ϕ but different θ, four $v(\phi)$ measurements at different heights have to be made. This time, Prony's method is applied in terms of θ and two waves are to be discriminated.

Discussion: A simple method of multipath direction finding has been presented. If a minicomputer is carried with the system, a few seconds of data processing will give on-the-spot display of angles of arrival. A similar idea of using Bessel functions was proposed independently[2], but it requires a large number of higher harmonics so that it seems impractical compared with ours.

Acknowledgement: The authors express their sincere gratitude to Professors, Fumio Ikegami and Iwane Kimura for their encouragement. This research was supported by Japanese Ministry of Education in the form of grant-in-aid fund

for scientific research; No.1977-142029.

References: [1] F.B. Hildebrand,"Introduction to Numerical Analysis" McGraw Hill, 378-386 (1956)
[2] J. Fleuret and G. Haiman,"Detection angulaire d'ondes planes de surface par analyse de Fourier" L'onde electronique, 313-318 (1976)

* K. Sakurai has been transferred to KDD Ltd. after completing this research.

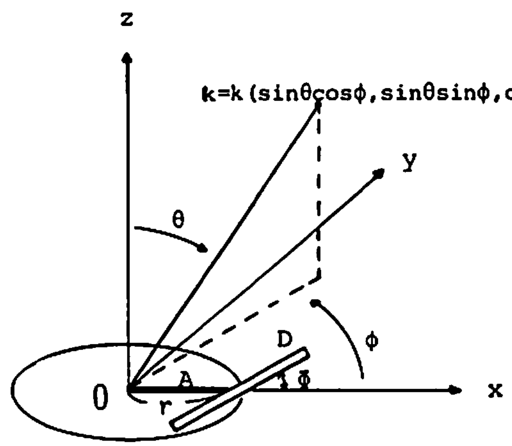

Fig.1 Eccentric rotation of a dipole
D:dipole, A:arm
k:wave number(vector)

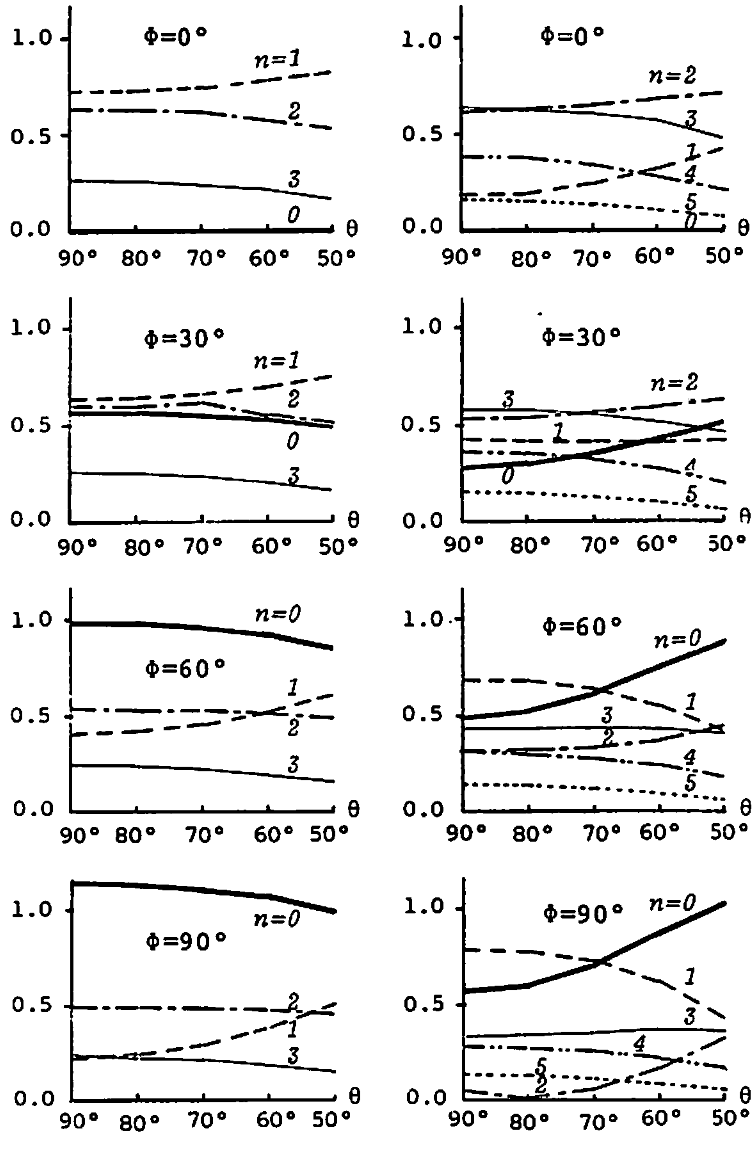

Fig.2 Fourier components $D_n(\theta)$

$|D_n(\theta)|$ is shown along the ordinate, while its phase variation is so small and omitted here.