Measurement System of Polarization and Phase Components for Evaluating Cellular Phone Antenna Performance in Multipath Propagation Environments

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1. Introduction

One of the conventional statistical methods for evaluating antenna performances in multipath propagation environments (mobile environments) is to use Pattern Effective Gain (PAG) [1], in which the received power of both vertical and horizontal polarization components are used for evaluation. However, in practical field operation, some inconsistency was often experienced with the practical antenna performance. It was considered that this inconsistency was attributable to lack of phase components in the evaluation, and so a method, in which phase components in both incident waves and the antenna system are taken into account in the evaluation, has been proposed [2].

This paper first describes a newly developed system, which can measure *phases* as well as the amplitude of both vertical and horizontal polarization components of received signals. The objective of the development of this system is to attain more reasonable evaluation of the antenna performance in multipath environments as compared with the use of the conventional method. The paper goes on to describe measurement of field parameters obtained by using this system in both urban and suburban areas of Tokyo. This system has also been applied to measure antenna parameters and the results obtained by using one of the latest PDC mobile phones are introduced. Finally, a fading property of the received power of the antenna with consideration of the measured *phases*, simulated in a dynamic mobile situation by using the method introduced here, is described.

2. Measurement system of polarization and phase components

The measurement system is designed to separately detect the vertical and horizontal components of the incident electric field, finding their phase components at the same time.

Fig. 1 depicts the block diagram of the measurement system and the specifications are shown in Table 1. Fig. 2 shows the coordinate system, where $\mathbf{i}_\theta$ and $\mathbf{i}_\phi$ are unit vectors corresponding to θ and ϕ components, respectively. The measurement system consists of two Yagi-Uda antennas, an antenna rotator, two down-converters, two received-signal-strength-indicators (RSSI), a phase detection circuit, a digital storage oscilloscope (DSO), and a personal computer (PC). The two Yagi-Uda antennas share the same axis and their elements are crossed orthogonal to each other so that the vertical E_θ and horizontal E_ϕ components of the incident electric field can be received at the same time, as shown in Fig. 1. The incident electric field is measured in azimuth ($\theta=\pi/2$) by rotating the Yagi-Uda antenna. The phase detection circuit provides IQ signals, by which phase difference δ_F between the vertical and horizontal polarization components is calculated. The PC controls the antenna rotator and the DSO. The PC is also used for calculating parameters such as the major axis (a), the minor axis (b) and the tilt angle ψ of a polarization ellipse from the power P_θ of the vertical polarization component, the power P_ϕ of the horizontal polarization component, and δ_F. By using these parameters the incident electric field **E** in azimuth is expressed by [2].

$$\mathbf{E}(\phi) = \mathbf{i}_\theta E_\theta(\phi) + \mathbf{i}_\phi E_\phi(\phi)\exp[j\delta_F(\phi)] \tag{1}$$

In the measurement, a reference antenna is used to find phases ζ_θ and ζ_ϕ of the vertical and horizontal components, respectively, as the difference from that of the reference antenna, as shown in Fig. 3. Practically these two phases ζ_θ and ζ_ϕ can be obtained by means of switches in the measurement as Fig. 3 shows. Now Equ (1) is rewritten as:

$$\mathbf{E}(\phi) = \mathbf{i}_\theta E_\theta(\phi)\exp[j\zeta_\theta(\phi)] + \mathbf{i}_\phi E_\phi(\phi)\exp[j\zeta_\phi(\phi)] \quad (2)$$

3. Measurement of field parameters

The practical field measurements were performed in both urban and suburban areas of Tokyo. The down link control channel of the PDC system was utilized in order to identify the received wave channel. Since the control channel is assigned to every sector in a base station coverage area, the parameters of received waves can easily be evaluated.

An example of the measured results is shown in Fig. 4, where Fig. 4(a) and Fig. 4(b) show the incident field distribution patterns (field pattern) $P_\theta(\phi)$ and $P_\phi(\phi)$, respectively, in which arrows indicate direction of major incident waves. Fig. 4(c) and Fig. 4(d), respectively, show $\zeta_\theta(\phi)$ and $\zeta_\phi(\phi)$ with respect to the antenna direction ϕ. Fig. 5 shows polarization ellipses of three major incident waves calculated from the measured results for the incident angles ϕ=64°, 190°, and 353°. From the figure, variation of the polarization ellipses depending on the incident angle of waves can be clearly seen.

4. Evaluation of an antenna performance with measured parameters

The measurement system can be used for obtaining antenna parameters as well as field parameters. Fig. 6 (a) shows the set-up for measuring antenna parameters in an anechoic chamber and Fig. 6 (b) is a view of the set-up. To simulate a talk position, a mobile phone, one of the latest PDC models, was placed close to a human head phantom, with an inclined angle of 60°. Although the basic concept of the measurement is the same as that shown in Fig. 1, the practical set-up differs in that the phantom, to which a transmitting antenna was mounted, was rotated while the Yagi-Uda antenna remained halted. In this case, antenna parameters are evaluated by using antenna transfer function $\mathbf{T}(\phi')$ as follows:,

$$\mathbf{T}(\phi') = \mathbf{i}_\theta h_\theta D_\theta(\phi')\exp[j\zeta'_\theta(\phi')] + \mathbf{i}_\phi h_\phi D_\phi(\phi')\exp[j\zeta'_\phi(\phi')] \quad (3)$$

where h_θ and h_ϕ are the effective length characterizing the antenna performance, and $D_\theta(\phi')$ and $D_\phi(\phi')$ are antenna gain patterns, in each vertical and horizontal components, respectively. Here ϕ' denotes the angle taken as the sub-coordinate system to express antenna gain patterns. $\mathbf{T}(\phi')$ gives the open-circuit voltage $V(\phi, \phi')$ at the out-put terminal of a receiving antenna along with the incident electric field $\mathbf{E}(\phi)$ as follows:,

$$V(\phi,\phi') = \mathbf{E}(\phi)\cdot\mathbf{T}(\phi') \quad (4)$$

Then the received power of the antenna is calculated by using $V(\phi, \phi')$.

Fig. 7 shows measured parameters for a case where a $\lambda/4$ whip antenna was applied to the PDC mobile phone. The mean value of $D_\phi(\phi')$ was observed to be greater than that of $D_\theta(\phi')$, because of the inclined set-up for the talk situation of the PDC mobile phone.

The received power on the assumption of the practical field operation can be calculated by taking phase components $\zeta_\theta(\phi)$, $\zeta_\phi(\phi)$, $\zeta'_\theta(\phi')$ and $\zeta'_\phi(\phi')$ of the incident electric field and the antenna gain patterns, respectively, in the evaluation of the antenna performance.

Fig. 8 shows is the cumulative probability distribution (CPD) of the received power of the measured mobile phone in a dynamic situation whose initial condition is set by using the measured field parameters, obtained by the method described above. This is a result evaluated for a mobile phone moving over 10 m with a speed of 3 km/h. It can be seen that the CPD almost follows the Rayleigh distribution, which is shown by a line in Fig. 8.

As a result of taking phase components into account, we can come to evaluate the antenna performance as *fading or dynamic* property in the multipath environment, based on the measured parameters of the real fields and the mobile phone antenna in the actual usage, whereas the antenna performance is evaluated as the statistical average value by the use of the conventional method.

5. Conclusions

A system for the measurement of polarization and phase components as well as the amplitude of the received signals has been developed in order to improve the evaluation of an antenna performance in the multipath environment. Some results obtained by using this system have been introduced and an improved result has been described by giving an example, where a PDC mobile phone was used. This paper described the effectiveness of a newly developed measurement system, and has shown that, as a consequence of the use of this system, evaluation of antenna performances in a multipath environment can be improved as compared with the use of the conventional method. This indicates also the significance of considering phase characteristics of the incident field and the antenna system in the evaluation of antenna performances. We will evaluate multiple-antenna performances in the multipath environment by using this measurement system. It is supposed to be useful for designing the new concept of mobile antenna capable of realizing diversity or adaptive control at mobile terminal.

References

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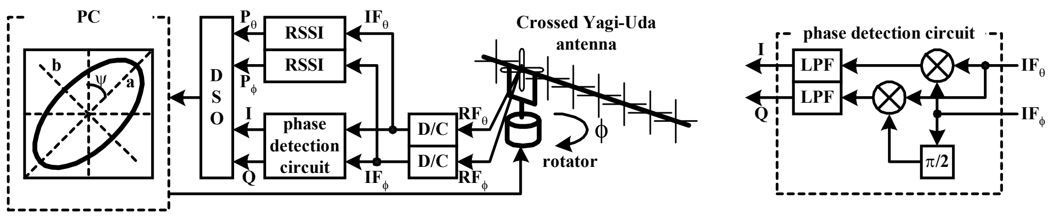
[2] Y.Nakagawa, M.Mimura, K.Miyano, M.Hasegawa, Y.Koyanagi and K.Fujimoto, "New Antenna Evaluation Method with Polarization Characteristics for Small Zone Cellular", 4th Int. Conf. Multi-Dimensional Mobile Communications, pp.109-116, 2001



(a) (b)

Fig. 1 (a)Block diagram of polarization and phase measurement system, (b)Phase detection circuit

Table 1 Specifications of the measurement system

Radio Frequency		800[MHz]
Intermediate Frequency		400[kHz]
Input dynamic range		40[dB]
Crossed Yagi-Uda antenna	Directivity	10[dBi]
	Half-power beamwidth	30[degrees]
	Cross polarization discrimination	20[dB]

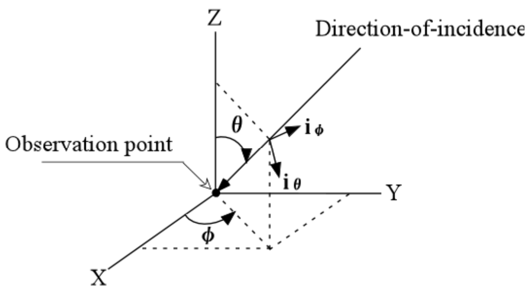


Fig. 2 Coordinate system

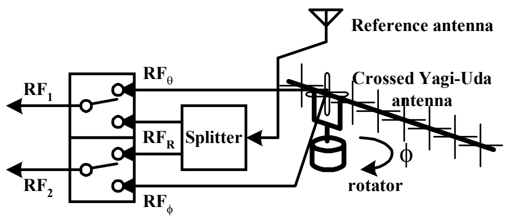
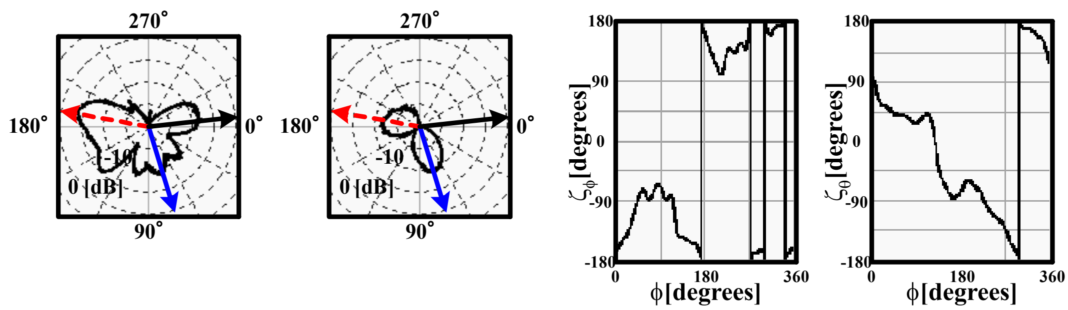
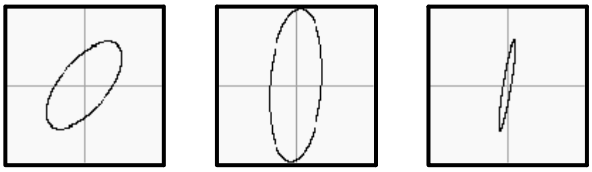


Fig. 3 Block diagram for measuring each phase of vertically and horizontally polarized components separately



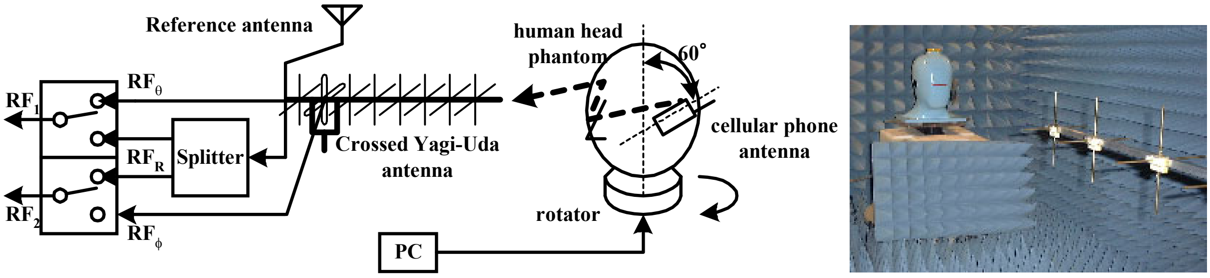
(a) (b) (c) (d)

Fig. 4 Measured field parameters; (a) $P_\theta(\phi)$, (b) $P_\phi(\phi)$, (c) $\zeta_\theta(\phi)$, and (d) $\zeta_\phi(\phi)$



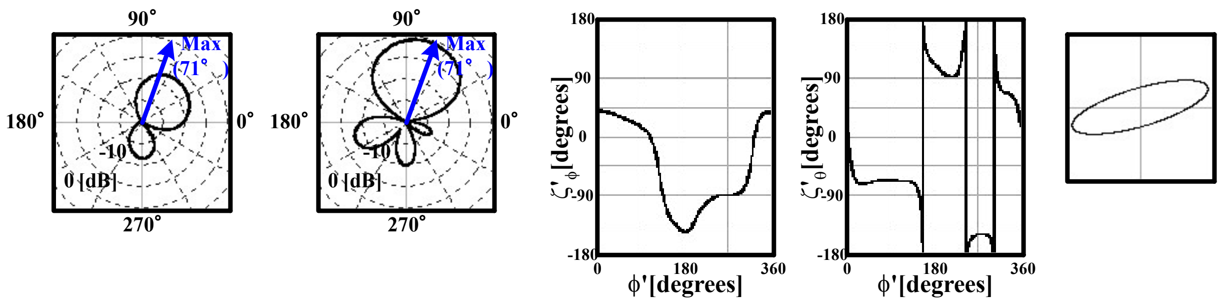
(a) (b) (c)

Fig. 5 Polarization ellipses of three major waves with incident angles ϕ=64°, 190° and 353° (a) ϕ=64°, (b) ϕ=190°, and (c) ϕ=353°



(a) (b)

Fig. 6 (a) Set-up for measuring antenna parameters by using a mobile phone in an anechoic chamber, (b) a view of the set-up



(a) (b) (c) (d) (e)

Fig. 7 Measured antenna parameters obtained by the set-up shown in Fig.6, (a) $D_\theta(\phi')$, (b) $D_\phi(\phi')$, (c) $\zeta'_\theta(\phi')$, (d) $\zeta'_\phi(\phi')$, and (e) Polarization ellipse(ϕ=71°)

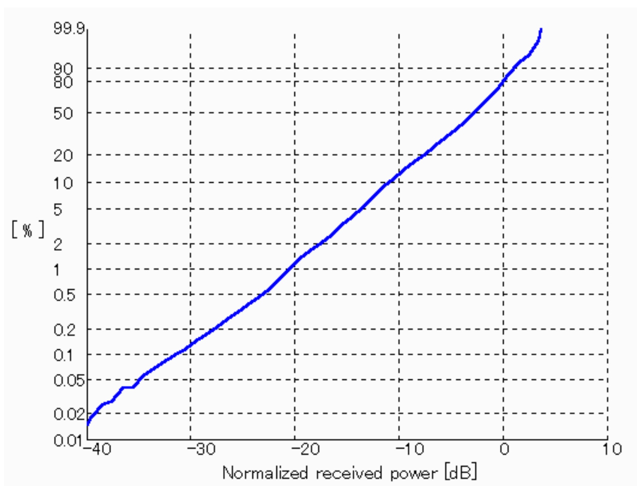


Fig. 8 CPD of the received power evaluated for a mobile phone in a dynamic mobile situation