EVALUATING MOBILE ANTENNA PERFORMANCE

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ABSTRACT

This paper reviews a method of evaluating the performance of mobile antennas that uses the theoretical expressions, proposed by the author, of the "Mean Effective Gain (MEG)" and the correlation coefficient between antenna diversity branches. Furthermore, the "Cross polarization Power Ratio (XPR)" measurement method, the directional statistical model of wave arrival in azimuth, and a simple method for measuring distribution parameters of wave arrival in indoor environments are described.

INTRODUCTION

In 1988, the author developed and proposed the theoretical expressions of "Mean Effective Gain (MEG)" of mobile antennas [1] and the correlation coefficient of antenna diversity branches [2]. The theory of MEG was derived from Yeh's theory [3], and was generalized by introducing some new definitions like the "Cross-polarization Power Ratio (XPR)" and so on. The author further derived an antenna diversity correlation equation that used the same notations. Recently, the effectiveness of these equations has been widely recognized, and they are often used in the analysis, optimum design and development of mobile antennas. This paper briefly reviews how the performance of mobile antennas can be evaluated by applying this theory and some other useful considerations of XPR measurement; it also reviews a method of estimating the parameters of angular density function of wave arrival.

THEORETICAL EXPRESSIONS OF MEG AND CORRELATION, AND REMARKS

(1) and (2) show the theoretical expression of mobile antenna MEG and the correlation coefficient of antenna diversity branches, respectively.

$$G_{MEG} = \oint \left[\frac{XPR}{1+XPR} G_{\theta}(\Omega)\, P_{\theta}(\Omega) + \frac{1}{1+XPR} G_{\phi}(\Omega)\, P_{\phi}(\Omega) \right] d\Omega \tag{1}$$

$$\rho_e = \frac{\left| \oint \left[XPR \cdot E_{\theta 1}(\Omega) E^{*}_{\theta 2}(\Omega) P_{\theta}(\Omega) + E_{\phi 1}(\Omega) E^{*}_{\phi 2}(\Omega) P_{\phi}(\Omega) \right] \cdot \exp(-j\beta x)\, d\Omega \right|^2}{\oint \left[XPR \cdot G_{\theta 1}(\Omega) P_{\theta}(\Omega) + G_{\phi 1}(\Omega) P_{\phi}(\Omega) \right] d\Omega \times \oint \left[XPR \cdot G_{\theta 2}(\Omega) P_{\theta}(\Omega) + G_{\phi 2}(\Omega) P_{\phi}(\Omega) \right] d\Omega} \tag{2}$$

where Ω represents the coordinate point (θ, ϕ) in the spherical coordinate system, and

$$\oint d\Omega = \int_0^{2\pi} \int_0^{\pi} \sin\theta \, d\theta d\phi \tag{3}$$

indicates integration over the spherical surface; $P_{\theta}(\theta, \phi)$ and $P_{\phi}(\theta, \phi)$ are the angular density functions of incident waves of the θ and ϕ components; they satisfy the following equation:

$$\oint P_{\theta}(\Omega)\, d\Omega = \oint P_{\phi}(\Omega)\, d\Omega = 1 \tag{4}$$

G_q and G_f are the q and f components of the power gain pattern of the antenna. Also, E_{qk} and E_{fk} are the complex envelopes of the q and f components of the electric radiation pattern for antenna k (k=1,2); x is the phase difference of the incident waves at the two antennas. ***XPR*** is the ratio of arrival powers of the vertically and horizontally polarizations.

These two equations offer the following five advantages;

(A1) The variation in polarization characteristics, due mainly to human operation, can be accounted for. (A2) The mobile antenna performance can be evaluated while ignoring the impact of antenna polarization at the base station due to the introduction of the notation XPR. (A3) Suitable evaluations are possible by utilizing the angular power density function of wave arrival most appropriate for the propagation environment under consideration. A directional angular power density function makes the characteristics of MEG and correlation also directional. (A4) The degradation in antenna performance due to the human body effect can be evaluated [4],[5]. (A5) Since the MEG and correlation equations use common propagation parameters, the diversity gain (system gain), which is decided by both the correlation and the difference in median values between antenna branches (the MEG difference), can be evaluated by using the same propagation parameters [6].

In particular, the correlation equation considers the phase difference in the antenna spacing of the diversity branches, co- and cross- polarization components, and the antenna radiation characteristics, and so can be applied to evaluate space, polarization, and pattern diversity performance.

XPR MEASUREMENT METHOD

This Chapter describes a useful method recommended by the author for measuring accurately the XPR value in a multipath environment. The XPR is defined by the ratio between the total arrival power of E_q component and that of E_f component. As the power gain pattern of measurement antenna for each polarization is defined by $G_q^{(V)}$, $G_f^{(V)}$, $G_q^{(H)}$, $G_f^{(H)}$, the measurement value of XPR is expressed as follows:

$$XPR_{meas.} = XPR \cdot \frac{\oint \left\{ G_q^{(V)}(W)\, P_q(W) + \frac{1}{XPR} G_f^{(V)}(W)\, P_f(W) \right\} dW}{\oint \left\{ XPR \cdot G_q^{(H)}(W)\, P_q(W) + G_f^{(H)}(W)\, P_f(W) \right\} dW} \tag{5}$$

If the measurement antennas for both vertical and horizontal polarization is an ideal isotropic antenna, i.e., $G_q^{(V)}(W)$ =1, $G_f^{(V)}(W)$ =0 and $G_q^{(H)}(W)$ =0, $G_f^{(H)}(W)$ =1, the relation, $XPR_{meas.} = XPR$, can be obtained easily. However, since all practical measurement antennas are not isotropic, and so are sensitive to the cross polarization component, the measurement accuracy depends upon both the radiation characteristics of measurement antennas and the angular distribution of wave arrival. The keys to accurate measurement is (i) to reduce the cross polarization sensitivity, and (ii) to use measurement antennas that have broad beam width and the same radiation pattern as each other. The proposed method uses a vertically-oriented half wavelength dipole antenna for the vertical polarization and a slotted cylinder antenna for the horizontally polarization [7]. A theoretical investigation showed excellent accuracy. Fig.1 shows the estimation error with this method. When the mean arrival angles in elevation, m_V and m_H, are less than 30 degrees, the measurement error is less than 1 dB.

OMNIDIRECTIONAL AND DIRECTIONAL STATISTICAL MODELS OF WAVE ARRIVAL IN AZIMUTH

The author had already presented a statistical distribution model, which has Gaussian distribution in elevation but uniform in azimuth, that well duplicates a mobile antenna moving randomly in a macro cell environment [1]. In a street micro cell, for instance, it is obvious that the angular power density function has some directional distribution in azimuth, i.e. along the street. In this case, the evaluated MEG and correlation characteristics should show some degree of directionality. The author has studied the directional model and reported that the MEG value evaluated by the uniform model gives the mean value of the directional MEGs for all azimuth angles [8]. A directional model that has Gaussian distribution in both elevation and azimuth was assumed. The angular distribution functions are expressed as (6) and (7).

$$P_\theta(\theta,\phi) = A_\theta \exp\left[-\frac{\left\{\theta-\left(\frac{\pi}{2}-m_V\right)\right\}^2}{2\sigma_V^2}\right]\cdot\exp\left[-\frac{(\phi-A)^2}{2S^2}\right] \tag{6}$$

$$P_\phi(\theta,\phi) = A_\phi \exp\left[-\frac{\left\{\theta-\left(\frac{\pi}{2}-m_H\right)\right\}^2}{2\sigma_H^2}\right]\cdot\exp\left[-\frac{(\phi-A)^2}{2S^2}\right], \tag{7}$$

$$(0\le\theta\le\pi,\quad A-\pi\le\phi\le A+\pi)$$

where angle A indicates the mean arrival angle in azimuth and S is the standard deviation. In (6) and (7), the same distribution in azimuth is assumed, but it can be changed for each polarization individually.

Fig.2 shows the directional MEG characteristics of a half wavelength dipole antenna with inclination angle, α, of 55 degrees from the zenith direction; the corresponding MEG is almost -3 dBi [1] in the omnidirectional model. It is found that the MEG characteristics exhibit a directional effect, related to the antenna direction. It was also found that the standard deviation S in azimuth increases, the MEG variation in azimuth becomes more uniform, since the model then approaches the omnidirectional model. However, the point to note is that the mean value of the directional MEG over all azimuth angles corresponds to the performance of -3 dBi (omnidirectional model), and it does not depend on the standard deviation of the directional model. The omnidirectional model is derived from the assumption that the mobile antenna moves randomly enough in a multipath propagation environment that the mean value of the effective gain over all antenna directions during the randomly oriented operation of a mobile terminal in azimuth is evaluated. This is true when the mobile antenna is passive. However, when an adaptive antenna is used together with automatic control of antenna directivity, the evaluation using the directional model becomes more significant. When using an adaptive antenna at the mobile station in a future system, a dynamic directional model that includes time delay and a method of designing adaptive antennas for mobile terminals will be required.

ESTIMATION OF STATISTICAL DISTRIBUTION PARAMETER IN INDOOR ENVIRONMENTS

In an indoor test site, the transmitting and receiving points are set out-of-sight in order to make the moving route of a test antenna approach a Rayleigh fading environment. The transmitting and receiving antennas are set mid-way from floor to ceiling, so the mean arrival angles in elevation of statistical distribution model can be assumed to be 0 degrees for both polarizations. This is because larger elevation angles of arriving waves increases the attenuation due to multiple reflections from the floor and the ceiling. Since XPR can be measured accurately by the slotted cylinder antenna method, the parameters to be measured are the standard deviations, σ_V and σ_H. Parameter, σ_V, can be evaluated by using the difference MEG characteristics of vertically and horizontally oriented half wavelength dipole antenna. Similarly, parameter σ_H can be evaluated by using the difference MEG characteristics of vertically and horizontally oriented slotted cylinder antenna. The MEGs and correlations calculated by using measured parameters show excellent agreement with measured results [5],[9],[10].

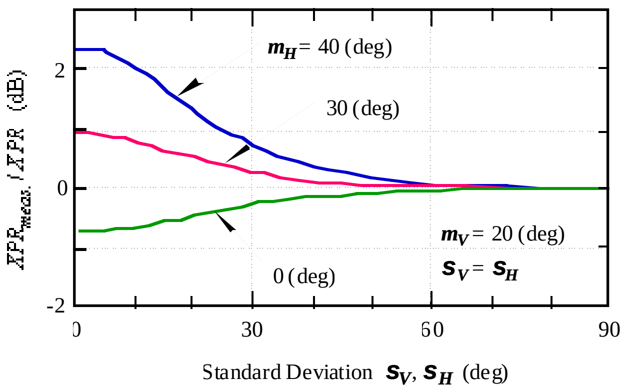

Fig. 1 Measurement error in method using slotted cylinder antenna. ($m_V = m_H$, $s_V = s_H$)

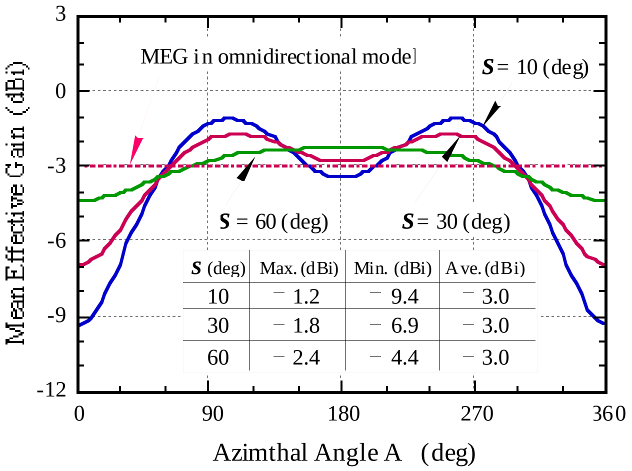

Fig. 2 MEG characteristics vs azimuthal angle A. $a = 55$ (deg), XPR = 0.0 (dB), $m_V = m_H = 20$ (deg), $s_V = s_H = 20$ (deg)

CONCLUSION

This paper reviews theoretical and experimental methods for evaluating the MEG and antenna correlation, and related topics. Some of the author's opinions on the statistical distribution model of wave arrival were described.

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