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Concept of Diversity Antenna Gain

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Abstract

To evaluate the performance of the diversity antennas, MEG of each antenna and correlation between them have been used as the parameters. However, use of two separated values are inconvenient for the comparison between two different sets of diversity antennas. The authors have proposed the concept of diversity antenna gain, which is a single parameter that directly expresses the performance of the diversity antennas. This TD reviews the concept and definition of diversity antenna gain.

1 Introduction

In Japan, we have been using the 2G TDMA system called PDC. Different from GSM, the diversity reception has been manatory for the PDC terminals. Therefore, there have been a lot of studies about the diversity antennas in the terminal.

For the evaluation of the diversity antennas, Takeuchi et.al. have proved that the complex radiation pattern correlation is equivalent to the fading envelope correlation [1].

In the multipath environment, the effective sensitivity is proportional to the mean effective gain (MEG) which has been proposed by Taga [2].

For the time being, the diversity antennas have been evaluated by using these two separated parameters. The advantage of these parameters is that the antenna engineers can compute these two values just from the complex radiation patterns of the antennas.

However, the performance comparison between two different diversity antennas is not straightforward due to these two parameters are separated to each other.

The authors have proposed the diversity antenna gain (DAG) based on the diversity performance in the multipath environment, in which modulation and diversity schemes are taken into account as well as MEG and correlation [3]. This TD reviews the definition of DAG and some comparison examples.

2 Definition of DAG

2.1 MEG and correlation

As is described in Introduction, MEG and correlation coefficients are both obtained from the complex radiation patterns and the angular power spectrum as

$$G_e = \int_0^{2\pi}\int_0^{\pi}\left(\frac{X}{1+X}G_\theta P_\theta + \frac{1}{1+X}G_\varphi P_\varphi\right)\mathrm{d}\Omega \qquad (1)$$

$$\rho_e = \frac{\left|\int_0^{2\pi}\int_0^{\pi}\left(XE_{\theta1}E_{\theta2}^*P_\theta + E_{\varphi1}E_{\varphi2}^*P_\varphi\right)\mathrm{d}\Omega\right|^2}{\int_0^{2\pi}\int_0^{\pi}\left(XE_{\theta1}E_{\theta1}^*P_\theta + E_{\varphi1}E_{\varphi1}^*P_\varphi\right)\mathrm{d}\Omega\cdot\int_0^{2\pi}\int_0^{\pi}\left(XE_{\theta2}E_{\theta2}^*P_\theta + E_{\varphi2}E_{\varphi2}^*P_\varphi\right)\mathrm{d}\Omega}, \quad (2)$$

where Ω denotes solid angle, X represents the cross polarization power ratio. G_θ and G_φ are θ and φ components of the antenna power gain, which take account of the impedance mismatch loss. $E_{\theta k}$ and $E_{\varphi k}$ $(k = 1,\ 2)$ are the complex antenna directivities for V and H polarizations respectively. P_θ and P_φ are the angular power spectrum.

2.2 MRC diversity

To evaluate the diversity performance by using MEG and correlation, the diversity scheme shall be specified. In the practical implementation, the switching diversity is most popular. The performance of switching diversity is upper-bounded by the selection combining diversity. Maximum ratio combining, in contrast, is not often used in the conventional products. However, MRC is advantageous in the computation of the diversity performance, and is described in this TD.

By using MEG and correlation, the 2-branch fading correlation matrix $\mathbf{R}$ is expressed as

$$\mathbf{R} = \Gamma_0 \begin{bmatrix} G_{e1} & \sqrt{G_{e1}G_{e2}\rho_{e12}} \\ \sqrt{G_{e1}G_{e2}\rho_{e12}} & G_{e2} \end{bmatrix}, \quad (3)$$

where Γ_0 is the signal to noise ratio for a ideal dual-polarized isotropic antenna, of which the MEG is 0 dB. When SNR is under consideration, it is usual that the average noise power is constant, but the signal strength is changing. It is noted in case that Γ_0 is proportional to the average incident wave power.

The eigenvalues of Eq. (3) are given as

$$\lambda_1 = \frac{1}{2}\Gamma_0\left[G_{e1} + G_{e2} + \sqrt{(G_{e1}+G_{e2})^2 - 4G_{e1}G_{e2}(1-\rho_{e12})}\right], \quad (4)$$

$$\lambda_2 = \frac{1}{2}\Gamma_0\left[G_{e1} + G_{e2} - \sqrt{(G_{e1}+G_{e2})^2 - 4G_{e1}G_{e2}(1-\rho_{e12})}\right]. \quad (5)$$

It is noted that the diversity antennas under consideration is equivalent to the uncorrelated branches with the average branch power of λ_1 and λ_2. The PDF $p(\gamma)$ and CDF $P(\gamma \le x)$ of output SNR γ is given by using Eqs. (4) and (5) as

$$p(\gamma) = \frac{1}{\lambda_1 - \lambda_2}\left\{\exp\left(-\frac{\gamma}{\lambda_1}\right) - \exp\left(-\frac{\gamma}{\lambda_2}\right)\right\}, \quad (6)$$

$$P(\gamma \le x) = \frac{1}{\lambda_1 - \lambda_2}\left[\lambda_1\left\{1 - \exp\left(-\frac{x}{\lambda_1}\right)\right\} - \lambda_2\left\{1 - \exp\left(-\frac{x}{\lambda_2}\right)\right\}\right]. \quad (7)$$

2.3 BER performance

As far as the fading fluctuation is slow enough so that the random FM effect is negligible, the average BER is the expectation of the bit error probability under AWGN channel $p_e(\gamma)$ as

$$\bar{P}_e = \int_0^\infty p(\gamma)p_e(\gamma)\mathrm{d}\gamma. \quad (8)$$

Let us consider $\pi/4$-shift QPSK with the coherent detection for example, p_e is given as

$$p_e(r) = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{\gamma}{2}}\right). \quad (9)$$

Table 1: Two sets of diversity antennas for the comparison

	Diversity antennas A	Diversity antennas B
Correlation ρ_{e12}	0.1	0.8
MEG G_{e1}	0 dBi	0 dBi
MEG G_{e2}	-3 dBi	0 dBi

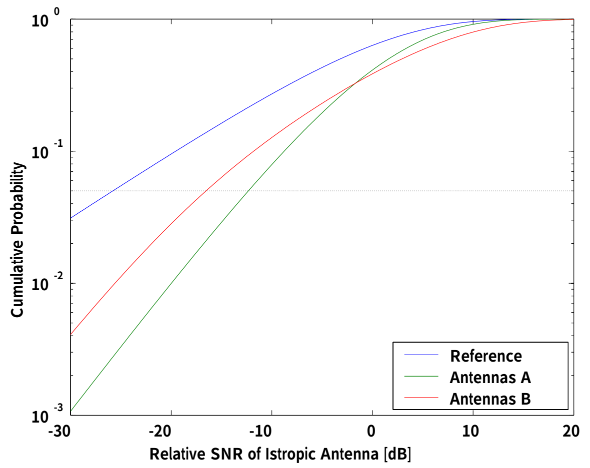

Figure 1: CDF of output SNR of diversity antennas.

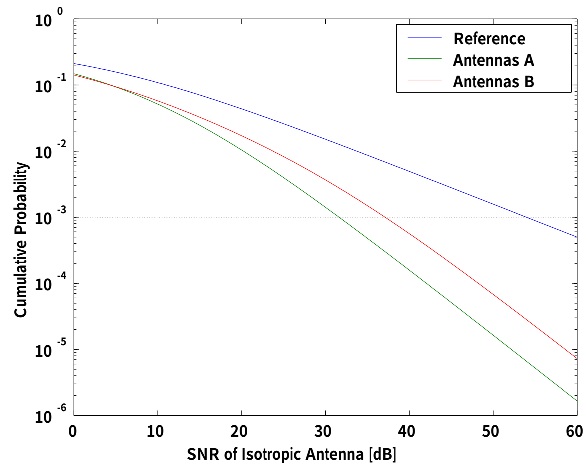

Figure 2: Average BER of diversity antennas.

By substituting Eqs. (6) and (9), the average BER after MRC is given as

$$\bar{P}_e = \frac{1}{2} - \frac{1}{2(\lambda_1 - \lambda_2)} \left(\frac{\lambda_1}{\sqrt{\frac{2}{\lambda_1} + 1}} - \frac{\lambda_2}{\sqrt{\frac{2}{\lambda_2} + 1}} \right). \tag{10}$$

2.4 DAG

The diversity antenna gain can be defined in the following two manners.

DAG defined for outage probability If the fading is very slow, outage probability is a good criterion to measure the link quality. Therefore, the DAG-OP is defined as the gain of Γ_0, SNR for isotropic antenna, to satisfy the specified outage probability.

DAG defined for average BER If the fading is sufficiently fast, average BER is a good criterion to measure the link quality. Therefore, the DAG-BER is defined as the gain of Γ_0, SNR for isotropic antenna, to satisfy the specified average BER.

3 Example

Let us consider an example shown in Table 1. Without considering DAG, we can not point out which is the better diversity antennas.

Figure 1 shows the CDF of the output SNR of the diversity antennas. For comparison, that for a single isotropic antenna is also shown. If the required outage probability is 5 %, DAG for diversity antennas A is 22.4 dB, whereas DAG for diversity antennas B is 16.9 dB. It is concluded that DAG-OP of A is 5.5 dB higher than DAG-OP of B.

Figure 2 shows the average BER of the diversity antennas. For comparison, that for a single isotropic antenna is also shown. If the required average BER is 1.0×10^{-3}, DAG for diversity antennas A is 13.5 dB, whereas DAG for diversity antennas B is 9.3 dB. It is concluded that DAG-BER of A is 4.2 dB higher than DAG-BER of B.

4 Conclusion

This TD has reviewed the concept of diversity antenna gain (DAG). From the results of the previous section, the following conclusions are obtained.

- DAG can directly express the diversity performance under some specific environment and some specific modem and some specific diversity schem.
- DAG value depends on which criteria the user needs. In case of DAG-BER, the value becomes smaller if the required BER is higher.
- This devinition is almost trivial, but it is still necessary to clearly present the definition.

References

[1] T. Takeuchi, F. Ikegami, S. Yoshida and Y. Tokui, Trans. IECE (B), vol. J67-B, no. 5, pp. 570–571, May 1984 (in Japanese).

[2] T. Taga, IEEE Trans. Veh. Tech., vol. 39, no. 2, pp. 117–131, May 1990.

[3] K. Ogawa and J. Takada, Electronics and Communications in Japan, pt. 2, vol. 84, no. 6, pp. 10–23, June 2001. (Original Japanese version has been published as Trans. IEICE (B), vol. J83-B, no. 6, pp. 852–865, June 2000.)