FREQUENCY CORRELATION CHARACTERISTICS OF RECEIVED SIGNAL LEVEL IN WIDE-BAND MOBILE RADIO CHANNEL

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1. INTRODUCTION

Multimedia services in mobile communications require high speed transmission rates. As a result, transmission bandwidth has been widening. Mobile radio channels are expected to change from narrow to wide-band, and there have been many studies on delay spread and received signal level variation to facilitate this change. According to studies, the instantaneous received signal level distribution in wide-band systems is different from that in narrow-band systems [1]-[3]. However, an autocorrelation of the envelope of received signal levels in wide-band systems is reported to be similar to that in narrow-band systems, this is true theoretically and has been demonstrated by using computer simulation [4]. However, frequency correlation, one of the most important characteristics in received signal level variation, hasn't been well investigated.

In this paper, the dependence of the frequency correlation on the received bandwidth is discussed theoretically and then is demonstrated by a computer simulation and an experiment using a fading simulator.

2. THEORETICAL STUDY

A. Propagation Model

Fig. 1 shows the propagation model in wide-band transmission. It assumes that multipath waves arrive at the receiving point as follows.

i) In a non-line-of-sight propagation path, the arriving waves have amplitudes A_i and propagation path lengths L_i. These are distributed uniformly within a fixed range and are independent of each other.

ii) The number of arriving waves is N, and the arrival angles θ_i of the waves are distributed uniformly from 0 to 2π in the horizontal plane.

iii) As the transmission bandwidth is $2\Delta F$, the transmitted power spectrum is constant over the frequency band $f_c \pm \Delta F$. The amplitude of each arriving wave is also constant over the received bandwidth.

iv) The receiving bandwidth is $2\Delta f$ and is centered at f_c, where $\Delta f \leqq \Delta F$.

B. Derivation of frequency correlation equation

The received signal level P is given by [2] when multipath waves are received at the received bandwidth $2\Delta f$ in the propagation model shown in Fig. 1. The signal level is

$$P = 2\Delta f \sum_{i=1}^{N} A_i^2 + \frac{2}{K} \sum_{i=1}^{N}{}' \sum_{j=1}^{N}{}' \frac{A_i A_j}{\Delta L_{ij}} \left[\cos(K f_c \Delta L_{ij}) \sin(K \Delta f \Delta L_{ij})\right], \qquad (1)$$

where $K = 2\pi / c$, c is the speed of light, $\Delta L_{ij} = L_i - L_j$, and $\sum_{i=1}^{N}{}' \sum_{j=1}^{N}{}' = \sum_{i=1}^{N} \sum_{j=1}^{N} (i \neq j)$. We define two received signal levels at the center frequency f_c and $f_s = f_c + s$, separated at a distance of s from f_c, as $P(f_c)$ and $P(f_s)$. The frequency correlation coefficient $\rho(s)$ is generally expressed as

$$\rho(s) = \frac{\langle P(f_c)P(f_s)\rangle - \langle P(f_c)\rangle\langle P(f_s)\rangle}{\sqrt{\left(\langle P(f_c)^2\rangle - \langle P(f_c)\rangle^2\right)\left(\langle P(f_s)^2\rangle - \langle P(f_s)\rangle^2\right)}}, \tag{2}$$

where < > denotes the ensemble average. Substituting Equation (1) into Equation (2), and arranging it under the condition of the propagation model, we obtain [2]

$$\rho(s) = \frac{\left\langle \sum_{i=1}^{N}{}' \sum_{j=1}^{N}{}' \frac{\{1-\cos(\beta\Delta L_{ij})\}\cos(\alpha\Delta L_{ij})}{\Delta L_{ij}^2} \right\rangle}{\left\langle \sum_{i=1}^{N}{}' \sum_{j=1}^{N}{}' \frac{1-\cos(\beta\Delta L_{ij})}{\Delta L_{ij}^2} \right\rangle}, \tag{3}$$

where $\alpha = Ks$ and $\beta = 2K\Delta f$. Assuming that the number of arriving waves N is large, the ensemble average can be replaced with integration with respect to ΔL_{ij}, after being multiplied by the probability density of ΔL_{ij}. The cosine terms are expanded to an infinite series, and the series is integrated with respect to ΔL_{ij}. Finally we derive the frequency correlation equation $\rho(s)$ as follows.

$$\rho(s) = \sum_{n=1}^{\infty} \frac{(-1)^n \Delta L_{\max}^{2n}}{(2n)!2n(2n-1)} \left[\alpha^{2n} - \frac{1}{2}(\gamma_1^{2n} + \gamma_2^{2n})\right] \Big/ \sum_{n=1}^{\infty} \frac{(-1)^{n+1} \Delta L_{\max}^{2n}}{(2n)!2n(2n-1)} \beta^{2n}, \tag{4}$$

where $\gamma_1 = \alpha + \beta$ and $\gamma_2 = \alpha - \beta$. Equation (4) shows the frequency correlation coefficient for the received signal level. The equation has three factors of a frequency separation s, a received bandwidth $2\Delta f$ and a maximum difference in path length $\Delta L_{\max}$. The correlation coefficient $\rho(s)$ calculated by using Equation (4) is shown by the solid lines in Fig. 2 as a parameter of $2\Delta f$. The calculation conditions are listed in Table 1. When $\Delta L_{\max}$ is 300m as shown in Fig. 2(a), $\rho(s)$ decreases as s increases, becoming large value as $2\Delta f$ becomes large. In other words, the wider the received bandwidth $2\Delta f$ is, the higher the frequency correlation coefficient $\rho(s)$ is. When $\Delta L_{\max}$ is 30m as shown in Fig. 2(b), $\rho(s)$ has a large value and decreases gradually as s increases. Furthermore, $\rho(s)$ is almost independent of $2\Delta f$.

3. SIMULATION

A. Simulation method

To prove the validity of Equation (4) for the frequency correlation coefficient $\rho(s)$, computer simulations were performed. A received bandwidth $2\Delta f$ and a maximum difference in path length $\Delta L_{\max}$ were set as parameters. The simulation method follows. First, the propagation path was generated based on the propagation model. Next, the received signal levels $P(f_c)$ and $P(f_s)$ were calculated for a fixed receiving point. The signal level variations due to movement could also be calculated by using Equation (1) because ΔL_{ij} is expressed as $\Delta L_{ij}=L_i-L_j-z(\cos\theta_i-\cos\theta_j)$ for moving distance z. By using the values of $P(f_c)$ and $P(f_s)$ for the moving distance, $\rho(s)$ was calculated based on Equation (2). To be representative, the propagation path was simulated 500 times, the average value is defined as the correlation coefficient for s, $2\Delta f$ and $\Delta L_{\max}$. The simulation was performed with varying values of s between 0 and 3MHz at intervals of 0.2MHz. The results are plotted in Fig. 2, and the simulation conditions are listed in Table 1. The center frequency f_c was 1.9GHz, and the number of arriving waves N was 10. The received bandwidth $2\Delta f$ and the maximum difference in path length $\Delta L_{\max}$ were the same as in the theoretical calculation, $2\Delta f$ =0.1, 1and 3MHz, $\Delta L_{\max}$ =300m and 30m.

B. Simulation results

The simulation results for $\rho(s)$ are shown by the symbols ●, ▲ and ■ in Fig. 2. The simulation results match the theoretical values of the solid line in both Fig. 2(a) and (b).

4. EXPERIMENT USING FADING SIMULATOR

A. Experimental system and method

To further confirm the theoretical results, an experiment using a fading simulator was done. The experimental parameters are listed in Table 2, and the system is shown in Fig. 3. The RF wave was modulated by a base band signal from a pulse generator, and became a wide-band signal with BPSK modulation. The wide-band signal was fed to a fading simulator with set propagation parameters, and fading was added to it. The signals were received by two spectrum analyzers with received center frequencies f_c and f_s. The frequency correlation coefficient was calculated by using Equation (2) with received signal levels $P(f_c)$ and $P(f_s)$. The difference in the received center frequency s between the spectrum analyzers is varied between 0 and 3MHz at intervals of 0.2MHz. The number of arriving waves N was 6, and the average amplitude A_i and path length L_i for each wave were distributed uniformly within a fixed range. Using these conditions, the measurement was repeated 10 times for each of s, $2\Delta f$ and ΔL_{max}. The average value was defined as $\rho(s)$.

B. Experiment results

Measurement results are shown using the symbols ○ and △ in Fig. 2(a) and (b) for the parameter $2\Delta f$. The measurement results for both ΔL_{max}=300m and 30m match the theoretical values.

5. CONCLUSION

To clarify the frequency correlation characteristics of a received signal level in wide-band mobile radio channel, the study was performed theoretically and by computer simulation and fading simulator. First, the equation for the frequency correlation coefficient $\rho(s)$ was derived based on a wide-band propagation model. This equation has three factors of a frequency separation s, a receiving bandwidth of $2\Delta f$ and a maximum difference in path length ΔL_{max}. To prove the validity of this equation, a computer simulation and an experiment using a fading simulator were performed. The simulation and the experimental results matched the theoretical ones.

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Table 1 Theoretical calculation and simulation parameters

	THEORY	SIMULATION
Radio frequency f_c	——	1.9GHz
Number of arriving waves N	——	10
Received bandwidth $2\Delta f$	0.1, 1, 3MHz	
Maximum difference in path length ΔL_{max}	30, 300m	

Table 2 Experimental parameters

Transmitter	Radio frequency	1.006GHz
	Modulation	BPSK
	Base band signal	PN code, 5Mbps
Receiver	Received bandwidth	0.1, 1MHz
	Video bandwidth	1kHz
Propagation path	Maximum difference in path length	30, 300m
	Number of arriving waves	6
	Amplitude distribution of arriving wave	Rayleigh
	Maximum doppler frequency	33.6Hz

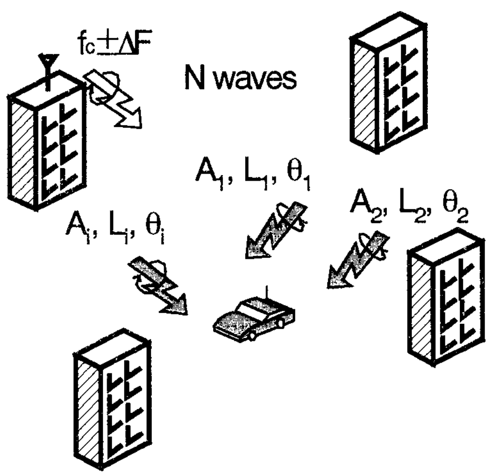


Fig. 1. Propagation model.

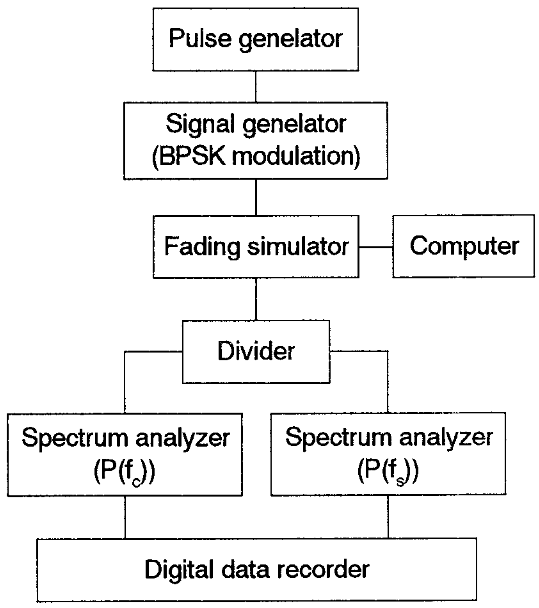
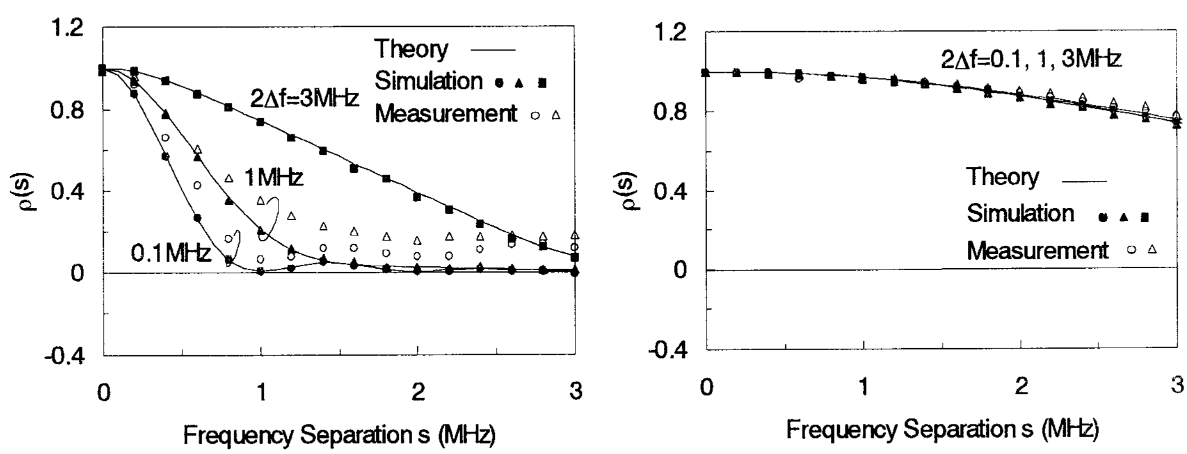


Fig. 3. Experimental system.



(a) ΔL_{max}=300m. (b) ΔL_{max}=30m.

Fig. 2. Frequency correlation characteristics.