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A Study on the Implementation of Channel Simulator for Mobile Communications

(이동통신용 채널시뮬레이터 구현에 관한 연구)

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要　約

본 연구에서는 이동 통신의 채널 모델링에서 일어나는 레일리 고속 페이딩 시뮬레이터를 구현하고 그 성능을 분석하였다. 페이딩 환경을 위하여 위상변조 신호의 주파수 합성방식과 잡음원의 스펙트럼 shaping 방식의 두 모델을 사용하였으며, 스펙트럼은 무지향성 안테나에 적합하도록 선택하였다. 성능 분석의 주요 parameter인 레벨 교차수 및 누적분포 함수로 부터 이론치와 근접한 실험 결과를 얻었다.

Abstract

In this study, the Rayleigh fast fading simulators encountered in channel modelling of mobile radio have been implemented and evaluated. Two models used for the fading environment were frequency composition of phase modulated signals and shaping spectrum of noise sources with filters. The spectrum chosen for our purpose is appropriate to an omnidirectional antenna.

From results of the experiment with various parameters, we have obtained satisfying results which are closely agreed to theoretical values.

I. Introduction

The received signal of a mobile radio is affected by multipath interferences which are caused by obstacles such as buildings and terrains. The field strength of the received signal varies in amplitude and phase. This field strength variation is called Rayleigh fading. The amplitude statistics of the received signal envelope with probability distribution roughly from -30 to + 10dB are Rayleigh-distributed, and the phase is uniformly distributed from $-\pi$ to $+\pi$. This fading has a serious effect on the performance of mobile radio systems because it brings about random errors and burst errors. Especially, it is difficult for us to measure and regenerate the actual channel data since mobile propagation environment has non-stationary process. Upon this, these fading simulators allow us to carry out propagation test in a laboratory and greatly help us in the system design and evaluation.

This paper describes the development of two models of fading simulators in UHF band (450 MHz) for channel configuration and the results of characteristic analysis with several vehicle speeds (40km/h, 70km/h, and 100km/

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h). The Rayleigh envelope statistics such as power spectrum, level crossing rate (LCR), and cumulative distribution function (CDF) are compared to the theoretical prediction, respectively.

II. Fading Channel Description

The single frequency carrier arrives at the receiver via multipaths having different angles in mobile radio communications, and each signal component would get a Doppler shift, namely,

$$f_i = (v/\lambda)\cos\theta_i = f_D\cos\theta_i \qquad (1)$$

where v is the vehicle speed, λ is the carrier wavelength, θ_i is the relative arrival angle of the i-th component, and f_D is the maximum Doppler shift.

For an omnidirectional antenna which is the most common type, the theoretical spectrum of the received signal is given as follows [1], [2] :

$$S(f) = \begin{cases} E^2/\pi f_D \sqrt{|1-(f/f_D)^2|}, & f \le f_D \\ 0, & f > f_D \end{cases} \qquad (2)$$

where E is the rms value of the received signal envelope.

The received fading signal may be expressed as

$$\begin{aligned} r(t) &= x(t)\cos\omega_c t + y(t)\sin\omega_c t \qquad (3) \\ &= R(t)\cos(\omega_c t + \theta(t)) \end{aligned}$$

and

$$x(t) = \Sigma A_i \cos(\omega_i t + \phi_i)$$

$$y(t) = \Sigma A_i \sin(\omega_i t + \phi_i) \qquad (4)$$

where x and y are independent, identically distributed zero mean Gaussian random variables, and A_i, ω_i & ϕ_i are the amplitude, frequency, and phase of the i-th signal [3]. Thus, the envelope of received signal, R, has Rayleigh distribution, and the phase, θ, is uniformly distributed from $-\pi$ to $+\pi$.

The Rayleigh probability density function with mean zero and standard deviation σ can be written as:

$$p(R) = R/\sigma^2 \exp(-R^2/2\sigma^2) \qquad (5)$$

And, the cumulative probability distribution of r(t) which is the probability that envelope of the received signal is equal to or less than level A, is given

$$\begin{aligned} P(R \le A) &= \int_0^A (R/\sigma^2)\exp(-R^2/2\sigma^2)\,dR \\ &= 1 - \exp(-A^2/2\sigma^2) \qquad (6) \end{aligned}$$

Finally, the level crossing rate is the total number of expected crossings per second in a given level A, and this is regarded as a second-order statistics.

$$N_R = \sqrt{2\pi}\, f_D\, \rho \exp(-\rho^2) \qquad (7)$$

where $\rho = R/R_{rms}$

The cumulative probability distribution and the level crossing rate are essential parameters in characteristic analysis of fading simulators.

III. Implementation

1. Model I : Frequency Composition of Phase Modulated Signals

To generate Rayleigh approximation, we can represent signal as superposition of waves [4].

$$\begin{aligned} Y(t) = \sum_{n=1}^{No} &[\exp\{j(\omega_D t\cos\alpha_n + \phi_n)\} \\ &+ \exp\{-j(\omega_D t\cos\alpha_n + \phi_{-n})\}] \qquad (8) \\ &+ \exp\{j(\omega_D t + \phi_N)\} + \exp\{-j(\omega_D t + \phi_{-N})\}, \end{aligned}$$

$$N_0 = 1/2\,(N/2-1), \quad \alpha_n = 2\pi n/N, \; n = 1, 2, ---, N$$

From Eq. (8), it follows that the Rayleigh approximation is good for $N \geqslant 6$ (N/2:odd integer), where ω_D represents the maximum Doppler shift.

The block diagram of such a simulator is shown in Fig.1. along with an illustration of the frequency spacings of the oscillators for N_0=8.

Low-frequency oscillators with frequencies equal to the Doppler shift $\omega_D \cos(2\pi n/N)$, n= 1, 2, - - -, 8, and one with frequency ω_D are used to generate waveform. The amplitude of

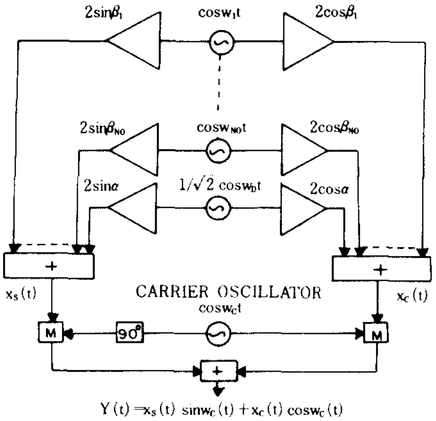


Fig.1. Block Diagram of Model I.

all the components are made equal to unity except for the one with frequency ω_D which is set equal to $1/\sqrt{2}$. The phase β_n are chosen appropriately so that the probability distribution of the phase will be as close as possible to a uniform distribution. The proper oscillator phases are provided by amplifiers with gains set equal to $2\cos\beta_n$ or $2\sin\beta_n$.

The output of the individual oscillator with the appropriate gain factor are summed to produce in-phase ($x_c(t)$) and quadrature ($x_s(t)$) components.

From the block diagram, we get

$$Y(t) = x_c(t) \cos\omega_c t + x_s(t) \sin\omega_c t$$

$$\text{where } x_c(t) = 2\sum_{n=1}^{8} \cos\beta_n \cos\omega_n t + \sqrt{2} \cos\alpha \cos\omega_D t$$

$$x_s(t) = 2\sum_{n=1}^{8} \sin\beta_n \,\mathrm{cow}\,\omega_n t + \sqrt{2} \sin\alpha \cos\omega_D t. \tag{9}$$

The phase of Y(t) is probably random and uniformly distributed from $-\pi$ to π.

In Fig. 2. baseband frequencies are generated by using x-tal oscillator and divided properly to provide eight frequencies and the maximum Doppler frequency. This output passed through an analog low pass filter for smoothing waveform.

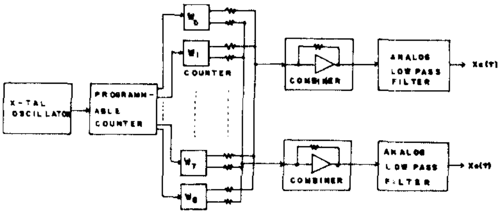


Fig. 2. Circuit Diagram of Model I.

2. Model II : Shaping Spectrum of Noise Source

Simulation of the fading spectrum appropriate to mobile radio is obtained by properly shaping spectrum of the independent noise source. The block diagram of this model is shown in Fig. 3, and this model used to obtain the Rayleigh fading singals is published in [5].

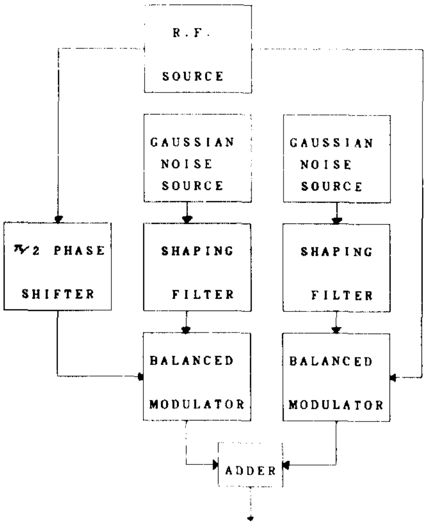


Fig.3. Block Diagram of Model II.

Fig. 4. is the circuit diagram of one of the noise sources and shaping filters. The spectrum of the Doppler spread S(f) can be obtained by passing the output of each Gaussian noise source through a shaping filter whose response approximates the spectrum of the Doppler spread [6]. The Gaussian noise is obtained from zener diode operating near breakdown voltage. The power spectrum of this diode was measured from 2 Hz to 500 KHz.

To generate a Rayleigh fading signal, several methods are available for realizing the shaping filter. These methods include using active filter, switched-capacitor filter, and digital filter. For the convenience of implementation, the active RC filter method has been used. The cut-off frequency of this filter is same as the maximum Doppler frequency. The shaping filter consists of two active filters: a 0.1dB ripple low pass filter and a multiple-Q band pass filter that is used for peaking the maximum Doppler frequency [7].

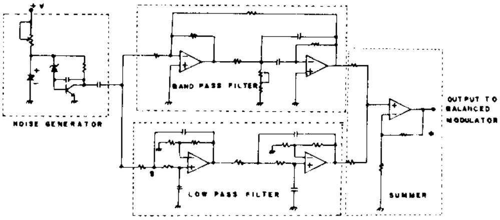


Fig. 4. Circuit Diagram of Model II.

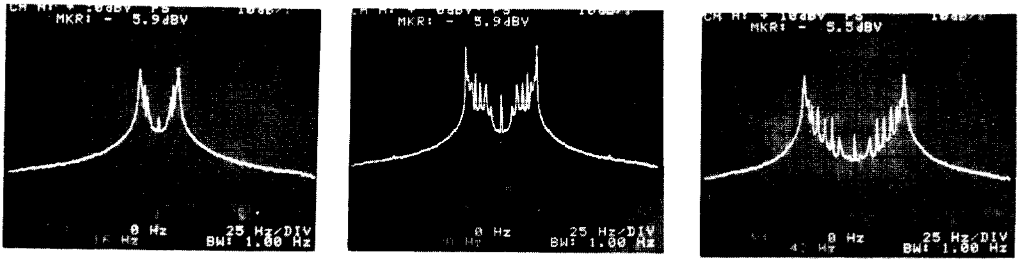
IV. Numerical and Experimental Result

The performance of the channel simulators has been evaluated by comparing the envelope statistics of the simulated fading signals with those of the theoretical Rayleigh signal, specifically in points of LCR, and CDF.

Fig. 5. and 6. depict the baseband spectrum for frequency composition and shaping filter. Additionally, we have found that the output spectrum of modulated signal is analogous to the baseband spectrum.

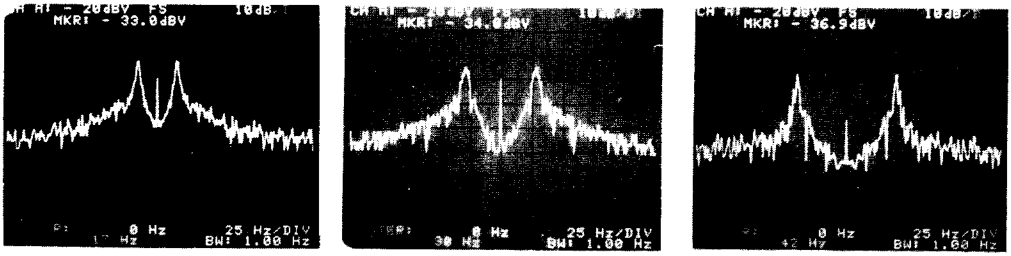
We have measured and analyzed the Rayleigh fading distributed data which was obtained for scores of seconds using micro/mini-computer with tools of simulation and test. All data has been normalized and analyzed after having A/D conversion in in-phase components and quadrature components as shown in Fig. 7.

The experimental results of parameters of two simulators are shown in Fig. 8 and 9. We can deduce from these figures that experimental results slightly diverge from the theoretical



(a) 17Hz (b) 30Hz (c) 42Hz

Fig.5. Spectrum of Model I.



(a) 17Hz (b) 30Hz (c) 42Hz

Fig.6. Spectrum of Model II.

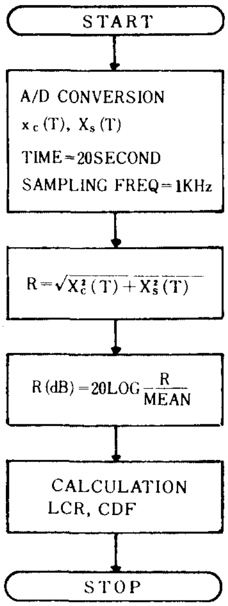


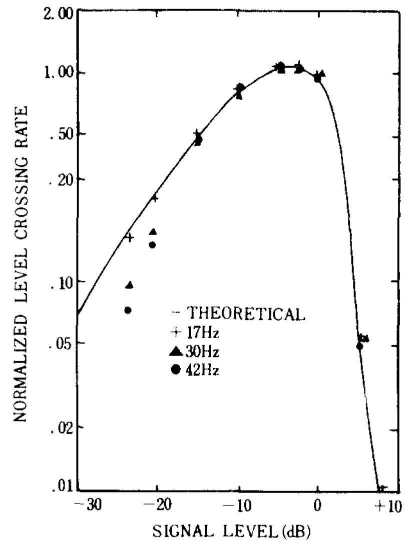
Fig.7. Flowchart for Envelope Statistics Measurement.

values as increasing the maximum Doppler frequency owing to the number of N_0 in model I and the characteristics of shaping filter in model II. Photographs of two simulators are shown in Fig. 10 and 11.

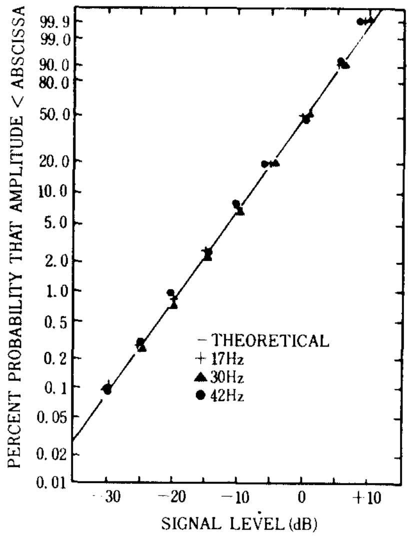
We have confirmed that LCR is very significant parameter in the measurement of the characteristics of fading simulators. Finally, it is recommended that we can improve the performance of simulators as increasing of N_0 and amelioration of shaping filter, respectively.

V. Conclusion

In this paper, we have developed fast fading channel simulators for mobile radio and presented the performance comparisons between the two models. We have confirmed that these fading simulators could be used for channel modelling of mobile radio communications owing to nearly agreement of experimental data with theoretical values.



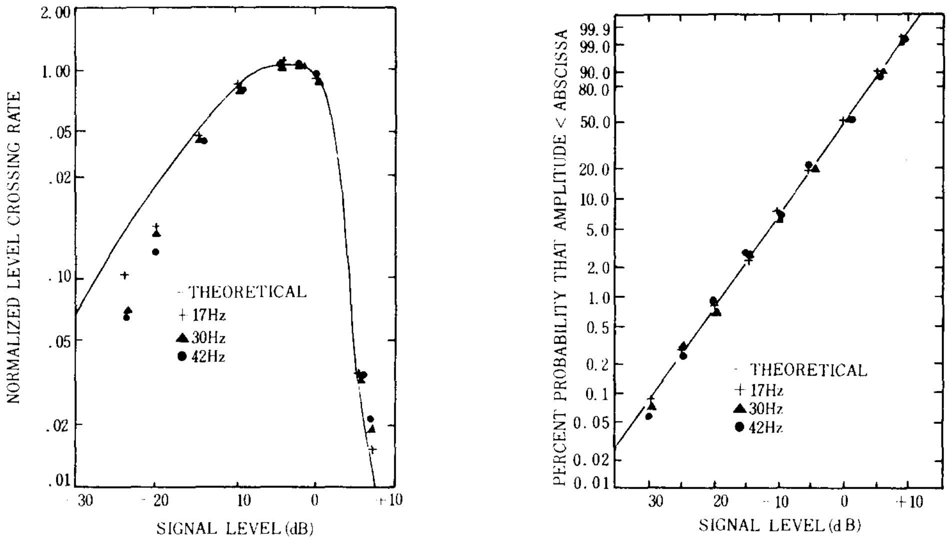
(a) LCR



(b) CDF

Fig.8. Experimental Result of Model I.

We have recognized that the model of frequency composition of phase modulated signals is more flexible in a viewpoint of performance because this device could be easily improved as increasing the number of phase modulated signals, on the other hand, the model of shaping spectrum of noise sources has more expandability. These models can be readily applicable to different types of antenna as rearranging of phase and designing shaping filter of noise sources, respectively. These fading channel simulators are very useful to



(a) LCR (b) CDF

Fig.9. Experimental Result.

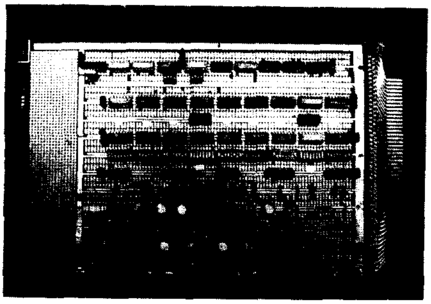


Fig.10. Simulator Model I.

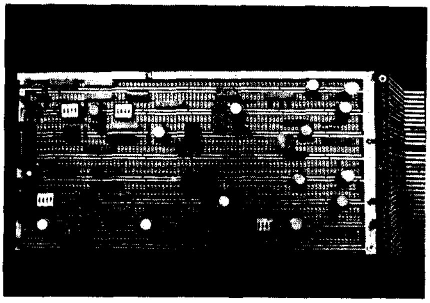


Fig.11. Simulator Model II.

carry out various propagation tests in a laboratory without field test and to evaluate mobile radio systems.

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