FREQUENCY-SELECTIVE FADING SIMULATOR FOR MOBILE RADIO COMMUNICATIONS

Takashi UEDA and Hiroshi SUZUKI

NTT Radio Communication Systems Laboratories

1. INTRODUCTION

In mobile radio communications, high bit-rate transmission over 64 kb/s suffers severe transmission performance degradation caused by frequency-selective fading. To overcome this degradation, techniques such as equalization, diversity and anti-multipath modulation are being investigated, and some outdoor experimental results for these techniques have already been reported[1],[2]. For the effective evaluation of these techniques, a fading simulator is required[3]. So far, however, all of the frequency-selective fading simulators that have been presented have the disadvantage that they can only simulate slow fading with rough discrete control of amplitude, phase, and delay time. This paper describes the structure and characteristics of a frequency-selective fading simulator which generates almost continuous fast fading.

2. CHANNEL MODEL

Transmitter output signal $s(t)$ with a rate $1/T$ is given by the following presentation:

$$s(t)=\mathrm{Re}[E_m(t)\exp(j\omega_c t)] \quad (1)$$

where $\mathrm{Re}[x]$ denotes the real part of the complex number x, $E_m(t)$ is a complex envelope of the modulated signal, and ω_c is the angular carrier frequency of the modulator. The received signal $r(t)$ through the channel is given as a sum of several delay waves:

$$r(t)=\mathrm{Re}\left[\sum_{k=1}^{N_c} A_k(t)E_k(t-\tau_k)\exp(j\omega_c(t-\tau_k))\right] \quad (2)$$

where N_c is the number of delay waves all with different delay times, and τ_k and $A_k(t)$ are the delay time and complex envelope of the k-th delay wave, respectively. In the mobile radio channels, it is well known that $A_k(t)$ fluctuates at a rate below the maximum Doppler frequency which is determined by the carrier frequency and moving velocity.

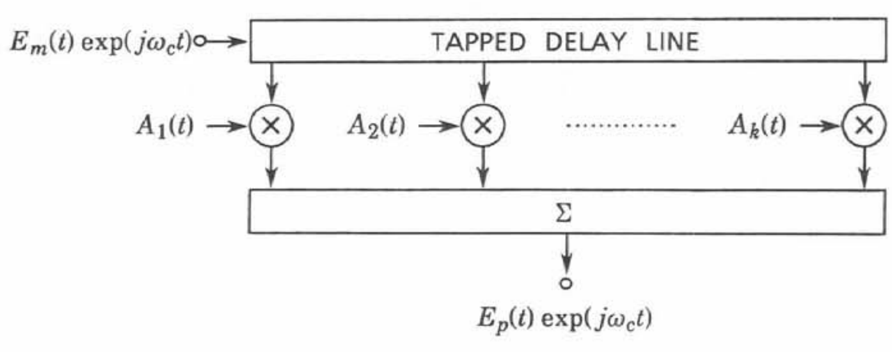


Fig. 1 CHANNEL MODEL

The above described radio channel model is depicted in **Fig. 1**. In this model, each delay wave is generated by a tapped delay line, whose tap interval is much less than T. The outputs of the tapped delay line are weighted by $A_k(t)$, and combined. According to the propagation measurement, the delay time spread τ_k is from 2 to 4 μs in urban areas, and up to 20 μs in mountainous areas[4]. The maximum Doppler frequency becomes 140 Hz when the carrier frequency is 1.5 GHz and the moving velocity is 100 km/h.

3. HARDWARE STRUCTURE

Equation (2) is equivalent to the following equations:

$$r(t) = \mathrm{Re}[E_p(t)\exp(j\omega_c t)] \tag{3-a}$$

$$E_p(t) = \sum_{k=1}^{N_c} A_k(t) E_m(t-\tau_k) \exp(-j\omega_c \tau_k) \tag{3-b}$$

where $E_p(t)$ is a complex envelope of the received signal. These equations are mathematically equivalent to baseband representation of the fading. This representation can be directly implemented by a digital circuit processing complex number and a quadrature modulator circuit, as shown in **Fig. 2**. The digital circuit consists of a 2-dimension transversal filter. In order to simulate the dynamic channel profile, tap coefficients of the filter are updated in real-time by microprocessors and the DSPs. The microprocessors generate tap coefficient values corresponding to a propagation model on $A_k(t)$, and the DSPs interpolate the values almost continuously.

An actual simulator including auxiliary circuits is shown in **Fig. 3**. The input data sequence is transformed into the baseband I-Q waveforms of a modulation scheme, and a fading wave is generated by the transversal filter LSIs. Output signals of the transversal filter LSIs are converted into analog signals by D/A converters and low-pass filters. The baseband analog signal is converted to a modulated carrier signal by the quadrature modulator. This simulator supports three interfaces available for the following receiver evaluations:

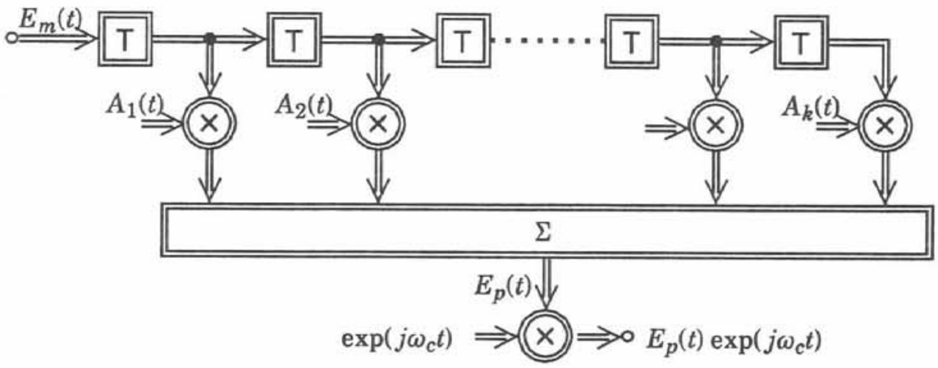


Fig.2 DIGITAL CIRCUIT MODEL

(1) Digital interface to the equalizer and timing processor.

(2) Analog interface to the A/Ds of the receiver.

(3) Carrier Interface to the radio receiver.

In terms of the channel model, parameter requirements for the simulator are as follows:

(1) Maximum delay time of up to 20 μs is required to simulate the various propagation models.

(2) Maximum sampling rate for the transversal filter of up to 4 Msample/s is required in order to deal with signals with a symbol rate up to 500 ksymbol/s and a symbol interval T divided into 8 samples.

(3) Dynamic range of the simulator output is 70 dB due to fading.

(4) Maximum Doppler frequency is up to 150 Hz.

4. RESULTS

Performance of the experimental simulator is shown in **Table**, and the simulator output signals of QPSK (roll-off factor: 0.5, 1.024 Mb/s) modulation are shown in **Fig. 4**. The figure shows signal space diagrams and eye patterns at the analog interface, and the modulated signal spectrum (center frequency: 90 MHz) at the carrier interface; (a) without a delay wave, (b) with a $2T$-delay wave whose amplitude level is equal to the direct wave and whose relative phase is 120 degrees.

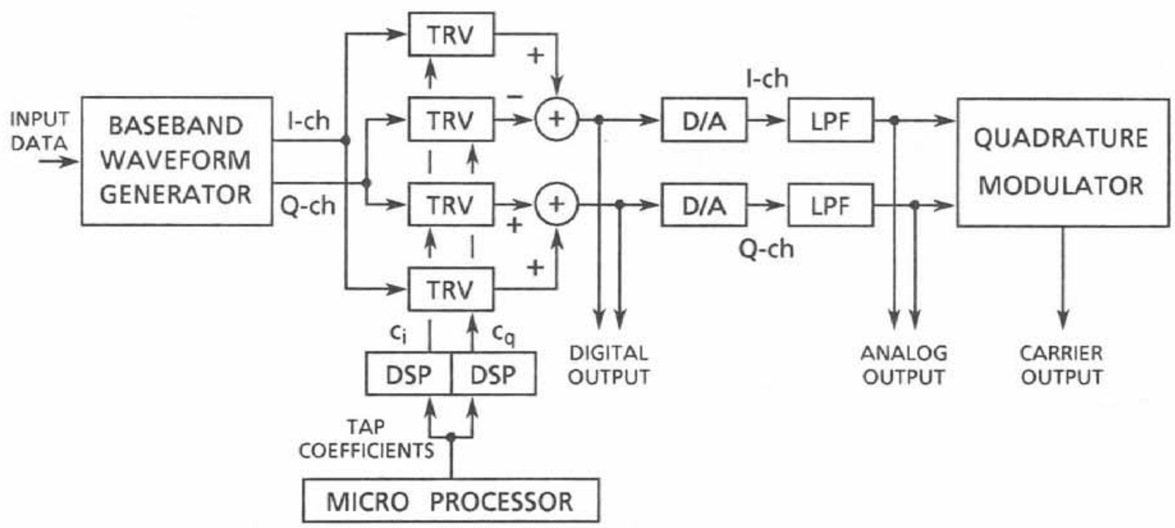
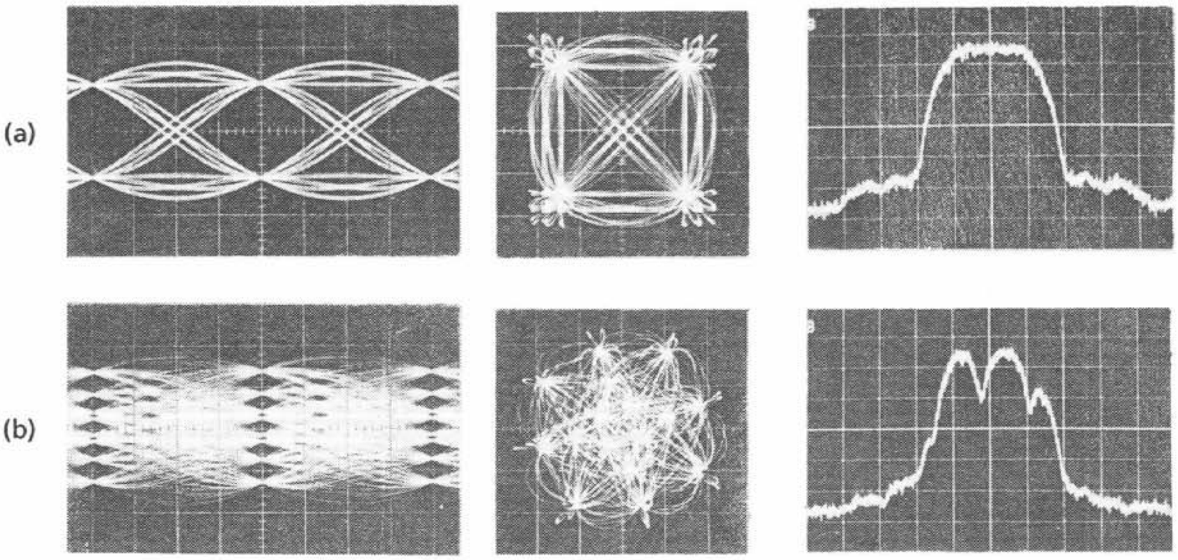


Fig. 3 SIMULATOR CIRCUITS

Sampling Rate	5 Msample/s
Time Interval	200 ns
Maximum Delay Time	25.6 μs
Maximum Delay Waves	128
Dynamic Range	70 dB

Table REALIZED PERFORMANCE



EYE PATTERN 0.5 μs/DIV　　SIGNAL SPACE DIAGRAM　　SPECTRUM 200 kHz/DIV (H) 10 dB/DIV (V)

Fig. 4 OUTPUT SIGNAL

5. CONCLUSION

A frequency-selective fading simulator is realized by applying digital signal processing, and the following results are obtained.

(1) The simulator can generate a fading wave at a rate below 5 Msample/s, with a maximum delay time of 25.6 μs and a minimum time resolution of 200 ns.

(2) Dynamic range of the simulator output is about 70 dB.

(3) The maximum Doppler frequency increases to 100 Hz when the simulator generates two delay waves and each wave changes its phase with constant angular velocity. In this implementation, the changing signal phase is quantized by 8 bits, and the maximum Doppler frequency can be increased by reducing the phase quantization bits.

ACKNOWLEDGEMENT

The authors wish to acknowledge to Dr. Masaaki Shinji and Dr. Takeshi Hattori for their guidance and helpful suggestions.

REFERENCES

[1] S. U. H. Qureshi, "Adaptive Equalization," *Proc. IEEE*, vol. 73, pp. 1349-1387, Sep. 1985.

[2] J. -E. Stjernvall, B. Hedberg and S. Ekemark, "Radio Test Performance of a Narrowband TDMA System," in *Proc. IEEE VTC* (Tampa, Florida), pp. 293-299, June 1987.

[3] H. Arnold and W. F. Bodtmann, "A Hybrid Multichannel Hardware Simulator for Frequency-Selective Mobile Radio Paths," *IEEE Trans.*, vol. COM-31, pp. 370-377, March 1983.

[4] D. C. Cox and R. P. Leck, "Distributions of Multipath Delay Spread and Average Excess Delay for 910-MHz Urban Mobile Radio Paths," *IEEE Trans.*, vol. AP-23, pp. 206-213, March 1975.