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Convenient Co-channel Interference Detection Methods for Digital Cellular Radio

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1. INTRODUCTION

In a cellular or microcellular system, the signal transmission performance is generally limited not by additive thermal noise but by co-channel interference [1]. Thus, the detection of carrier to co-channel interference ratio (C/I) is of great importance for monitoring the channel quality.

In this paper, we show that the multipath delay spread estimation method previously proposed by the authors [2][3] can be applied to the detection of C/I for BPSK and for $\pi/4$-shift QPSK [4]. It is possible to estimate C/I using quadrature-channel (Q-ch) detector output for a BPSK signal and using amplitude difference between in-phase channel (I-ch) and Q-ch detector outputs for a $\pi/4$-shift QPSK signal. The results of computer simulation and laboratory experiment prove that the proposed scheme is very useful for in-service monitoring of C/I.

2. PRINCIPLES

Fig.1 shows a block diagram of a differential detector for BPSK. If the upper part, i.e. I-ch, is assumed to yield a normal eye pattern of a BPSK signal, then the lower part shows the Q-ch detector output and no signal appears generally. However, when an interference signal is added to the original signal, non-zero signal appears even at this Q-ch detector output. We will try to estimate C/I from this Q-ch output.

Fig.2 shows a differential detector for $\pi/4$-shift QPSK. In this case, obviously the C/I quantity cannot be obtained from the Q-ch detector output directly. We note that, for $\pi/4$-shift QPSK, generally $|I| = |Q|$ holds true, where $|I|$ and $|Q|$ mean the magnitudes of I-ch and Q-ch outputs, respectively. However, if an interference signal exists, then signal constellation is getting distorted and $|I| = |Q|$ does not necessarily holds. Thus, we expect that information on C/I is obtained from the measurement of averaged $||I| - |Q||$.

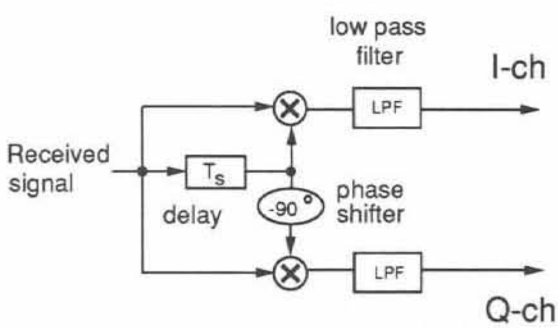

Fig.1 Block diagram of differential detector for BPSK.

When only one interference signal exists, the I-ch and Q-ch outputs of a differential detector are calculated for both BPSK and $\pi/4$-shift QPSK, as follows:

$$I = A_C{}^2\{\cos\Delta\theta_C + \rho\cos(\Delta\theta_C + \phi) + \rho\cos(\Delta\theta_I - \phi) + \rho^2\cos\Delta\theta_I\}$$
$$Q = A_C{}^2\{\sin\Delta\theta_C + \rho\sin(\Delta\theta_C + \phi) + \rho\sin(\Delta\theta_I - \phi) + \rho^2\sin\Delta\theta_I\}$$

where ϕ is a phase difference between carrier and interference, A_C is a magnitude of carrier, A_I is a magnitude of interference, and $\rho = A_I/A_C$. $\Delta\theta_C, \Delta\theta_I \in \{0, \pi\}$ for BPSK, and $\Delta\theta_C, \Delta\theta_I \in \{\pm\pi/4、\pm3\pi/4\}$ for $\pi/4$-shift QPSK are carrier phase shifts of C and I over a symbol period, respectively.

For BPSK, if each of four phases of $\Delta\theta_C$ and $\Delta\theta_I$ takes place equally likely and ϕ is uniformly distributed, then averaged $|Q|$, denoted as $\overline{|Q|}$, is calculated as follows:

$$\overline{|Q|} = \rho A_C{}^2 K \text{ (K is a constant)}$$

For $\pi/4$-shift QPSK, if $\rho \ll 1$, the polarity of the above Q-ch output expression is determined by the first term. Then the expression

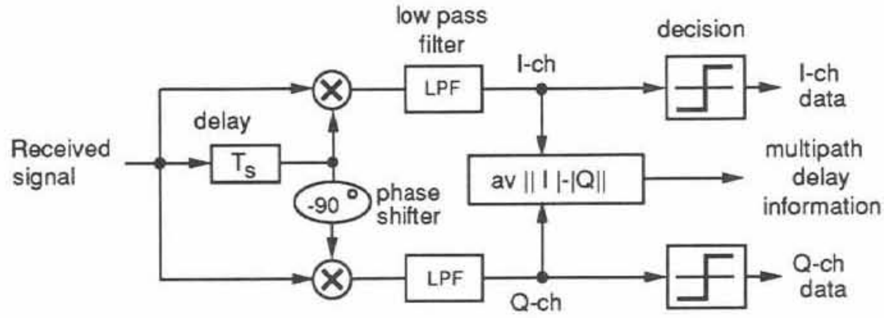

Fig.2 Block diagram of differential detector for $\pi/4$-shift QPSK.

of $||I| - |Q||$ can be derived assuming that phases $\Delta\theta_C$, and $\Delta\theta_I$ occur with the same probabilities and ϕ is uniformly distributed, i.e.,

$$\overline{||I| - |Q||} = \rho A_C{}^2 K' \ (K' \text{ is a constant})$$

To sum up, for both BPSK and $\pi/4$-shift QPSK, it is possible to detect interference signal level or C/I from the measurement of $\overline{|Q|}$ or $\overline{||I| - |Q||}$. The effect of $A_C{}^2$ can be removed by applying the received signal to a hard limiter circuit.

3. COMPUTER SIMULATION

3.1 COMPUTER SIMULATION MODEL

To examine the characteristic of the proposed method, computer simulation has been performed assuming a propagation model where carrier(C) and interference (I) are subjected to mutually independent Rayleigh fading. A root-Nyquist filter with a roll-off factor of 50 % is adopted. We also assumed a hard-limiter in the receiver to avoid the fluctuation of detector output caused by the received signal power variation.

3.2 COMPUTER SIMULATION RESULTS

Fig. 3 shows the simulation result of Q-ch detector output of BPSK plotted against C/I. We observe that $\overline{|Q|}$ increases almost linearly as C/I(dB) decreases from 30 dB to 0 dB when E_b/N_0 is greater than or equal to 30 dB.

For $\pi/4$-shift QPSK, however, there arises a problem. Due to the transient response caused by a bandwidth restriction filter, $\overline{||I| - |Q||}$ has an offset and its dynamic range shrinks even if C/I changes largely.

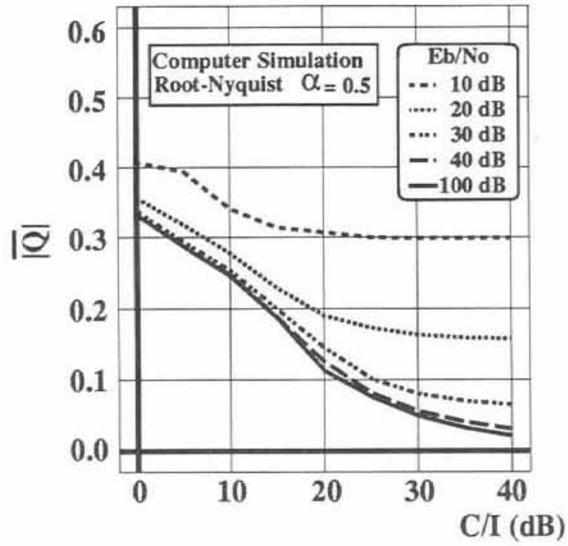

Fig.3 $\overline{|Q|}$ vs. C/I for BPSK.

To avoid this offset, we propose a method that makes use of sampled values of $||I| - |Q||$ at the center of each symbol interval. By applying this sampling method, dynamic range of the output was found to be enlarged. Fig. 4 shows detector output vs. C/I that is obtained by this method. As the curves show, a detector output has a good correspondence with C/I variation.

4. LABORATORY EXPERIMENT

4.1 LABORATORY EXPERIMENT SYSTEM

To confirm the computer simulation result, we made laboratory measurements for $\pi/4$-shift QPSK. For this purpose, we utilized the same hardware circuit as was used for a multipath delay spread detection [3] shown in Fig. 5.

I-ch and Q-ch detector outputs are sampled

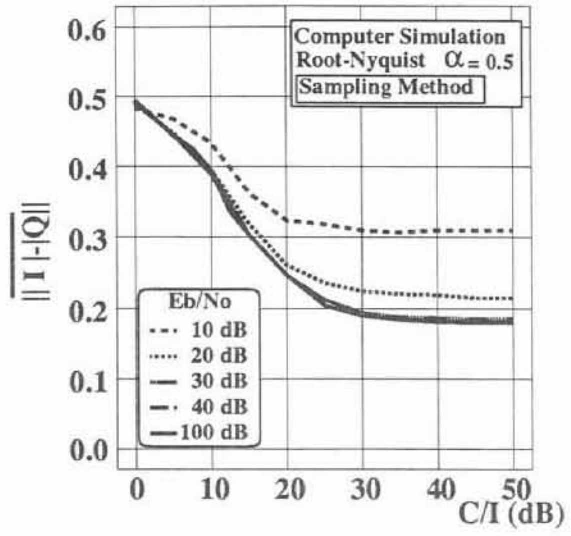

Fig.4 $\overline{||I|-|Q||}$ vs. C/I for $\pi/4$-shift QPSK.

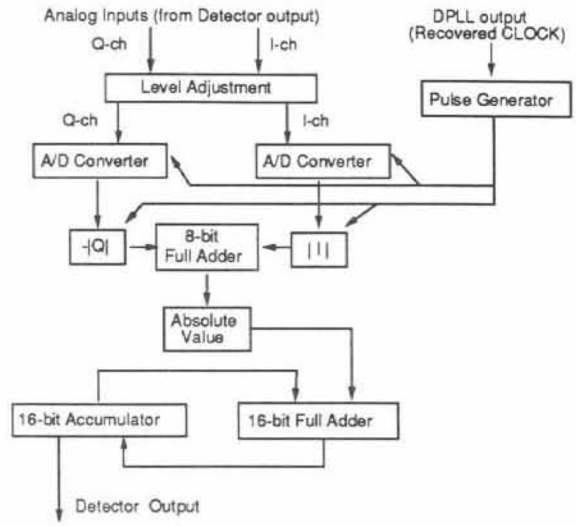

Fig.5 Block diagram of hardware for $\overline{||I|-|Q||}$ measurement.

by the recovered clock, and then quantized by 8bit A/D converter. $||I|-|Q||$ is calculated and accumulated to give an averaged $||I|-|Q||$ by a digital circuit.

Fig. 6 shows a block diagram of the laboratory transmission experiment system.

4.2 EXPERIMENTAL RESULTS

First, when only a co-channel interference exists, we found that there existed a good correspondence between C/I and detector output ($\overline{||I|-|Q||}$). This corresponds to the curve denoted as $\tau/T_S = 0.0$ in Fig. 7.

Next, the monitoring characteristics in a general propagation environment, where both multipath delay spread and co-channel interference exist, are investigated. Fig. 7 shows experimental results showing how detector output vs. C/I relation changes when τ/T_S is increased, assuming a mutually-uncorrelated Rayleigh-distributed two-ray model with average $D/U = 0$ dB and a roll-off filter of $BT_S = 2.0$. When τ/T_S approaches unity, i.e. a very bad condition, detector output is observed to be nearly saturated and is affected only slightly by C/I variation.

As BER was measured at the same time, we plotted the relation between detector output and BER in Fig. 8. In spite of the fact that plotted data in Fig. 8 covers broad range of parameters of laboratory measurement system, i.e., C/I from 0 to 40 dB, τ/T_S from 0 to 1.0 and average D/U from 0 to 12 dB, quite a good relation between BER and detector output was found to our surprise. Therefore, it seems to be possible to estimate to a certain degree of accuracy BER of system from the value of detector output since the scattering of the curves for the various values of parameters is very small.

5. CONCLUDING REMARKS

The relationships between C/I and the value of $\overline{|Q|}$ for BPSK or $\overline{||I|-|Q||}$ for $\pi/4$-shift QPSK were studied by computer simulation and the latter also by laboratory experiments. As a result, it is confirmed that the values of $\overline{|Q|}$ and $\overline{||I|-|Q||}$ can be used for in-service monitoring of C/I. To avoid the degradation due to bandwidth restriction for $\pi/4$-shift QPSK, we proposed the method that measures sampled $\overline{||I|-|Q||}$.

When multipath delay spread is not negligible, however, the curves $\overline{|Q|}$ or $\overline{||I|-|Q||}$ vs. C/I are influenced to a large extent. Even in such a circumstance, we found that quite good relations are observed between BER and $\overline{|Q|}$ or $\overline{||I|-|Q||}$. These are very useful relations for in-service monitoring of a channel quality.

Since the C/I is a very important factor in determining the performance of a cellular radio system, the proposed scheme might find a place in various applications for performance improvement, such as in antenna branch selection of the various diversity reception system, and also in decision making of intra- or inter-cell handoff.

ACKNOWLEDGMENT

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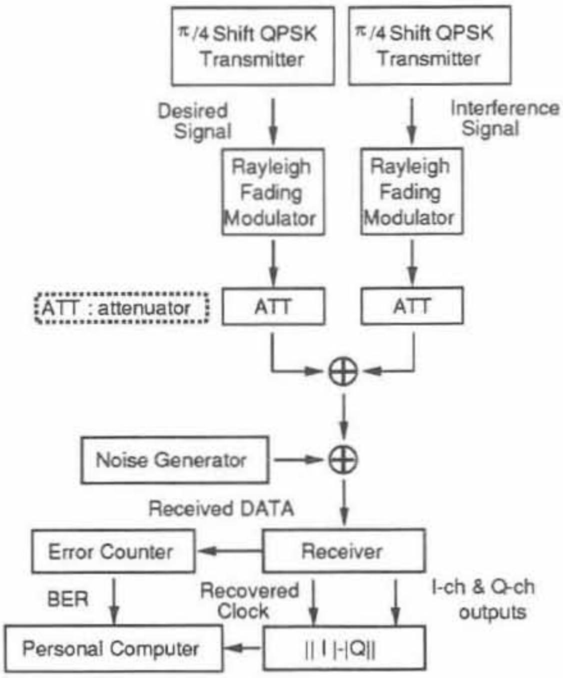

Fig.6 Block diagram of laboratory experiment system.

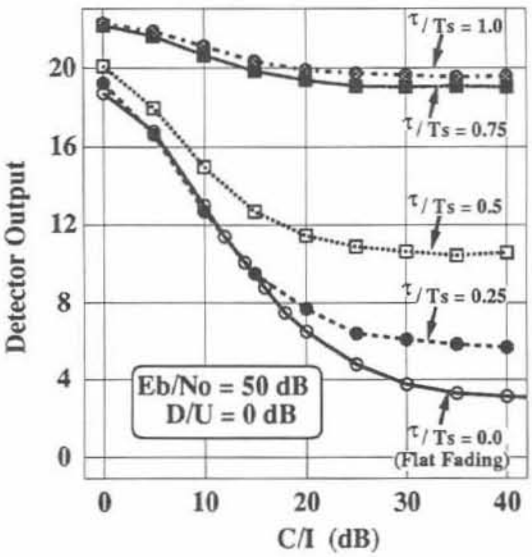

Fig.7 Laboratory measurement of detector output vs. C/I.

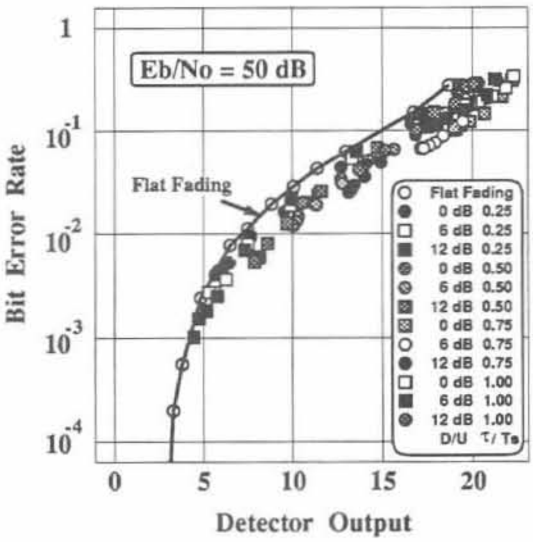

Fig.8 BER vs. detector output (sampling method).

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