論 文

주파수 선택성 페이딩 환경하에서 $\frac{\pi}{4}$ shift QPSK 변조방식에 대한 다중파의 시간지역 검출법 제안

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A Multipath Delay Time Detection Method For $\pi/4$ Shift QPSK Modulation Under The Frequency Selective Fading Environment

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要 約 디지탈 이동통신 전송로에 있어서 고속통신을 위한 시스템의 성능은 다중파 지연 분산에 의해 크게 좌우된다. 본 논문에서는 최근 디지탈 자동차 전화의 변복조방식으로 채택된 $\pi/4$ shift QPSK에 대해, 간이 다중파 지연시간 검출방법으로써, 직교채널간섭량(CCI)을 이용하는 방법을 제안하였다. $\pi/4$ Shift QPSK 신호는 원래 직교채널에 정보를 갖고있기 때문에 BPSK 변조방식처럼 Quadrature 채널에서 간섭량을 얻기 위하여 주파수 체배기와 지연검파 방식을 제안하였다. 또한 다중파 전파환경하에서, 격렬하게 변하는 직교채널 간섭량으로 부터 정보를 얻는 방법으로서 절대치 평균과 실효치 평균을 취하는 방법을 제안하였으며, 아울러 지연분산과 직교채널 간섭량과의 관계도 조사하였다. 이론적인 결과를 확인하기 위하여, 준정적인 2파 모델과 Rayleigh 분포 2파모델하에서 computer simulation을 수행하였다. simulation 결과 좋은결과가 얻어졌으나, 본방식은 송신 대역제한에 어느정도 민감하다는 것이 밝혀졌다. 또한 H/W 실현시 주요부분인 주파수 체배기에 대한 H/W 구성 방안도 제안하였다.

ABSTRACT It is well known that digital transmission performance over a mobile/portable radio communication channel is severely degraded by multipath delay time spread. In this paper, We propose a simple multipath delay time detection method, which has a merit of in-serviceable, yet simple H/W realizability for $\pi/4$ shift QPSK by detecting cross channel interference. A $\pi/4$ shift QPSK signal originally has quadrature channel(Q-ch) component. Thus in order to measure CCI between in-phase channel(I-ch) and quadrature channel(Q-ch), which closely related to multipath delay time, Frequency doubling scheme(frequency doubler) and differential detector is proposed, which makes $\pi/4$ shift QPSK signal look like BPSK and also makes it possible for CCI to be detected at I-ch detector output. To get an information from time varying I-ch output signal under the multipath fading environment, a method for obtaining the mean of the absolute value($V_{MABS}(t)$) and another one for obtaining the root mean square value($V_{RMS}(t)$) of CCI are proposed. Furthermore, a relationship between delay spread and CCI is also analyzed. In order to confirm theoretical results, computer simulation has been carried out under the quasi-static and Reyleigh distributed two ray multipath fading environments. A fairly good result was obtained. However it was also shown that this method is sensitive to bandwidth restriction to some extent. In addition, some idea for a simple hardware realization for the frequency doubler are given.

I. Introduction

Nowadays, a demand for high speed digital radio communication, such as ISDN service in digital mobile/portable communication and indoor high-speed radio communication service is in creasing.

On the other hand, multipath delay time dispersion in the digital mobile communication causes severe intersymbol interference(ISI) and also crosstalk between in-phase and quadrat-

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ure-phase signals. These ISI and cross channel interference(CCI) over a randomly time varying link make the eye pattern of received signals get distorted and so they limit the maximum usable transmission rate. Especially when propagation delay time difference of signals constituting the multipath signal is not negligible compared to the transmission signal bit interval, the transmitted signal suffers from severe frequency selective fading and so the systme performance is degraded due to error floor(i.e., so called irreducible BER) even though signal-to noise ratio(SNR) is high enough[1] Hence, the measurement of multipath delay characteristics in such a time varying channel is very important for estimating the communication performance in a high speed digital radio transmission.

Generally as a measurement method for multipath delay profile, special signals, such as a very sharp pulse or pseudo random code sequence combined with a sliding correlator at the receiver side are usually used[2]. This method gives us detailed information about the multipath fading channel. But it requires a very broad bandwidth and complicated measuring equipments. On the other hand, knowing the relative changing tendencies of the channel quality over some short communication intervals provides us a very useful information in a practical application, if it is measurable without any special signal during signal transmission and also implemented by a simple circuit. In this respect, Yoshida et al. studied an in-service, yet simple multipath delay time detection method for BPSK signal merely by measuring the detector output at the quadrature channel[3]. Good correspondence between the multipath delay spread and CCI quantities were confirmed by laboratory measurement and also field test[4]. In this paper, we extend this method to a $\pi/4$ shift QPSK signal.

In a real urban area, many previous studies have suggested that a few ray multipath model is sometimes more appropriate to reality, especially on streets having a small street angle[5]. Throughout this paper, multipath fading channel is assumed to be quasi static and Rayleigh distributed two or three ray model for the simplicity of theoretical analysis. Also, a differential detector is assumed because of its robustness for multipath delay distortion.

Ⅱ. Principle

2.1 Cross Channel Interference

Under the multipath propagation environment, the transfer function of the channel can be viewed as a line time varying filter defined by (1) in a simple static two ray mode[6].

$$H(\omega)=1+\rho\exp(-\phi)\exp(-j(\omega-\omega_c)\tau) \qquad (1)$$

where ω_c is angular carrier frequency, ρ is inverse of instantaneous amplitude ratio of desired wave(D wave, its amplitude is A_d) to undesired wave(U wave, its amplitude is A_u), i.e., $\rho=A_u/A_d$ and τ is the delay difference between the two paths, and also ϕ is the instantaneous phase difference between two waves($\phi=\omega_c\tau$).

In this case if $\tau\neq 0$, the transfer function of the multipath medium becomes asymmetrical with respect to ω_c except for the case of $\phi=0$ and π. This asymmetric characteristic of the transfer function causes a cross channel interference between I ch and Q ch components of the transmitted signal[7].

2.2 Ferquency doubler

$\pi/4$ shift QPSK is a very useful modulation scheme for digital mobile communication. The phase difference between adjacent two symbols is $\pm\pi/4$, $\pm 3\pi/4$ and the resultant signal constellation looks like 8 PSK[8]. However in quadrature PSK modulation such as $\pi/4$ shift QPSK, CCI quantities can not be obtained directly from the quadrature channel(Q ch) detector output as in BPSK because of its own value at the Q ch output. To solve this problem, we have adopted a frequency doubling method which makes $\pi/4$ shift QPSK signal look like a BPSK signal.

If the x axis is assumed to represent the present phase, the signal transition diagram for $\pi/4$ shift QPSK becomes as shown in Fig. 1(a). After the signals are passed through a frequency doubler, all the signal phases are assembled on the y axis as shown in Fig.(b). Therefore we can detect CCI values from the in phase channel(I ch) detector output when there exists multipath delay time. For a static two ray model shown in Fig.2, the detected output through the differential detector after passing frequency doubler at the I ch is calculated as follows ;

(a)

$$Re\{[A_D e^{j\theta_n} + A_U e^{j(\theta_{n-1}+\phi)}]^2 \cdot [A_D e^{j\theta_{n-1}} + A_U e^{j(\theta_{n-2}+\phi)}]^2\}$$
$$= \frac{1}{4}\{A_D^2 A_U^2 \cos(\theta_n-\theta_{n-2})[\cos(\theta_n-\theta_{n-2}-2\phi)$$
$$+2]+2A_D A_U \cos(\frac{1}{2}(\theta_n-\theta_{n-2})-\phi)$$
$$\cdot [A_D^2 \cos(\frac{1}{2}(3\theta_n-2\theta_{n-1}-\theta_{n-2}))$$
$$+A_U^2 \cos(\frac{1}{2}(\theta_n-2\theta_{n-1}-3\theta_{n-2}))]\} \quad (2)$$

(b)

$$Re\{[A_D e^{j\theta_n} + A_U e^{j(\theta_n+\phi)}]^2 \cdot [A_D e^{j\theta_{n-1}} + A_U e^{j(\theta_{n-1}+\phi)}]^2\}$$
$$= 0$$

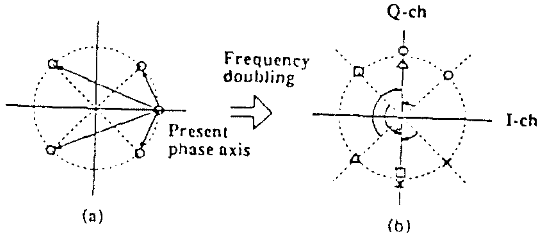

Figure 1 : Frequency doubler.

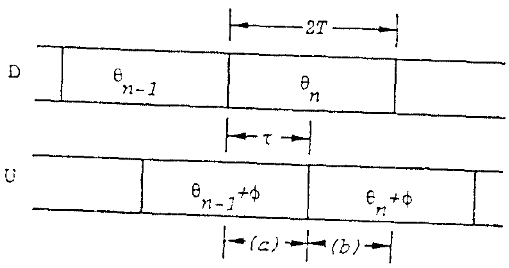

Figure 2 : Carrier phase of $\pi/4$ shift QPSK signal in two ray multipath model.

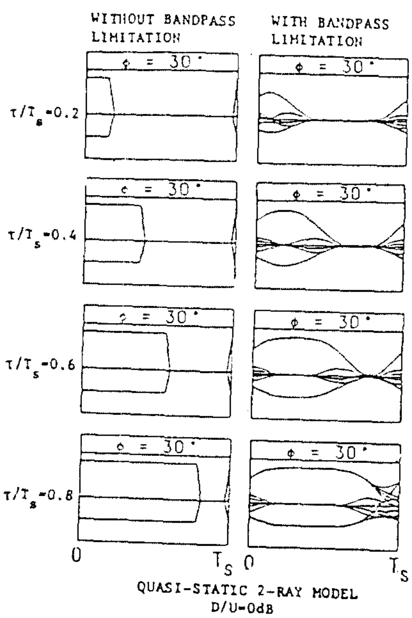

Figure 3 : Eye patterns of I-ch detector output.

This result shows that the non zero width of the I ch output is proportional to multipath delay time. Fig.3 shows the eye pattern for the detected CCI in $\pi/4$ shift QPSK for a static two ray model, with parameters D/U $(1/\rho)=0$ dB, $\phi=30°$, and τ/T_s is 0.2, 0.4, 0.6 and 0.8 from the top(symbol duration $T_s=2T$, T is bit interval), respectively. As τ/T_s increases, non zero detected outputs are observed to be extended in proportion to τ/T_s as expected theoretically. Fig.3(b) shows the eye pattern of CCI which is passed through band limitation filter with $B_tT=3.0(B_t=3$dB point). The detected CCI also increases in proportion to τ/T_s, but it shows that overlapping tails of other pulses[9] influence badly on detecting CCI. In this simulation, the influence of thermal noise on CCI is not considered here.

III. The relation between CCI and multipath parameters

Although CCI has a close relation with multipath delay parameters, instantaneous CCI value changes rapidly with time varying multipath fading parameters and transmitted information symbol patterns as shown by Eq.(2). In order to get the required information on multipath delay time from the varied CCI, two practical measurement procedures are considered, i.e., measurement of mean of the absolute value(MABS) and mean of the root mean square(RMS) value of CCI.

3.1 CCI measuring procedure

For a practical CCI measurement, the following conditions should be considered.

1) Due to the rapidly changing CCI values, it is necessary to take an average on CCI values over an appropriate time interval to obtain a relatively stable value.

2) When averaging CCI, it is necessary to rectify the detected CCI value before averaging to avoid the cancellation due to the alternating polarity of CCI.

3) We can not actually expect signal level at the receiver side because of the largely fluctuated input signal strength in actual application. Hence in order to remove this influence of fluctuating received signal strength level whose value depends on fading and transmitted symbol patterns, it is necessary to take a normalized MABS and RMS value of the I ch detector output by dividing it with the average received signal power.

From the above results, two measurement parameters which are defined by Eq.(3) and Eq.(4) are proposed[3].

The mean of the absolute value($V_{MABS}(t)$) : MABS

$$V_{MABS}(t) = \frac{1}{P}\frac{1}{2LT_s}\int_{-LT_s}^{LT_s} |v_I(t)|\,dt, \qquad (3)$$

The root mean square value($V_{RMS}(t)$) : RMS

$$V_{RMS}(t) = \frac{1}{P}\sqrt{\frac{1}{2LT_s}\int_{-LT_s}^{LT_s} v_I^2(t)\,dt}, \qquad (4)$$

where $2L$ is number of symbols over which the average calculation is taken, and P is the average signal power.

3.2 The relation between CCI and delay spread S

Normalized delay spread S, which gives us the effective information about multipath delay time, is defined by the square root of the second central moment of a power delay profile[4]. In two-ray and three-ray multipath fading models, S is defined by (5) and (6), respectively.

$$S = \frac{1}{T}\sqrt{\frac{\sum_k (\tau_k - D)^2 P(\tau_k)}{\sum_k P(\tau_k)}} = \frac{A_d A_u}{A_D^2 + A_U^2}\frac{\tau}{T} = \frac{\rho}{1+\rho^2}\frac{\tau}{T} \quad (5)$$

in two-ray model.

$$S = \frac{\sqrt{\rho_1^2\rho_2^2(\tau_1-\tau_2)^2 + \tau_1^2\rho_1^2 + \tau_2^2\rho_2^2}}{1+\rho_1^2+\rho_2^2} \quad (6)$$

in three-ray model, where D is mean delay, τ_k is delay time of kth delayed wave and $P(\tau_k)$ is mean power of kth delay wave and also τ_1 and τ_2 are delay time difference of first and second delayed waves to D wave respectively, and ρ_1 and ρ_2 are inverse of the amplitude ratio of delayed waves with respect to D-waves.

Meanwhile, the dimension of detected output becomes the fourth power of voltage after passing through the frequency doubler and differential detector which is implemented by a squaring circuit and multiplier followed by LPF, respectively. For clarifying a relation between MABS / RMS of CCI and normalized delay spread, we have taken square root of $\upsilon_{MABS}(t)$ and $\upsilon_{RMS}(t)$ and then divided it by the received signal power for making detected CCI dimensionless.

Ⅳ. Simulation Results

Computer simulation was performed to examine the relation among MABS / RMS of CCI, multipath delay time, delay spread and bit error rate(BER) performance. Fig.4 is a block diagram of simulated system. The simulation is carried out at the equivalent baseband.

A nine stage PN sequence was used as test data. First, a stream of two-bit symbol is differently encoded with Gray code and then two-bit symbols are mapped into the phase according to $\pi/4$ shift QPSK rule. And next, it is passed through the raised cosine roll-off filter with $\alpha=0.5$ for pulse shaping and bandwidth limitation, where α is roll-off factor.

Two multipath fading model were assumed quasi static 2 and 3 ray model, where the signal strength and multipath delay time difference are constant and only carrier phase difference between two waves obeys a uniform distribution.

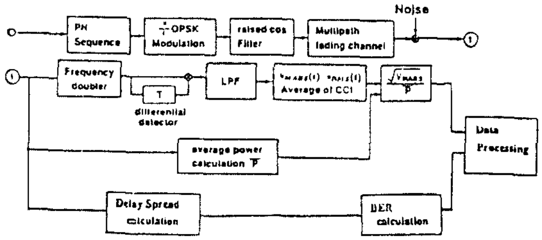

Figure 4 : Simulation block diagram.

Rayleigh distributed two ray model with $f_D T = 1/320$ and AWGN(f_D : maximum Doppler frequency defined by υ/λ where υ is vehicle speed and λ is wavelength).

Fig. 5. shows curves of CCI value(MABS, RMS) versus delay time τ/T with D / U ratio as a parameter and $B_t T=3.0$. As the delay

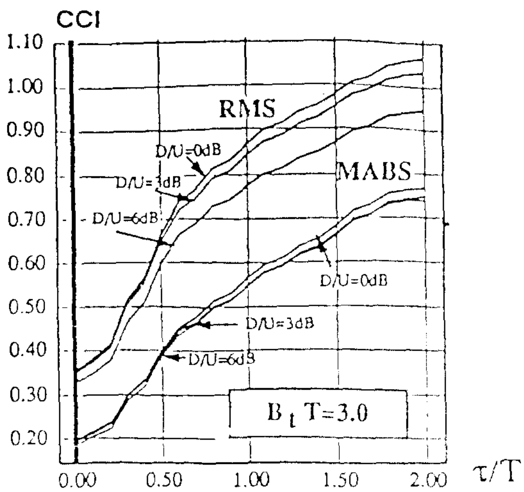

Figure 5 : Delay time vs. MABS and RMS of CCI.

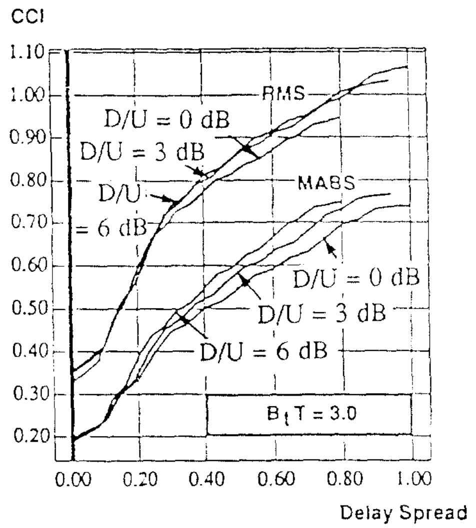

Figure 6 : Delay spread vs. MABS and RMS of CCI.

time τ / T increases, MABS / RMS of CCI quantities increase almost linearly. Between two method of averaging scheme the MABS curves show that they have smaller variation than RMS value with respect to varying D / U ratios.

Fig. 6. is the result which is replotted by using data in Fig.5. with respect to normalized rms delay spread S. Fig. 7. shows the result under quasi static three ray model. they show that both MABS and RMS of CCI have strong correlation with delay spread S.

On the other hand, in the region where delay time $\tau / T < 0.2$ with $B_t T=3.0$ as shown in Fig. 5, MABS has no correlation with τ/T, i.e., has a almost constant value with respect to incr easing τ/T. To investigate this, we simulate the effect of the transmit band limitation filter by varying $B_t T$ from 1.0 to 4.0 and the case with no bandwidth limitation respectively. In Fig.8, the effect of band limitation is very little for $B_t T \geq 4.0$ but the effect is big for $B_t T \leq 3.0$. Hence MABS value of CCI is dependent on the bandwidth of the band limitation filter. Particularly in case of $B_t T=1.0$, this method shows some limitation to be used in the app lication of simple hardware realization.

On the other hand, as shown in Fig.9, band limitation of $B_t T \geq 1.0$ under Rayleigh fading two ray model in noisy environment does not influence on BER. So if we pay attention to the sampling point than the one in case of $B_t T=0.5$, this method can be applicable over $B_t T \geq 1.5$ although CCI has almost constant value for $\tau \leq 0.5 T_s$ delay time. Furthermore, since this region is small comparing to symbol interval, for example within 1μS for 48.6kbps transmit rate, this method can be thought to be available.

For more severe multipath condition, simu lation is performed under Rayleigh fading two ray model with $B_t T=3.0$ and $B_t T=4.0$ (Bandwidth of receiving BPF B_r : 3dB point). Generally in existence of a fading, the avera ging period need to be set sufficiently large compared to fading period because MABS / RMS of CCI value depend on the averaging period. Hence the calculation is repeated 150 times of the fading period based on our previous study[3]. Even in Rayleigh fading enviroment, Fig.10 shows a good correlation between delay spread and MABS of CCI even though CCI has more higher value than in Fig.6. But its shape is almost the same. However RMS value shows some variations with respect to dealy spread.

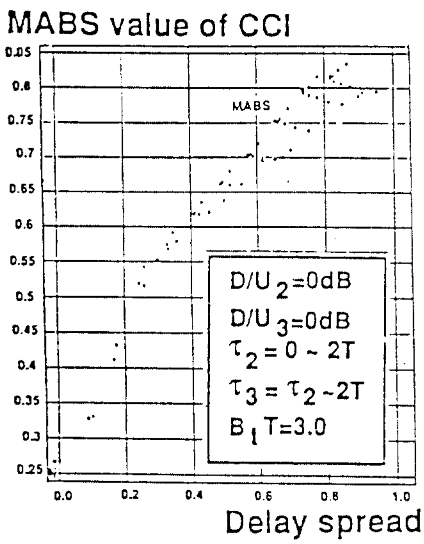

Figure 7 : Delay spread vs. MABS of CCI under quasi-static three-ray model.

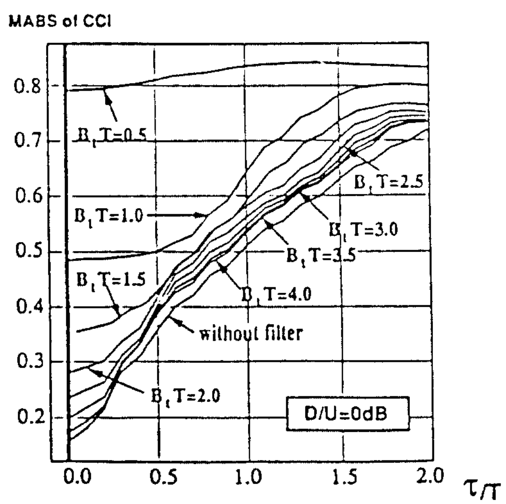

Figure 8 : Delay time vs. MABS of CCI with varying B_tT

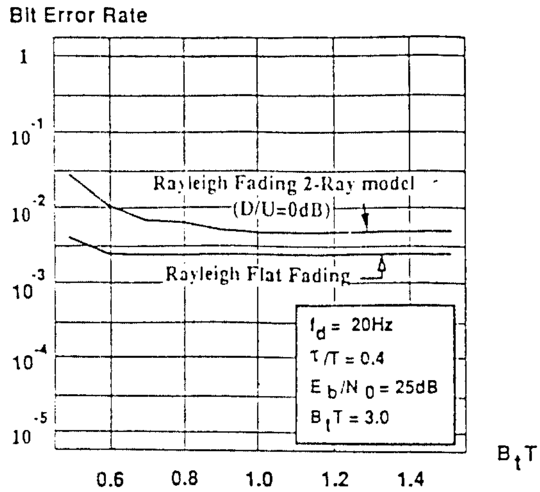

Figure 9 : BER performance with respect to B_tT

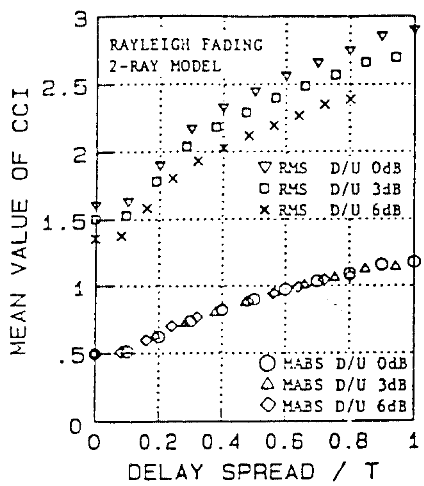

Figure 10 : Delay spread vs. MABS and RMS of CCI under Rayleigh fading two-ray model.

Delay time difference or delay spread is closely related to transmissible signal bandwidth, and also it is strongly correlated to BER performance of transmission line in frequency selective fading channel[10]. In order to estimate characteristics of BER with delay time, computer simulation was done under Rayleighdistributed two-ray model with maximum Doppler frequency as a parameter.

Fig.11. shows BER performance, where τ/T $=0.4$ and D/U ratio is 0 dB. E_b/N_0 for BER of 10^{-3} is about 25 dB, which is comparable result to reference[11]. Hence it shows us that error floor strongly depends on the delay time.

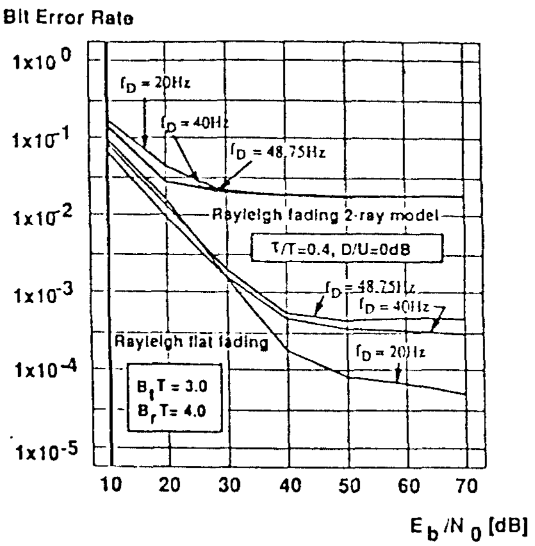

Figure 11 : BER performance under Rayleigh fading two ray model with maximum Doppler frequency as a parameter.

Fig.12. shows the results of relation between BER and delay spread, as well MABS of CCI for investigating the dependency of BER on delay time and also for checking the relation between CCI and BER variation characteristic. In case of delay spread over S≧0.3, BER becomes worse. Hence the variation characteristic of BER can be estimated from the CCI quantity.

Effects of noise was also simulated under Rayleigh fading tworay model, assuming D/U

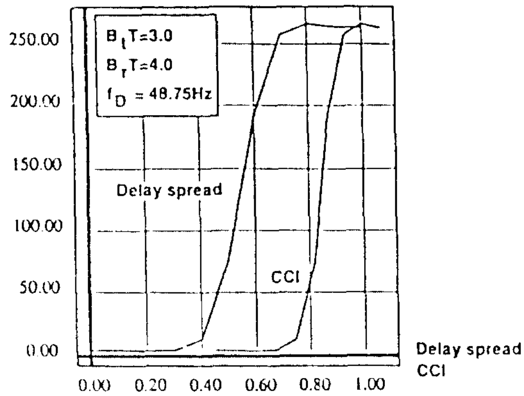

Figure 12 : BER performance vs. MABS of CCI and Delay Spread under Rayleigh fading two ray model.

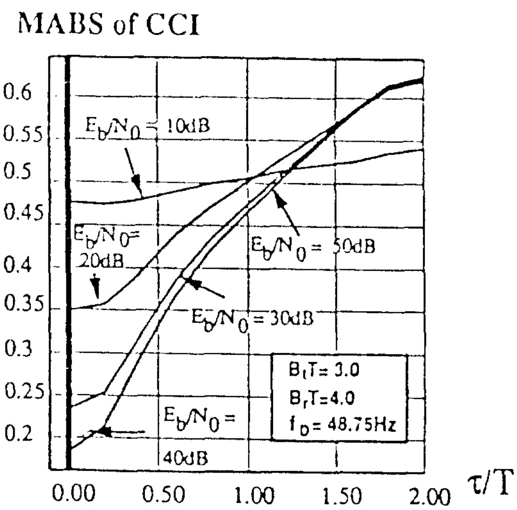

Figure 13 : Delay time vs. CCI under Rayleigh fading two raymodel with AWGN environment.

$=0$ dB, and $B_rT=4.0$. Fig.13. shows the result for the relation between MABS of CCI and delay time τ/T for various values E_b/N_0 as a parameter. As noise power increases, the corresponding MABS of CCI quantities also increase. Strong correlations between CCI and delay spread are shown when E_b/N_0 is over 30dB. In case of below $E_b/N_0=10$dB, no correlation is observed between them as in the case of Fig.11.

Ⅴ. Consideration on simple hardware

The method proposed above may be used in many applications, such as branch selection control of the diversity reception scheme and adaptive array antennas in frequency selective fading channel. Hardware can be realized by using either Digital Signal Processor(DSP) or discrete analog and digital components. Normally, processing data for frequency doubler can be obtained from A / D converter output in front of differential detector as in the simulation block diagram of Fig.4, but it requires standalone frequency doubling hardware. As a another method for simple hardware realization, we can utilize the output data obtained from the differential detectors in Fig.14, which is readily implemented in receiver.

Simulation results using this method show the same result as in Fig.5. Therefore hardware for frequency doubler can be thought to be simply realizable by using some discrete analog components, such as operational amplifiers, adder, and multipliers according to the above block diagram.

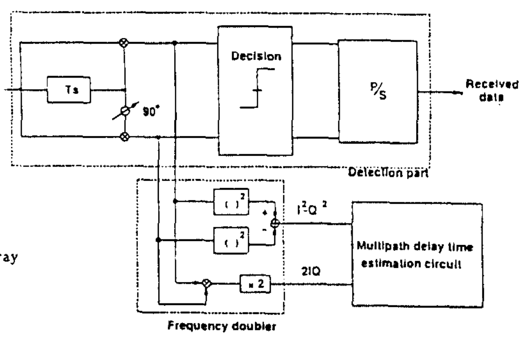

Figure 14 : Block diagram for the realization of frequency doubler.

Ⅵ. Concluding Remarks

The use of cross Channel Interference(CCI) is proposed for detecting multipath signal and also roughly estimating delay spread and BER performance for $\pi / 4$ shift QPSK in the viewpoint of simple hardware realization without special signals. As detecting methods, frequency doubling with differential detector and averaging schemes is taken.

Through theoretical analysis and computer simulation, the use of CCI was confirmed to be a good measure for detecting multipath delay time under quasi-static two, three-ray model and Rayleigh fading two-ray model. Hence this method can be utilized as a useful tool in analyzing the relative transmission quality and roughly estimation the delay spread in less than one symbol interval and the BER changing tendency over some short communication interval. Furthermore, as an application example, this can be used as a decision criterion of each branch in the diversity reception where relative transmission quality in a short communication interval need to be evaluated. However, as a further study, it is necessary to develop a method which can reduce performance degradation due to band-limitation filter, considering the actual band-limitation width in real application. And laboratory measurement and field are necessary to confirm this method.

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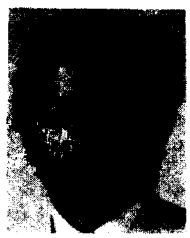

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