한국통신학회 1984년도 춘계학술발표회 논문집 ((1984. 5. 25)

동일채널간섭 및 임펄스성 잡음 환경하에서의 APK 시스템의 오율특성

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APK Error Performance in the Environment of Cochannel Interference and Impulsive Noise

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ABSTRACT

The error rate performance of amplitude phase keying(APK) system has been studied in the environment of cochannel interference and impulsive noise. We have derived the error probability equations of amplitude shift keying(ASK) signal and phase shift keying(PSK) signal, and combining the results, we have evaluated the circular APK signal which is the one of the several cases of APK arrays.

Using the derived equations, the circular APK system has been evaluated in terms of carrier-to-noise power ratio(CNR), carrier-to-interferer power ratio(CIR), and impulsive index.

The graphic results show us the best case and worst case of APK system, and good performance compared to the other systems in cochannel interference and impulsive noise.

1. Introduction

The increasing demands of data transmission in any particular application need the highly efficient utilization of various channels and effective modulation method, e.g. The M-ary PSK is one of such technique requiring less bandwidth than FM. In addition to spectrum efficient PSK, the combined modulation technique such as amplitude phase keying(APK) is used in digital signal transmission when the bandwidth efficiencies of 3 bits/s/Hz or higher is needed.[1] APK requires less power than PSK for the same error probability and alphabet size. Therefore APK becomes a potentially attractive modulation method for satellite communication.

However the ever increasing demand and supply for communication channel in radio frequency(RF) bands causes a serious problem of electromagnetic interference(EMI),[2] and in urban area, the impulsive noise, which is generated by many electromechanical devices and the ignition spark of automobile, etc., has also become a serious degradation factor to the receiving system.

Consequently, as the RF band is limited, the reuse of existing band which is in use has been considered in satellite communication such as Intelsat-IV and V,[3] and in mobile communications.

In this paper, cochannel interference

which is generated by the reuse of existing band in use, and impulsive noise which is generated in urban area are treated statistically.

2. Analysis Model

The analysis model is presented in Fig.1, where s(t) is the desired APK signal, n(t) the impulsive noise, and i(t) the other interfering signal.

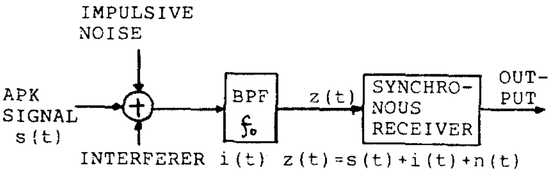


Fig.1. Analysis model.

Here the receiver is assumed to be perfectly synchronized with the transmitter.

(1) PSK Signal

The M-ary PSK signal can be represented as

$$s_p(t)=S\cos(2\pi f_0 t+2\pi\lambda/M) \qquad (1)$$

where S is the amplitude of PSK signal, f_0 the carrier frequency, M the number of levels, and λ (=0,1,...,M-1) the M-ary information. The probability of occurrence of each information is assumed to be same.

(2) ASK Signal

A 2L bit ASK signal received during the N'th interval with signaling interval T and carrier frequency f_0 can be represented as

$$s_A(t)=S_i\cos(2\pi f_0 t) \qquad NT\leq t\leq(N+1)T \quad (2)$$

where

$S_i\in\{\pm d,\pm 3d,\ldots,\pm(2L-1)d\}$; the amplitude of signal,

2d; the distance between two adjacent signal points,

L ; the number of levels of ASK signal.

(3) Impulsive Noise Model

In a number of digital transmission systems, in addition to Gaussian noise, impulsive noise interferer is also present. It might be generated in two cases. The one is man-made radio noise, and the other is natural impulsive random noise. In this paper, as an analytically tractable model of man-made and natural radio noise, Middleton's recently developed cannonical statistical-physical model of impulsive noise[4] is introduced.

The bandpassed impulsive noise can be written as

$$n(t)=E'\cos(2\pi f_0 t+\varphi_e) \qquad (3)$$

where E' and φ_e, which are independent random variables, are the envelope and the phase. The probability density function(p.d.f.) of the normalized envelope of n(t) has been formed by Middleton as

$$p(E)=e^{-A}\sum_{i=0}^{\infty}\frac{A^i}{i!}\frac{2E}{\sigma_i^2}e^{-\frac{E^2}{\sigma_i^2}} \qquad (4)$$

where,

$E\left(=E'/\sqrt{2(\sigma_G^2+\Omega_A)}\right)$; normalized noise envelope,

$\Gamma'\left(=\sigma_G^2/\Omega_A\right)$; the ratio of the intensity of the independent Gaussian component(σ_G^2) to the intensity of the "impulsive" component(Ω_A) of impulsive noise,

$\sigma_i^2=(i/A+\Gamma')/(1+\Gamma')$

A ; impulsive index.

The initial phase φ_e is assumed to be uniformly distributed in the interval between 0 and 2π.

(4) Interferer

The degradation in bit transmission quality, an increase in the probability of error, can be arison from many different sources. The cochannel interference is the main interest to get the adequate interference level for the allowable probability of bit error.

The reuse of existing band which is in use causes cochannel interference, which has been considered carefully in satellite communication system with cell splitting and polarization, and adopted in mobile telephone system with space-divided cells spaced sufficiently apart.

3. Statistical Characteristics of the Received Composite Wave

The phasor representation of the received PSK signal corrupted by the impulsive noise and the interferer has been shown in Fig.2.

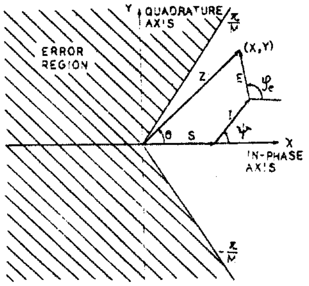


Fig.2. Phasor representation of the received PSK signals.

When the terminal of composite vector in the M-ary PSK system lies in the error region, an error is made in the receiver.

The symbol error probability of M-ary PSK signal has been derived as[5]

$$P_e=(1-1/M)-\sum_{n=1}^{\infty}\sum_{i=0}^{\infty}\frac{1}{\pi}\sin(n\pi/M)$$

$$\cdot\cos\left\{n\left[\tan^{-1}\frac{\sin(\phi+2\pi\nu/M)}{\sqrt{\beta}+\cos(\phi+2\pi\nu/M)}\right]\right\}$$

$$\cdot\frac{e^{-A}A^{i}}{i!}\cdot\frac{1}{(\sigma_i^2)^{n/2}}\cdot\frac{\Gamma(n+2)}{\Gamma(n+1)}\cdot X^{n/2}$$

$$\cdot{}_1F_1[n/2;n+1;-(\sigma_i^2)^{-1}\cdot X] \qquad (5)$$

where,

$X=\alpha+2\alpha\cos(\phi+2\pi\nu/M)/\sqrt{\beta}+\alpha/\beta$

ϕ $(=\psi-2\pi\nu/M)$; phase difference between carriers of signal and interferer,

α;CNR(carrier-to-noise power ratio),

β;CIR(carrier-to-interferer power ratio),

${}_1F_1[\cdot;\cdot;\cdot]$; confluent hypergeometric function,

$\Gamma(\cdot)$; gamma function.

For the calculation of bit error rate in eq.(5), M cases of $\nu=0$, $\nu=1,\ldots,$ and $\nu=M-1$ must be considered. Then the total probability of error is the average of M cases. Thus,

$$P_E=\frac{1}{M}\left(P_e\big|_{\nu=0}+P_e\big|_{\nu=1}+\cdots+P_e\big|_{\nu=M-1}\right) \qquad (6)$$

We show in Fig.3. the phasor diagram of the received L-level ASK signal corrupted by impulsive noise and cochannel interferer.

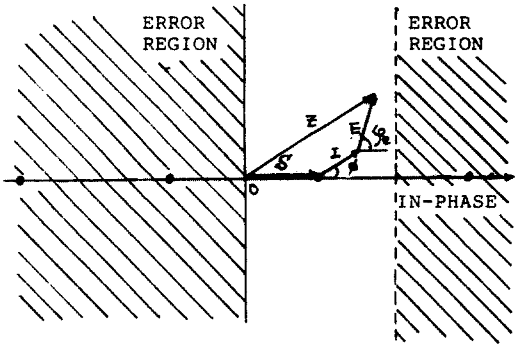


Fig.3. Phasor diagram of the received L-level ASK signal.

The derived error probability is

$$P_E=\frac{2L-1}{2L}\cdot\frac{e^{-A}}{\pi}\sum_{i=0}^{\infty}\frac{A^{i}}{i!}\left[(1-\sqrt{2/\beta}\cos\phi)\right.$$

$$\cdot\exp\left\{\frac{-\alpha}{\sigma_i^2}(1-\sqrt{2/\beta}\cos\phi)^2\right\}$$

$$-(1+\sqrt{2/\beta}\cos\phi)\cdot\exp\left\{\frac{-\alpha}{\sigma_i^2}(1+\sqrt{2/\beta}\right.$$

$$\left.\left.\cdot\cos\phi)^2\right\}\right] \qquad (7)$$

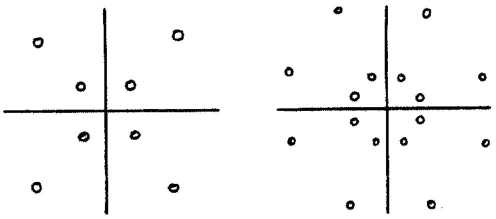
where,

α;CNR,

β;CIR,

ϕ;phase slip between signal and interferer.

Combining the results obtained in eq.(6) of M-ary PSK error rate and eq.(7) of L-level ASK error rate, we can derive the error rate of circular array case of APK system which is the one of the several cases of APK arrays. Fig.4. shows the signal diagrams of (4,4) circular array and (8,8) circular array as examples of APK system.



(a) (4,4) circular array (b) (8,8) circular array

Fig.4. Signal space diagram of APK signal.

The error rates of (4,4) circular array and (8,8) circular array APK system in this paper can be obtained as follows, because the amplitude and the phase are independent each other.

$$P_E\left\{(4,4)\ \mathrm{APK}\right\} = P_E(\text{2-level ASK}) + P_E(\text{4-PSK}) \qquad (8)$$

$$P_E\left\{(8,8)\ \mathrm{APK}\right\} = P_E(\text{2-level ASK}) + P_E(\text{8-PSK}) \qquad (9)$$

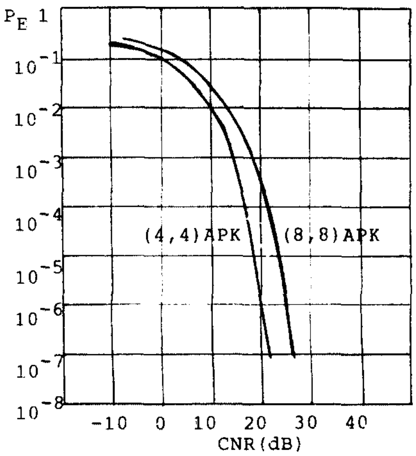
4. Discussions and Conclusions

Using the derived equations of L-level ASK signal and M-ary PSK signal, we have numerically calculated and evaluated the symbol error rate performance of APK system compared to ASK and PSK system.

At low CNR, the greater part of errors is caused by Gaussian noise, and at high CNR, the major factor causing the error is the impulsiveness.

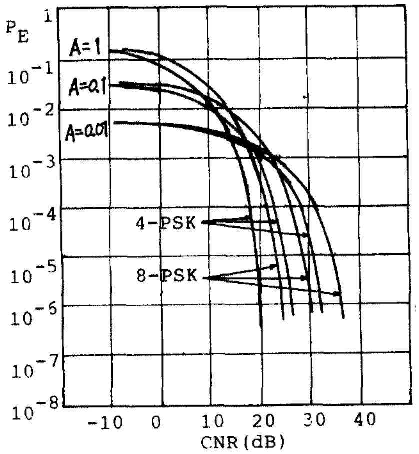
The (4,4) APK system shows good performance compared to 8-PSK system with same bits/s/Hz.

The most interesting result, however, is shown in Fig.5.6. This graph is the case of normalization by the worst case ($\phi=0°$) with the variation of phase difference between carriers of signal and interferer from 0° to 180°. The increase of the number of arrays show that the system have less dependence with the phase difference between the carriers of signal and interferer.



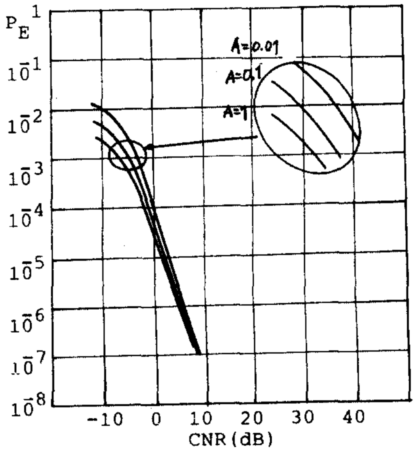
$A=1$, $\Gamma'=10$, $\phi=0°$, CIR=10 dB

Fig.5.1 The symbol error rate(SER) of APK signal interfered by Gaussian noise and cochannel interferer.



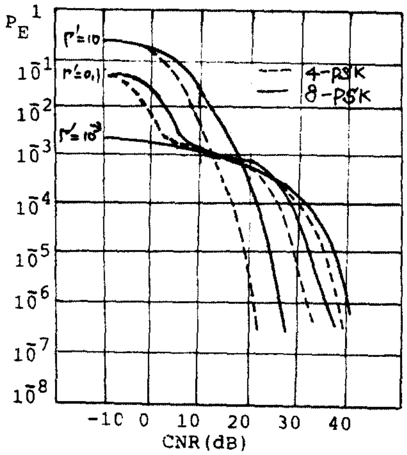
$\Gamma'=10^{-3}$, $\phi=0°$, CIR=10 dB

Fig.5.2. SER of PSK signal interfered by one interferer and impulsive noise.



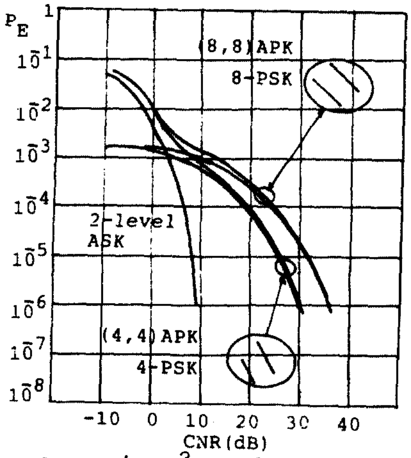
$\Gamma'=0.01$, $\phi=45°$, CIR=20 dB

Fig.5.3 SER of 2-level ASK signal interfered by one interferer and impulsive noise.



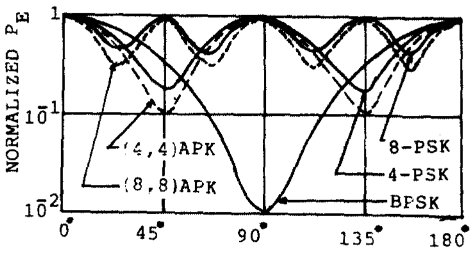
A=0.01, $\phi=0^\circ$, CIR=10 dB

Fig.5.4 SER of PSK signal interfered by one interferer and impulsive noise.



A=0.01, $\Gamma'=10^{-3}$, $\phi=0^\circ$, CIR=20 dB

Fig.5.5 SER of APK signal compared to PSK signal and ASK signal.



A=1, $\Gamma'=10$, CIR=10 dB, CNR=10 dB

Fig.5.6 SER normalized by the worst case ($\phi=0^\circ$).

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