Performance Analysis of 16 QAM System in a Composite Electromagnetic Interference Environment

복합 전자파 간섭 환경에서 16 QAM 시스템의 성능 분석

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Abstract

In this paper, the analysis model of a composite electromagnetic interference environment is proposed, and the composite interference consists of three types, i.e., impulse, sinusoidal, and rectangular type. Also, we have derived the p.d.f of the amplitude of the composite interference. And using a derived p.d.f, we have evaluated the performance of 16QAM (Quadrature Amplitude Modulation) system in a composite electromagnetic interference environment.

From the results, it is known that when impulse type interference is weaker than the others, the shape of p.d.f is dominantly governed by the power component ratio of sinusoidal and rectangular type interference. On the other hand, when impulse type interference is stronger, the effect of the other two interference becomes insignificant. Also, It is shown that the smaller both impulsive index (A) and the mean power component ratio (Γ') in impulse type interference are, the worse the performance of 16QAM system is.

요 약

본 논문에서는 복합 전자파 간섭 환경의 해석 모델을 제안하였고, 복합 간섭파는 임펄스, 사인파, 구형파 형태의 3가지 종류로 구성하였다. 또한, 복합 간섭파 진폭의 확률밀도함수를 유도하였다. 그리고 유도된 확률밀도함수를 이용하여 복합 전자 간섭 환경에서 16QAM 시스템의 성능을 구하였다.

얻어진 결과로부터 임펄스 형태의 간섭이 다른 간섭 성분에 비하여 약할 경우에는 확률밀도함수의 형태가 사인파나 구형파 형태 간섭의 전력 성분에 의하여 지배를 받음을 알 수 있었다. 반면에 임펄스 형태의 간섭이 강할 경우에는 다른 2개의 간섭 성분의 영향은 지배적이지 않음을 알 수 있었다. 또한, 임펄스 형태의 간섭에서 임펄스 지수(A)와 평균 전력 성분비 (Γ')가 적을수록 16QAM 시스템의 성능은 열화됨을 알 수 있었다.

Ⅰ. INTRODUCTION

It is well known that the electromagnetic interference (EMI) radiated from industrial, scientific and medical (ISM) apparatus seriously degrades the performance of wireless communication systems.

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ISM-band wireless communication system which employs a multi-level signal is designed to be sufficiently robust and reliable to operate in the presence of this electromagnetic interference. To satisfy this goal, the analysis model of a composite interference and performance evaluation of multi-level signal on ISM-band wireless communication system are needed.

As electromagnetic environment becomes more complicated and worse with the advent of a information society, it is necessary to study how to decrease the effects of electromagnetic interference to human body, various equipments, and communication system[1]~[3].

There are many papers presenting the effects of interference in various environment. But few indicates the analysis model of it. Thus, it is necessary to classify EMI and analyze the performance of communication system with the approximated interference model close to the real environment.

In order to investigate the effects of EMI, first, we have to know the amplitude distribution of EMI[4]~[6]. Because, however, the received signal corrupted by various types of EMI has very complex aspects, it is very difficult to obtain the p.d.f. of the combined amplitude of the received signal. Therefore, for analysis, it is necessary to confine a interference in the real environment to a specified approximation type of the interference[7].

QAM is a modulation scheme which provides high frequency spectrum efficiency. This modulation scheme has been used for a long time in the terrestrial radio communication system[8], and recently the use of QAM even in the mobile radio communication system is catching attention[9]. Therefore, the performance of QAM system in the EMI environment has to be investigated[10]. In this paper, we classify EMI such as impulsive, sinusoidal, and rectangular type interference and propose the analysis model of the composite interference. we have derived the p.d.f of the amplitude of composite interference. And then, using this model, we analyze the performance of 16QAM system in composite interference environment.

Ⅱ. MODEL OF COMPOSITE EMI

In fact, as the model of single type interference is insufficient to represent the complicated EMI environment in the real world, we assume that EMI consists of three type interference, i.e., impulse[11]~[13], sinusoidal, and rectangular type interference to model the EMI environment more close to the real world. Fig. 1. presents the schematic diagram of analysis model in EMI and AWGN.

The received signal corrupted by various types of EMI and AWGN can be expressed as follows

$$r(t) = s(t) + n(t) + I_1(t) + I_2(t) + \cdots + I_{N-1}(t) + I_N(t) \qquad (1)$$

where, $s(t)$; transmitted signal,
$n(t)$; AWGN(additive white Gaussian noise),
$I_N(t)$; infinite interferences.

In this paper, we assume that the number of interferences affecting communication system is finite.

$$I_{model}(t) \approx I_1(t) + I_2(t) + \cdots + I_{N-1}(t) + I_N(t) \qquad (2)$$

where, $I_{model}(t)$ is the composite EMI composed of three types of interference, and then it can be

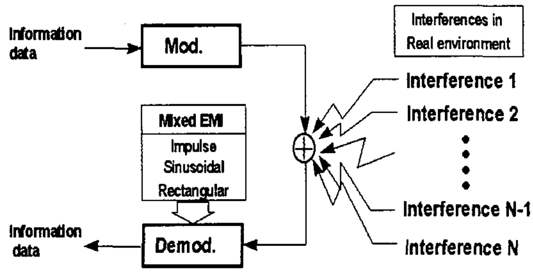


Fig. 1. Schematic diagram of analysis model.

expressed as follows.

$$I_{model}(t) = I_{IMP}(t) + I_R(t) + I_S(t) \quad (3)$$

where, $I_{IMP}(t)$; impulse type interference,
$I_S(t)$; sinusoidal type interference,
$I_R(t)$; rectangular type interference.

Therefore, the received signal expressed in demodulation block of analysis model is given by.

$$r'(t) = s(t) + n(t) + I_{model}(t) \quad (4)$$

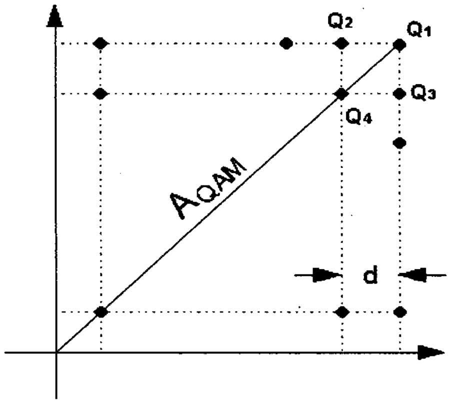
If we assume that three types of interference and AWGN are statistically independent of each other, the p.d.f. of the composite EMI containing AWGN can be expressed as follows by convolution combination.

$$p_c(x) = e^{-A} \sum_{j=0}^{\infty} \frac{A^j}{j!} \frac{1}{2\pi\sqrt{2\pi(W\sigma_j^2 + \sigma_N^2)}} \cdot \int_0^{\pi} \left[\exp\left\{ -\frac{(x+b-a\cdot\cos\theta)^2}{2(W\sigma_j^2+\sigma_N^2)} \right\} + \exp\left\{ -\frac{(x-b-a\cdot\cos\theta)^2}{2(W\sigma_j^2+\sigma_N^2)} \right\} \right] d\theta \quad (5)$$

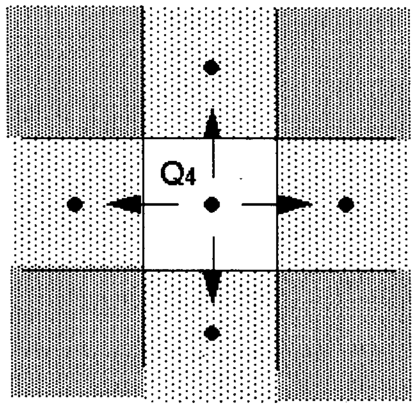
where, W ; power of impulse type interference,
σ_N^2 ; power of Gaussian type interference,
σ_j^2 ; $(j/A+\Gamma')/(1+\Gamma')$,
a ; peak amplitude of sinusoidal type interference,
b ; peak amplitude of rectangular type interference.

Ⅲ. PERFORMANCE EVALUATION OF 16QAM SYSTEM

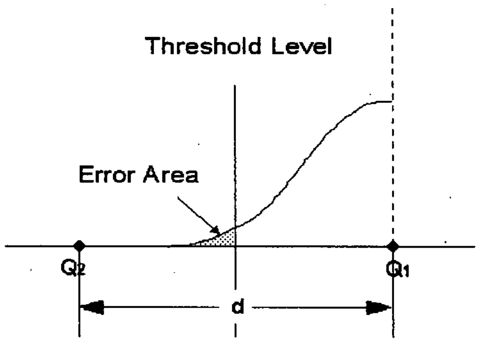
In this section, we analyze the performance of 16QAM system in the composite EMI and AWGN environment. Fig. 2. (a) presents constellations of signal, Fig. 2 (b) presents error probability of symbol Q_4 in four directions. Then, A_{QAM} is peak amplitude of the received signal and d is minimum distance between symbols. Also, we assume that the



(a) Signal constellation for N-ary QAM signal.



(b) Symbol error patterns of QAM signal.



(c) Error probability in one direction.

Fig. 2. Constellation and error decision of N-ary QAM.

symbol Q_1 in Fig. 2 (c) is transmitted in composite EMI and AWGN environment. Then the received signal's p.d.f. is affected by composite EMI and AWGN. In this case, an error (Q_2) occurs when it goes across threshold level of the p.d.f. magnitude. We assume that the distance between a symbol Q_1 and other symbol Q_2 is d and error decision level is at $d/2$ position. Then the received signals of the symbol Q_1 going across the decision level treats with error.

The error probability in one direction is expressed as follows by using Eq. (5).

$$Pe_1(e)=\frac{1}{4\pi}e^{-A}\sum_{j=0}^{\infty}\frac{A^j}{j!}\int_0^{\pi}\left[erfc\{K+M-N\cos\theta\}+erfc\{K-M-N\cos\theta\}\right]d\theta \quad (6)$$

where, $K=\sqrt{\frac{CNR\cdot CIR}{10(CIR+I_{IMP}R\cdot\sigma_j^2\cdot CNR)}}$,

$$M=\sqrt{\frac{CNR\cdot I_RR}{2\{CIR+I_{IMP}R\cdot\sigma_j^2\cdot CNR\}}},$$

$$N=\sqrt{\frac{CNR\cdot I_SR}{CIR+I_{IMP}R\cdot\sigma_j^2\cdot CNR}},$$

$CNR=\frac{(n-1)A_{QAM}^2}{6(\sqrt{n}-1)^2\sigma_n^2}$; carrier-to-noise power ratio,

$CIR=\frac{(n-1)A_{QAM}^2}{6(\sqrt{n}-1)^2 I_T}$; carrier-to-total interference power ratio,

$I_{IMP}R=\frac{W}{I_T}$; impulse type interference power per total interference power ratio,

$I_SR=\frac{a^2}{2I_T}$; sinusoidal type interference power per total interference power ratio,

$I_RR=\frac{b^2}{I_T}$; rectangular type interference power per total interference power ratio.

Therefore, by using Eq. (6), the symbol error probability of N-ary QAM is represented as follows.

$$Pe_2(e)=\frac{4}{n}\Big[2Pe_1(e)-Pe_1(e)^2+(\sqrt{n}-2)\times(3Pe_1(e)-2Pe_1(e)^2)+\left(\frac{\sqrt{n}}{2}-1\right)^2\times(4Pe_1(e)-4Pe_1(e)^2)\Big]$$
$$=\frac{4(n-\sqrt{n})}{n}Pe_1(e)-\frac{4(n-2\sqrt{n}+1)}{n}Pe_1(e)^2 \quad (7)$$

Finally, the symbol error probability of 16QAM signal is obtained as follows.

$$Pe_{16QAM}(e)=3Pe_1(e)-\frac{9}{4}Pe_1(e)^2 \quad (8)$$

Ⅳ. NUMERICAL RESULTS

Fig. 3 and Fig. 4. present the p.d.f. of the composite three types of interference according to component ratio of sinusoidal and rectangular type interference, at 10 % and 50 % of impulse component, respectively. Then we set the INR at 10 dB. The shape of p.d.f. is changing according to component ratio of sinusoidal and rectangular, at 10 % of impulse component, then it influences the performance of 16QAM system. The shape of p.d.f., at 50 % of impulse component, is narrower in width than that of p.d.f., at 10 %.

In Fig. 5~Fig. 10, we have analyzed the system performance with respect to CIR and CNR, at CIR=5 dB, 10 dB, 15 dB, 20 dB, and non interference. In Fig. 5~Fig. 7, the error performance of 16 QAM

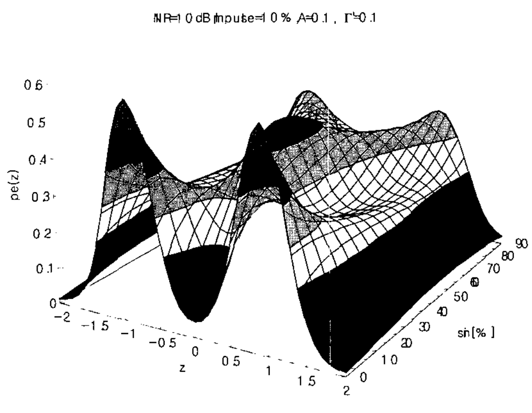


Fig. 3. P.d.f. of EMI in INR=10 dB and impulse component of 10 %(A=0.1, Γ'=0.1).

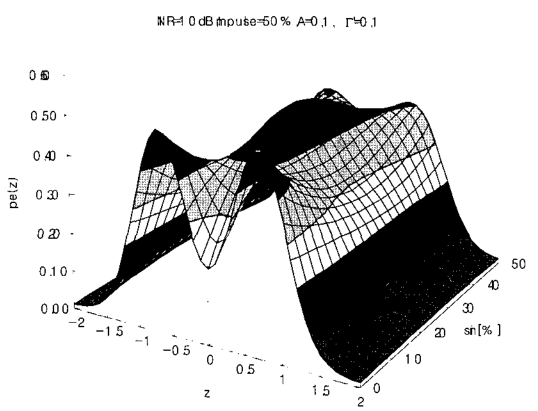


Fig. 4. P.d.f. of EMI in INR=10 dB and impulse component of 50 % (A=0.1, Γ'=0.1).

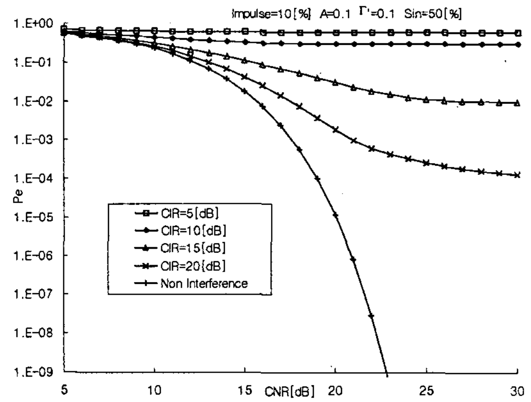


Fig. 6. Symbol error probabilities of 16QAM system(impulse=10 %, sinusoidal=50 %, rectangular=40 %, A=0.1, Γ'=0.1).

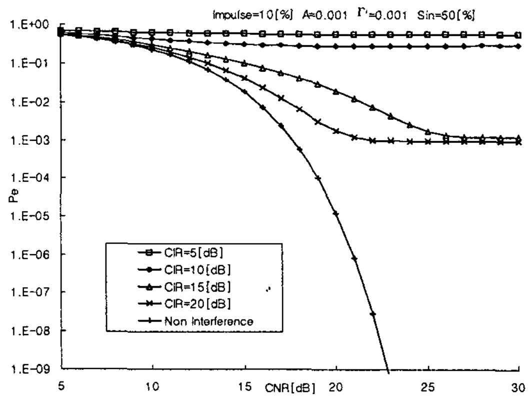


Fig. 5. Symbol error probabilities of 16QAM system(impulse=10 %, sinusoidal=50 %, rectangular=40 %, A=0.001, Γ'=0.001).

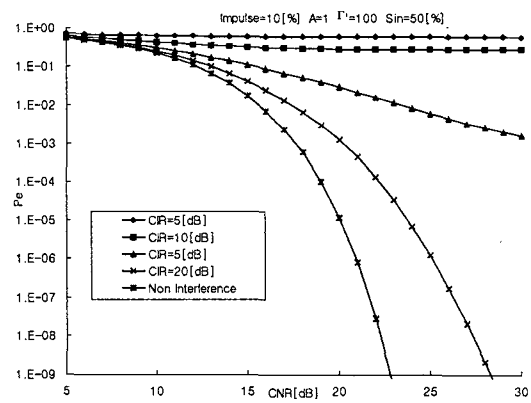


Fig. 7. Symbol error probabilities of 16QAM system(impulse=10 %, sinusoidal=50 %, rectangular=40 %, A=1, Γ'=100).

system, at 10 % of impulse component, 50 % of sinusoidal component, and 40 % of rectangular component, with A=0.001 and $\Gamma'=0.001$, A=0.1 and $\Gamma'=0.1$, and A=1 and $\Gamma'=100$, respectively. Here, the case of A=0.001 and $\Gamma'=0.001$ represents a severe impulse interference environment. As shown in these figures, the error performance is improved by the increase of the value of impulse index A and Γ'. We, however, could not achieved a good error performance for data communication system. Therefore, these results describe that the impulse interference dominantly causes the error performance degradation. In Fig. 8 ~ Fig. 10, when the impulse component is dominant than others, i.e., 50 % of impulse component, 10 % of sinusoidal component, and 40 % of rectangular component, with the same value of impulse index A and Γ', as in Fig. 5~Fig. 7, the error performance is more degraded.

Table 1. shows CNR for the symbol error probability(10^{-3}) with respect to the component

Table 1. CNR [dB] for the symbol error probability(10^{-3}). (rectangular = 40 %)

Impulse[%] sinusoidal[%] / CIR [dB]		A=0.001, Γ'=0.001		A=0.1, Γ'=0.1		A=1, Γ'=100	
		I=10% S=50%	I=50% S=10%	I=10% S=50%	I=50% S=10%	I=10% S=50%	I=50% S=10%
16 QAM	15	–	–	–	–	32.74	25.90
	20	22.63	22.05	20.92	20.48	20.19	19.80
	25	19.12	19.02	18.43	18.38	18.43	18.38
	30	18.09	18.09	17.90	17.90	17.90	17.90
	35	17.75	17.75	17.70	17.70	17.70	17.70

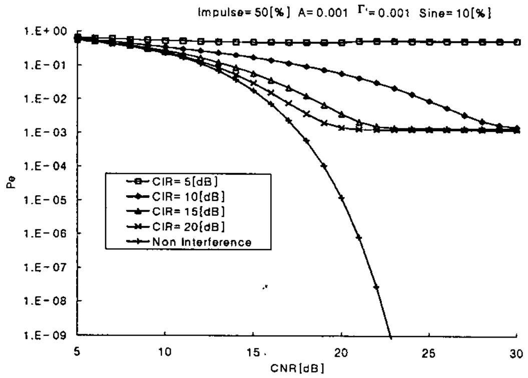


Fig. 8. Symbol error probabilities of 16QAM system(impulse=50 %, sinusoidal=10 %, rectangular=40%, A=0.001, Γ'=0.001).

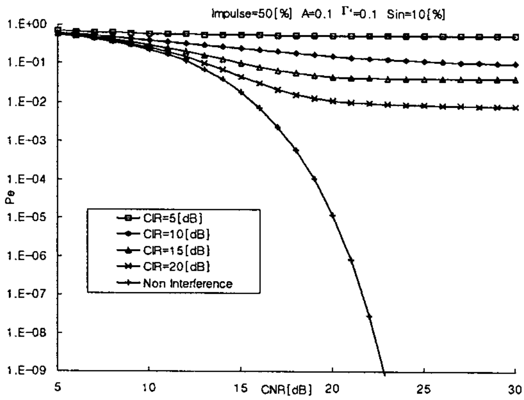


Fig. 9. Symbol error probabilities of 16QAM system(impulse=50 %, sinusoidal=10 %, rectangular=40 %, A=0.1, Γ'=0.1).

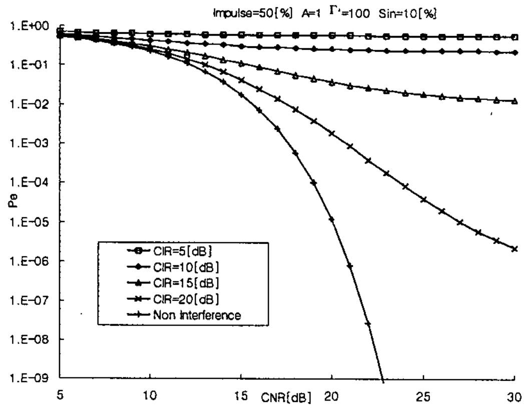


Fig. 10. Symbol error probabilities of 16QAM system(impulse=50 %, sinusoidal=10 %, rectangular=40 %, A=1, Γ'=100).

ratio of each interference, A, Γ', and CIR. From the table, in case of 10 % of impulse component, the 16QAM system has the worst performance, at CIR=20 dB, and A=0.001 and $\Gamma'=0.001$. And also in case of 50 % of impulse component, the 16QAM system has the best performance at CIR=20 dB, and A=1 and $\Gamma'=100$. The most important result that we have obtained is that the 16QAM system in the composite interference model proposed here requires at least 23 dB, at I=10 % and S=50 %, of CNR for the symbol error probability(10^{-3}) of voice communications.

V. CONCLUSION

In this paper, we have derived the p.d.f of the amplitude of composite electromagnetic interference. And then we have evaluated the performance of 16QAM system in the composite electromagnetic interference composed of three types of interference i.e., impulse, sinusoidal, and rectangular type interference.

From the results, it is known that when impulse type interference is weaker than others, the shape of p.d.f is mainly governed by the power component ratio of sinusoidal and rectangular type interference. On the other hand, when impulse type interference is stronger, the effect of other interferences becomes insignificant. Also, we have known that when impulse type interference occupies less than 10 % of total interference, the performance of 16QAM system is mainly governed by the power component ratio of sinusoidal and rectangular type interference. Conversely, when impulse type interference occupies over 50 %, the effect of other interferences becomes weaker. As both A and Γ' are decreasing, CNR should be increased to obtain symbol error rate 10^{-3} with component ratio of interferences and CIR value. Therefore, if we know which type of interference dominantly affects a communication system, we can establish the system which is less suspectible to the interference.

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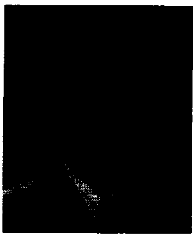

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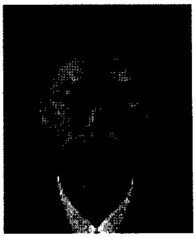

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