QAM 신호에 대한 FDM-FM 신호의 간섭 영향

- Data In Voice 의 경우 -

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RADIO FREQUENCY INTERFERENCE FROM FDM-FM SIGNALS ON QAM SIGNAL - DATA IN VOICE CASE -

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Abstract

In this paper we have investigated the effects of two wideband FDM-FM signals on n-ary QAM signal allocated between FDM-FM signals (in DIV case). Here, we assumed that the instantaneous frequency distribution of wideband FDM-FM signal is Gaussian. The numerical results of symbol error rate are given in graphs as the parameters of carrier to noise ratio (CNR), carrier to interference ratio (CIR) and normalized carrier separation between QAM and FDM-FM carrier frequencies.

I. Introduction

At present, terrestrial microwave, cable and satellite systems are intended for the transmission of analog, digital or combined source information. In the near future, the increase of TDM equipments and digital source information will be more significant than the increase of analog systems. Accordingly, many countries have tendency to make efficient use of existing analog microwave cable and satellite systems or hybrid information transmission. The hybrid systems are used for simultaneous transmission of time division multiplexed(TDM) or frequency division multiplexed(FDM) voice signal.
In this case, the frequency bands of conventional system, which as ordinally designed to carry only FDM signals should be shared by these digital and analog signals.
The primary objects of these hybrid transmission techniques e.q. DAV, DUV, DAVID, DUVID etc.[1][2] is to cause degradation to the existing analog performance while maintaning efficient data transmission.
Although digital source informations increase, hybrid systems are going to be required as long as FDM microwave systems carry the bulk of voice traffic.
Therefore, investication of the effects of analog signals on newly introduced digital signal in the same analog frequency bands in an interference environment needs.
Recently, QAM system is popular in many counries because QAM system has 5bit/s/Hz almost two times of transmission rate per Hz than 2bit/s/Hz of QPSK system and QAM system is efficient than the other conventional digital system in cost [3].
In this, we have investigated effects of two wideband FDM-FM signal on n-ary QAM signal which is between FDM-FM signals (in DIV case). Here, we assumed that the instataneous frequency distribution of wideband FDM-FM susnal is Gaussian.
And the numerical results of error performance are given in graphs as parameters of carrier to noise ratio (CNR), carrier to interference ratio (CIR), and normalized carrier separation between QAM and FDM-FM carrier frequencies.
Here, we considered wideband FDM-FM signals as analog signals and 16 QAM as digital signal.

II. Analysis Model

In this study, the transmission channel is assumed to be transparent so that the QAM signal arrives undistorted at the front end of QAM receiver. There, a stationary white Gaussian noise and the interferences of adjacent two FM signals are added. Then, the symbol errors will be due to the combined effects of interferences and noise.
In Fig.1 a general ferquency arrangement under concideration is shown, where FM signals are located adjacently of QAM signal, s(t), by amount of f_{dk} ($f_{dk}=f_{ik}-f_s$, f_{ik} : carrier frequency of the th FM signal, k =1,2)
The desired QAM singal, s(t), and the th FM interferer, i (t), can be represented as

$$s(t)= a(t)\cos\omega_s t + b(t)\sin\omega_s t \quad (1)$$

$$i_k(t)=I_k(t)\cos(\omega_{ik}+\lambda_k(t)+\xi_k) \quad (2)$$

where
a(t), b(t) : source information signals of QAM
I_k : amplitude of the k th FM signal
$f_{ik}=\omega_{ik}/2\pi$: carrier frequency of the k th FM signal

$\dot{\lambda}_k(t) = d\lambda_k(t)/dt$: baseband modulating FDM signal of k th FM signal

ξ_k : initial phase angle of the k th FM signal distributed uniformly $[0, 2\pi]$

The FDM-FM signals treated here are assumed to be wideband FM's which are all under the quasi-staionary condition, in which the spectrum of each FM modulated signal is uniquely determined by the statistical property of the its baseband modulating signal [4][5][6], and they are to be statistically independent of each other. Hence, the instantaneous frequency distribution of the k th FM signal, $P_{kf}(f)$, can be represented by eq. (3) [6]

$$P_{kf}(f) = \frac{1}{\sqrt{2\pi}\,\Delta f_k} \exp\left\{-\frac{(f-f_{ik})^2}{2\,\Delta f_k^2}\right\}$$
$$;\ f_{ik} \gg \Delta f_k \qquad (3)$$

where, Δf_k is the r.m.s frequency deviation from the carrier frequency f_{ik}.

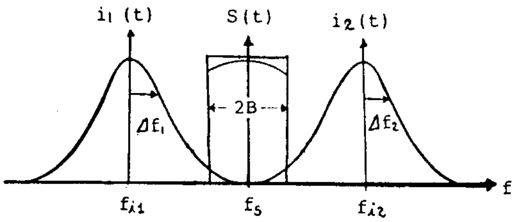

Fig. 1 DIV Frequency arrangement.

Therefore, instantaneously we can regard each wideband FM signal as a sinusoidal signal whose frequency is statistically defined by eq. (3). When FM signal enter the frequency range of QAM bandpass filter (BPF), the QAM signal is interfered and error may occur in the QAM detector. However, even if all the FM signals are outside of the BPF passband, error may be occured by only additive Gaussian noise. The possible states of entrance of FM signals into the passband of BPF can be given by an 4 X 2 matix as $\mathbb{A}$ in eq. (4).

$$\mathbb{A} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{bmatrix} \qquad (4)$$

(rows: g ↓, columns: k →)

In eq. (4) g=1 (the 1st row) indicates no interference case and g=4 (the last row) indicates two interference case [7]. Here, let (=1,2) be the probability of entrence 1 of the th FM signal into the BPF passband, then is given by

$$P_k = \int_{f_s-B}^{f_s+B} P_{kf}(f)\,df$$

$$= \frac{1}{2}\left[\mathrm{erf}\left(\frac{F_{dk}+b_k}{\sqrt{2}}\right) - \mathrm{erf}\left(\frac{F_{dk}-b_k}{\sqrt{2}}\right)\right] \qquad (5)$$

where $F_{dk} = \frac{f_{dk}}{\Delta f_k}$, $b_k = \frac{B}{\Delta f_k}$, $f_{dk} = f_{ik} \sim f_s$

Therefore, the probability of no entrance '0' is $1-P_k$. In eq. (5), replacing all the '1' elements by P_k and '0' elements by $(1-P_k)$, we can obtain the new matix $\mathbb{P}$:

$$\mathbb{P} = \begin{bmatrix} 1-P_1 & 1-P_2 \\ P_1 & 1-P_2 \\ 1-P_1 & P_2 \\ P_1 & P_2 \end{bmatrix} \qquad (6)$$

(rows: g ↓, columns: k →)

Here, we represented the state probability of k th row as P_k.

III. The Error Rate Performance of n-ary QAM signal

Since each interferer is assumed to be wideband FM, it can be whose distribution is a sinusoidal signal with random frequency whose distribution is determined by the probability density of the baseband modulating sinal (Gaussian signal in this paper). Therefore, at certain instant one of two FM interferers may be in the passband of the BPF for the QAM signal and the another may be outside.

In Fig. 2 we show the phasor diagram in Inphase channel without any loss of generality when all the adjacent FM signals are entered in the BPF passband. This case corresponds to the state represented by last row in the matix $\mathbb{A}$, and that at another certain instant only one FM interferer may exist in the BPF passband.

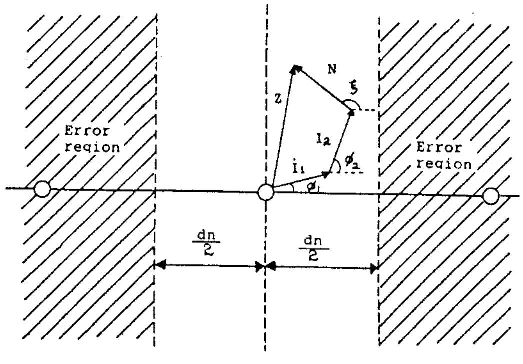

Fig. 2 Composite phasor diagram of received QAM signal of Inphase channel.

The composite signal Z in Fig. 2 is

$$Z = I_1\cos\phi_1 + I_2\cos\phi_2 + N \qquad (7)$$

where N is the narrowband Gaussian noise, ϕ_k the ralative phase between the k th FM interferer and Inphase axis.

When Z is larger then the half of the minimum symbol distance, dn, error occurs i.e.,

$$Z > \frac{dn}{2} \longrightarrow N > \frac{dn}{2} - I_1\cos\phi_1 - I_2\cos\phi_2 \qquad (8)$$

Therefore, the symbol error rate between adjacent two symbol is given by

$$P_{eo|\phi_1,\phi_2} = \int_{\frac{dn}{2} - I_1\cos\phi_1 - I_2\cos\phi_2}^{\infty} \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{x^2}{2\sigma_n^2}} dx$$

$$= \frac{1}{2}\,\mathrm{erfc}\left[\frac{dn}{2\sqrt{2}\sigma_n} - \frac{I_1\cos\phi_1}{\sqrt{2}\sigma_n} - \frac{I_2\cos\phi_2}{\sqrt{2}\sigma_n}\right] \qquad (9)$$

In n-ary QAM minimum distance between two symbol poits becomes

$$dn = \frac{\sqrt{2}}{\sqrt{n}-1} A \qquad (10)$$

where A is peak amplitude of n-ary QAM signal

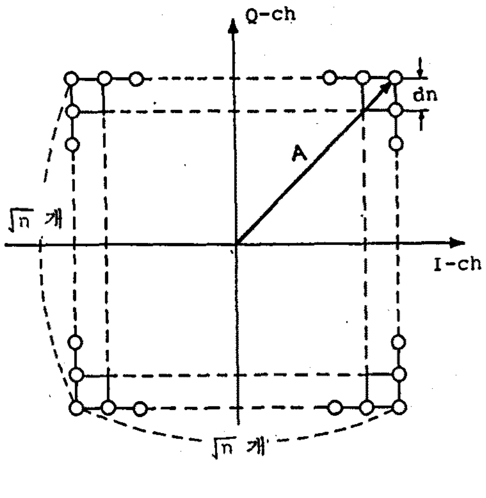

Fig. 3 Signal Constellation of n-ary QAM.

Therefore eq. (9) can be rewitten as

$$P_{eo|\phi_1,\phi_2} = \frac{1}{2}\,\mathrm{erfc}\left\{\frac{\sqrt{2}\sqrt{a}}{2(\sqrt{n}-1)} - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_1}}\cos\phi_1 - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_2}}\cos\phi_2\right\} \qquad (11)$$

where $a = \frac{A^2}{2\sigma_n^2}$: peak carrier power to noise power ratio (CNR)

$\beta_k = \left(\frac{\sqrt{2}A}{\sqrt{n}-1}\right)^2 / I_k^2$: carrier power to interferer power ratio (CIR)

Since Inphase and Quadrature channels are statistically independent similary we can derive the symbol error rate between two adjacent symbols in Quadrature channel to be same as in eq. (11)

Depending on the positon of symbol, the number of adjacent symbol is defferent, hence the average error probsbility becomes

$$P_{e|\phi_1,\phi_2} = \frac{2(n-\sqrt{n})}{n}\,\mathrm{erfc}\left\{\frac{\sqrt{2}\sqrt{a}}{2(\sqrt{n}-1)} - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_1}}\cdot\cos\phi_1 - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_2}}\cos\phi_2\right\} \qquad (12)$$

The conditional error probability for arbitary 'g'th state(row) in eq. (4), P_{eg}, can be obtained from P_e by choosing integrations and parameters corresponding to the 'g'th stat and eliminating the other.

Four conditional error probabilities, P_{e1} for '00', P_{e2} for '10', P_{e3} for '01', P_{e4} for '11', can be obtained as:

$$P_{e1} = \frac{2(n-\sqrt{n})}{n}\,\mathrm{erfc}\left\{\frac{\sqrt{2}\sqrt{a}}{2(\sqrt{n}-1)}\right\}$$

$$P_{e2} = \frac{2(n-\sqrt{n})}{\pi n}\int_0^{2\pi}\mathrm{erfc}\left\{\frac{\sqrt{2}\sqrt{a}}{2(\sqrt{n}-1)} - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_1}}\cdot\cos\phi_1\right\}d\phi_1$$

$$P_{e3} = \frac{2(n-\sqrt{n})}{\pi n}\int_0^{2\pi}\mathrm{erfc}\left\{\frac{\sqrt{2}\sqrt{a}}{2(\sqrt{n}-1)} - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_2}}\cos\phi_2\right\}d\phi_2$$

$$P_{e4} = \frac{(n-\sqrt{n})}{2\pi^2 n}\int_0^{2\pi}\int_0^{2\pi}\mathrm{erfc}\left\{\frac{\sqrt{2}\sqrt{a}}{2(\sqrt{n}-1)} - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_1}}\cos\phi_1 - \frac{\sqrt{2}}{(\sqrt{n}-1)}\sqrt{\frac{a}{\beta_2}}\cos\phi_2\right\}d\phi_1\,d\phi_2$$

$$(13)$$

Therefore, from eq. (4) and eq. (12) the average signal error probability of n-ary QAM signal with two FM interferers is obtained as:

$$\begin{aligned} PE &= \sum_{g=1}^{4} P_{eg}\cdot P_g \\ &= P_{e1}\,[(1-P_1)\cdot(1-P_2)] \\ &+ P_{e2}\,[\ P_1\ \cdot(1-P_2)] \\ &+ P_{e3}\,[(1-P_1)\cdot\ P_2\ ] \\ &+ P_{e4}\,[\ P_1\ \cdot\ P_2\ ] \end{aligned} \qquad (14)$$

Using the derived eq. (14), the symdol error rate performance of 16 QAM system have been evaluated with the CNR, CIR and normalized carrier separation between QAM and FDM-FM carrier frequency.
The numerical results are shown in Fig.4~Fig. 8.

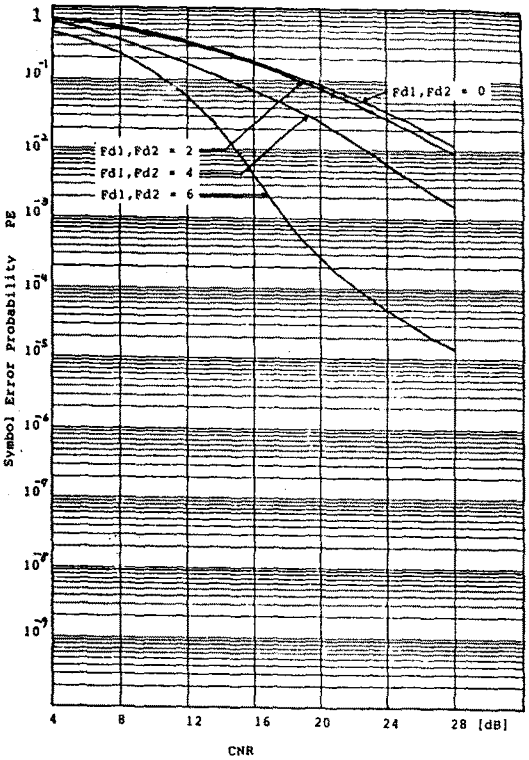

Fig. 4 Symbol error prob. of 16 QAM
(When CIR = 10 dB, b1=b2= 3).

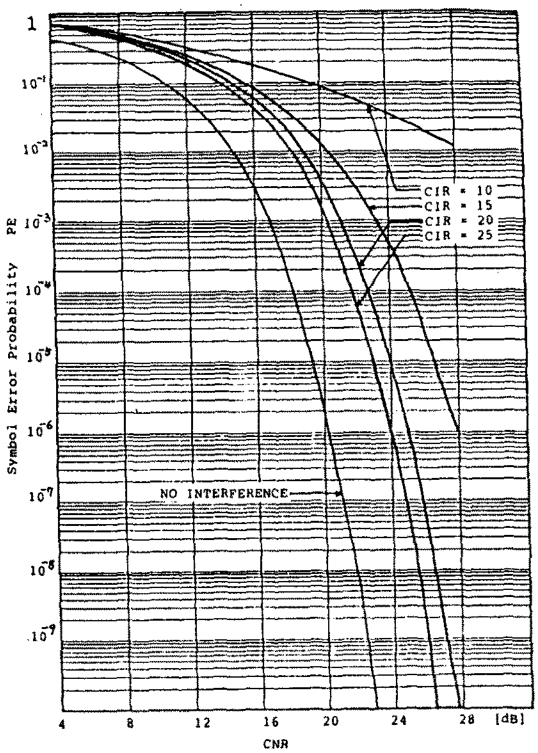

Fig. 5 Symbol error prob. of 16 QAM
(When Fd1= Fd2= 0, b1= b2= 3).

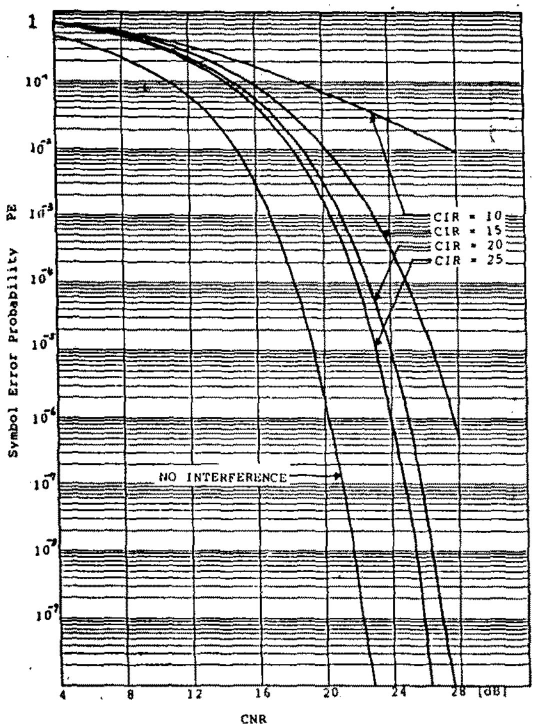

Fig. 6 Symbol error prob. of 16 QAM
(When Fd1= Fd2= 2, b1= b2= 3).

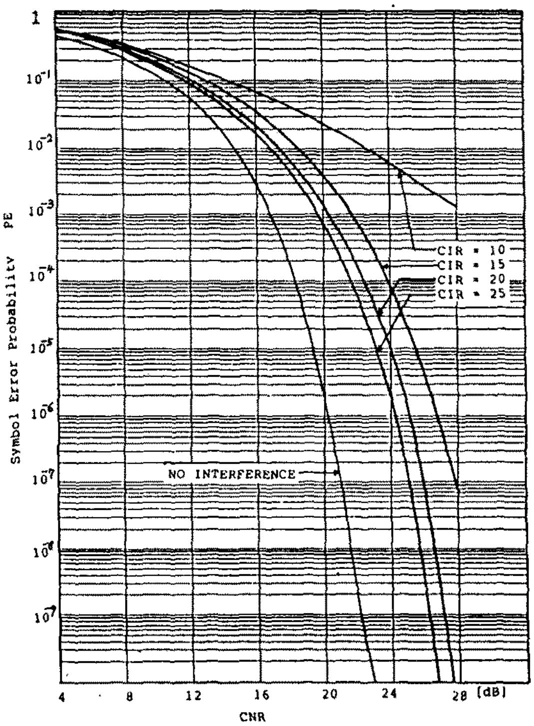

Fig. 7 Symbol error prob. of 16 QAM
(When Fd1= Fd2= 4, b1= b2= 3).

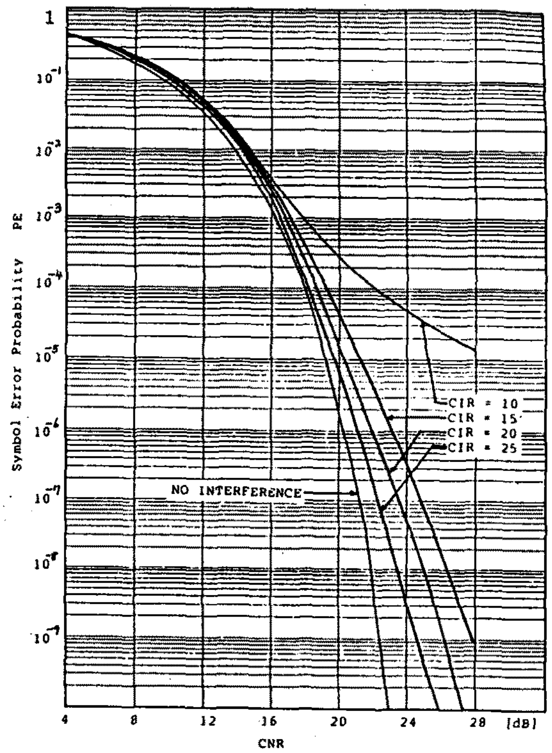

Fig. 8 Symbol error prob. of 16 QAM (When Fd1= Fd2= 6, b1= b2= 3).

IV. Conclution

This paper has investicated the effects of two wideband FM signals upon an n-ary QAM signal in an interference environment between analog and digital system, under the assumtion that the QAM signal is allocated between adjacently to two wideband FM signals in the same radio frequency bands.
A general equation of symbol error performance of an n-ary QAM signal with Gussian noise, and cochannel or adjacent channel interferences from two wideband FM signals has been derived. and the numerical results are given in graphs.
From numerical results, we can see that how the symbol error rate decrease as the Fdk increase when CIR and CNR is given. Accordingly, this analysis results can be used for design DIV systems in interference case, usefully.

References

[1] K.Feher, Digital Modulation Techniques in an Interference Environment, pp. 10.1 -10.12, Don White Consultants, Inc., 1977.

[2] K.Feher, Digital Communication, pp. 183-197, Prentice Hall, 1981.

[3] 조 성준, "16 QAM(직교 진폭 변조) 디지탈 마이크로파 통신 방식," 무선 제 19 호, pp.37-41, 1986, 3.

[4] Carlson, Communication Systems, pp. 238 -239, McGraw-Hill, 1975.

[5] M.Schwartz, Communication Systems And Techniques, pp. 163-166, McGraw-Hill, 1966.

[6] T.Schilling, Principle of Communication Systems, pp. 131-135, McGraw-Hill, 1971.

[7] Sung Joon Cho, N.Morinaga, T.Namekawa, "Effects of Intersystem Radio Interference from Wideband FM signal on PSK signal," (일본)전자 통신 학회 논문집(E), 제16권, 1호, pp. 31-38, 1980, 1.