COMPUTER-AIDED ANALYSIS OF INTERFERENCE AND INTERMODULATION DISTORTION IN FDMA DATA TRANSMISSION SYSTEMS

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ABSTRACT

Multi-carrier FDMA methods are widely used for transmitting digital data from several sources. In some cases, the digital signals may be controlled by a single clock and hence, the data channels may be fully synchronized. This paper describes a method for evaluating the characteristics of adjacent Channel interference (ACI), and intermodulation (IM) distortion in a FDMA data transmission system with synchronous data streams.

A computer simulation method is used to evaluate the statistical characteristics of ACI and IM. It is shown that the IM component is uncorrelated with signal components whether or not the data streams are synchronous. The distribution of the IM amplitude is shown to be Gaussian and hence, the IM can be treated as an additive Gaussian noise component. ACI in multichannel FDMA data transmission systems is also shown to exhibit similar characteristics.

INTRODUCTION

Digital signals from many sources may be transmitted over a channel using multi-carrier FDMA methods. If the FDMA system operates over a nonlinear communication channel, then the signal in each message channel has intermodulation (IM) distortion. Even in the case of a linear channel, there is adjacent channel interference (ACI). The effect of IM distortion and ACI is measured by the overall bit error probability in each digital message channel.

If the digital signals are asynchronous, and if the carrier waveforms have random phases, then it is reasonable to expect the IM distortion to have noise-like properties. However, with synchronous data streams, such a conjecture has to be supported by analytical and/or

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experimental results. This paper presents experimental evidence to show that the IM component is uncorrelated with the signal component whether or not the data streams are synchronous. The amplitude distribution of the IM component is Gaussian and hence, the IM can be treated as an additive Gaussian noise component. ACI in multi-channel FDMA data transmission system is shown to exhibit similar characteristics.

The contents of the paper are organized as follows. Section 2 contains a brief description of a multi-carrier FDMA system used in our study. Section 3 describes the computer simulation technique used for obtaining the statistical properties of IM and ACI components and the results are presented in section 4.

DETAILS OF THE SYSTEM

The FDMA system we studied consists of a 24 channel QPSK system in which each message channel is carrying T1 data stream at a rate of 1.544 MB/S. A block diagram of the system is shown in Figure 1. The FDMA signal is transmitted over a nonlinear satellite channel with a bandwidth of 40 MHz. Each T1 stream goes through a QPSK modulator, and the modulator output is filtered by a 1 MHz fourth order Butterworth filter before it is multiplexed with other signals.

The multiplexed signal is filtered at the spacecraft input by a sixth order Chebyshev filter with a bandwidth of 36 MHz and amplified by a TWT operating at 10 dB backoff from saturation. The spacecraft output filter is a 45 MHz sixth order Chebyshev filter. At the receiving earth station the individual QPSK signal is separated by a 1 MHz channel filter (4th order Butterworth) and coherently demodulated.

SIMULATION APPROACH

The effect of IM distortion and ACI on the bit error rate can be computed via direct simulation or by indirect simulation methods in which statistical properties of ACI and IM are computed. Direct simulation is impractical for the system being analyzed because of sample size requirements. There are 2^{24} bit combinations in each time slot, and the error rate has to be averaged over several bit intervals for ISI. Thus, the number of bits to be included in the simulations will be much greater than 2^{24} bits.

We used an indirect method to compute the effect of ACI and IM. The method is similar to the noise loading approach used in analog FDM transmission systems [1]. The main assumption involved in our approach is that ACI and IM are uncorrelated with the message waveform in a given channel and that they have nearly Gaussian amplitude distribution. This assumption, which is verified by our simulations, allows us to compute the error probability by adding IM and ACI on a power basis with the additive Gaussian noise in the down link.

The statistical properties of ACI and IM distortion were evaluated by leaving out one or more carriers and analyzing the properties of the IM and/or the ACI components that fall into the empty slot. Three adjacent slots were left empty while the measurements for IM distortion were taken in the middle slot. Only one channel was left out when the properties of ACI were analyzed.

The data streams in each of the channels were simulated by two random binary PN sequences. Each PN sequence was 32 bits long and was repeated 50 times making it a total of 1600 bits long. The 32 bit length for the basic sequence was selected because of intersymbol interference (ISI) considerations. All PN sequences had randomly selected starting numbers. In addition to the IM channel, one signal channel was measured (without IM and ACI) as a reference channel (ISI is the only distortion in this channel).

All of the simulations were carried out using a general purpose simulation package (SYSTID [2]).

RESULTS

Intermodulation Component (TM)

The spectrum of the transmitted FDM signal with three carriers deleted is shown in Figure 2. Figure 3 shows the same signal after the nonlinearity. (Notice the intermodulaiton distortion partially filling the empty slot). The spectrum and amplitude distribution of the IM distortion component, at the output of the modem receive filter, are shown in Figures 4 and 5. The amplitude distribution is nearly Gaussian. In addition the zero crossings of the IM component were found to be uncorrelated with the zero crossings of the signal, which means that the IM and signal components are uncorrelated at sampling times. Hence, the intermodulation distortion, for all practical purposes, can be treated as an additive noise component.

The signal to intermodulation power was computed to be

$$\left(\frac{S}{I}\right)_{IM} = 19.6\ dB \qquad (1)$$

The corresponding (E_b/N_o) is [3]

$$\left(\frac{E_b}{N_o}\right)_{IM} = 16.6dB$$

The statistical properties of the IM component were also evaluated for the case when the input bit streams were asynchronous. This case was simulated by allowing the bit rate for each loaded channel to be a random variable with a uniform distribution within ± 12% of the nominal rate of 1.544 Mbls. The statiscal characteristics of the IM component for the asynchronous case was essentially the same as for the synchronous case.

Adjacent Channel Interference (ACI)

The statistical properties of the adjacent channel interference were obtained by making the channel linear and measuring the interference characteristics in the empty slot. The spectrum of the ACI component, at the output of the modem receive filter, is shown in Figure 6. As in the IM case, the ACI component was also found to be uncorrelated with signal components, The amplitude distribution (Figure 7) exhibits a near Gaussian shape. Although the ACI distribution is truncated to about 4σ (determined by the bandwidth and shape of the filters) the analysis using a not truncated Gaussian will result in only a slightly more conservative design. Hence, the ACI component can also be treated as an independent additive Gaussian noise.

The signal to ACI power ratio was found to be

$$\left(\frac{S}{I}\right)_{ACI} = 23.6\ dB \qquad (2)$$

and the corresponding (E_b/N_o) was

$$\left(\frac{E_b}{N_o}\right)_{ACI} = 20.6\ dB$$

The combined (E_b/N_o) for IM and ACI for the system simulated was 15.2 dB. The spectrum of the sum of the ACI and IM components for the nonlinear channel is shown in Figure 8.

Error Rate

The bit error rate as a function of downlink E_b/N_o is shown in Figure 9 for various combination of transmission impairments. The linear case shown in Figure 9 includes ISI, but not ACI which is shown plotted separately. All of these plots were obtained by treating IM and ACI as additive noise components and computing (EbIN.) according to the formula

$$\left(\frac{E_b}{N_o}\right)_{Total} = \frac{(E_b/N_o)_1 \ (E_b/N_o)_2}{(E_b/N_o)_1 + (E_b/N_o)_2} \qquad (3)$$

Where $(E_b/N_o)_1$ and $(E_b/N_o)_2$ are the ratios for any two impairments which give a combined ratio of $(E_b/N_o)_{Total}$. For the system studied the degradation in performance at a system error rate of 10^{-4} is 1 dB due to ACI about 2 dB due to IM and a total of 3 dB due to the combined effects of ACI and IM.

CONCLUSIONS

We have presented simulation results which show that in a multicarrier FDM transmission system, the adjacent channel interference and intermodulation distortion can be treated as independent additive Gaussian noise components. The statistics of the ACI and IM component remains the same whether the input data streams are synchronous or asynchronous.

REFERENCES

[1] *Transmission Systemsfor Communications*, 4th edition, Bell Telephone Laboratories, 1970.

[2] M. Fashano and M. C. Austin, "A Flexible User Oriented Approach to Communication Systems Simulation", *Proceedings of ITC*, 1978, Los Angeles, CA.

[3] H. Spilker, *Digital Communications by Satellite*, Prentice Hall, 1978.

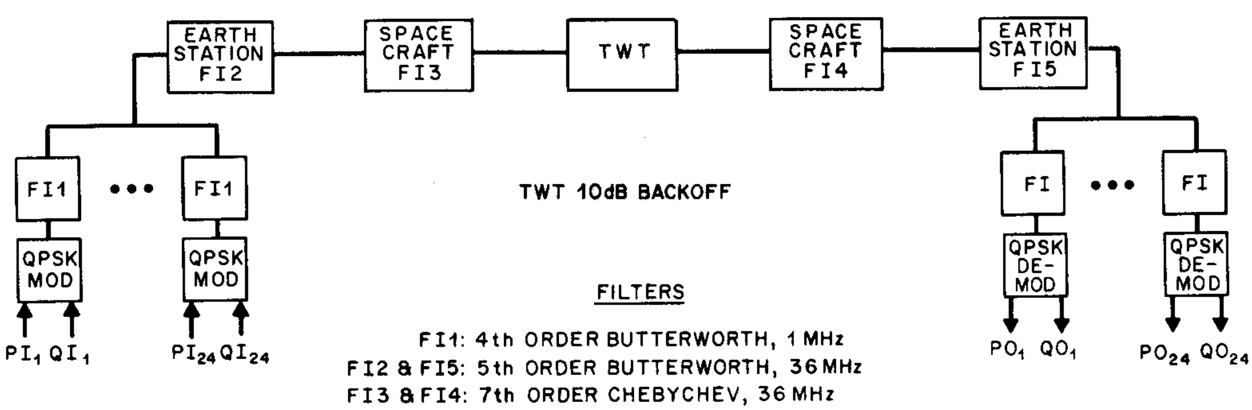

FIGURE 1 FDMA SATELLITE SYSTEM WITH 24 T1 CARRIERS

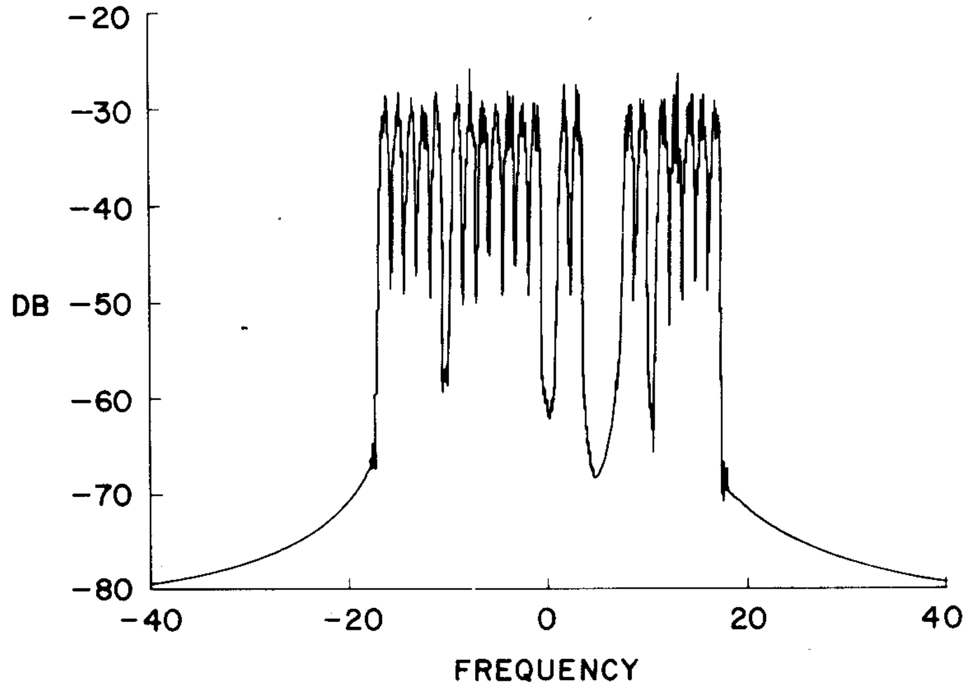

FIGURE 2 SPECTRUM OF SIGNAL WITH 3 CARRIER GAP

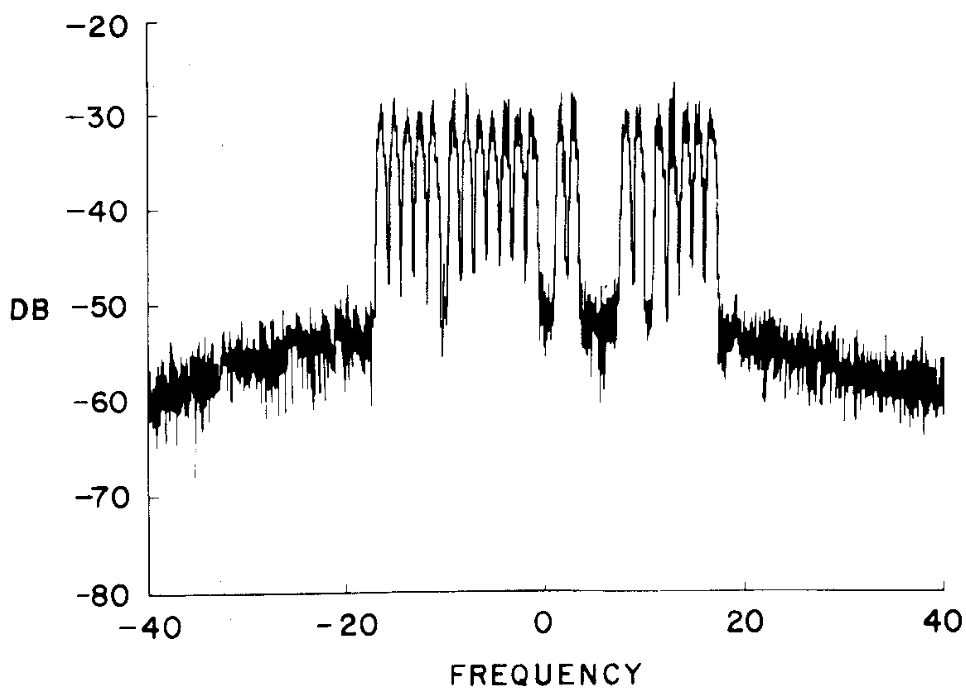

FIGURE 3 SPECTRUM OF SIGNAL WITH IM

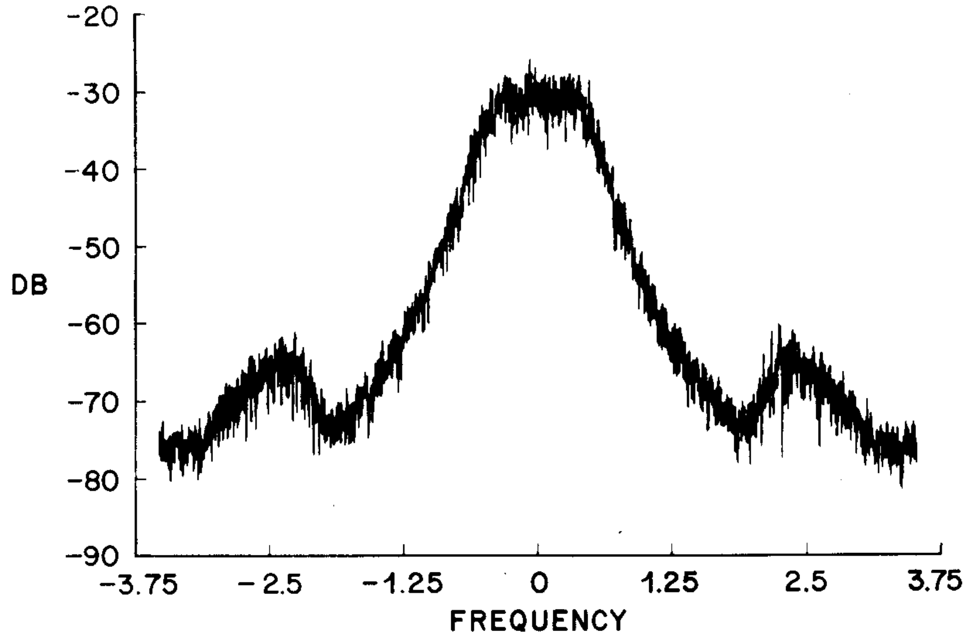

FIGURE 4 SPECTRUM OF IM IN ONE CHANNEL

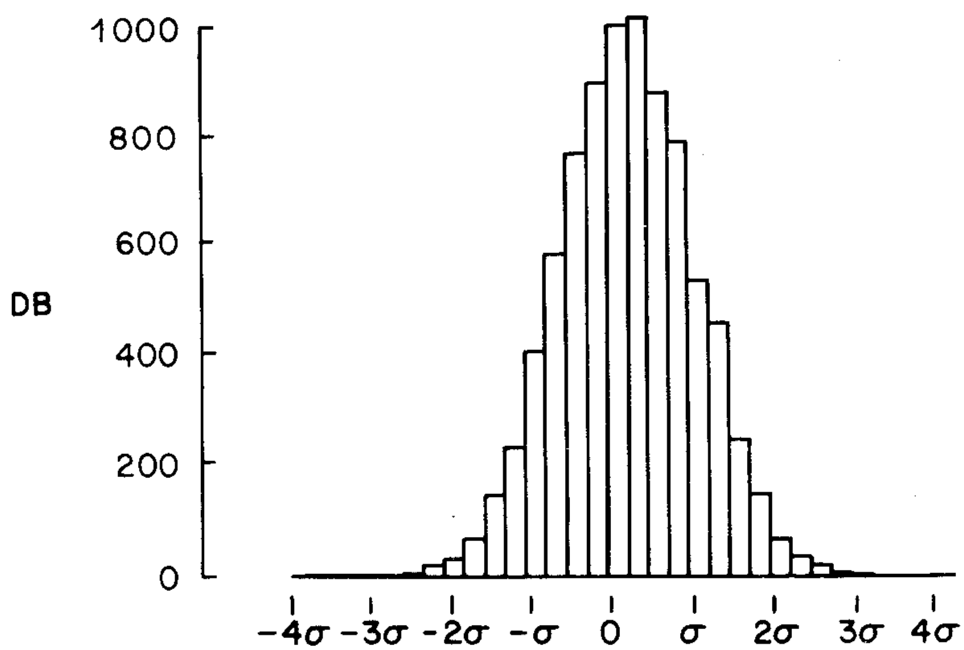

FIGURE 5 HISTOGRAM OF IM

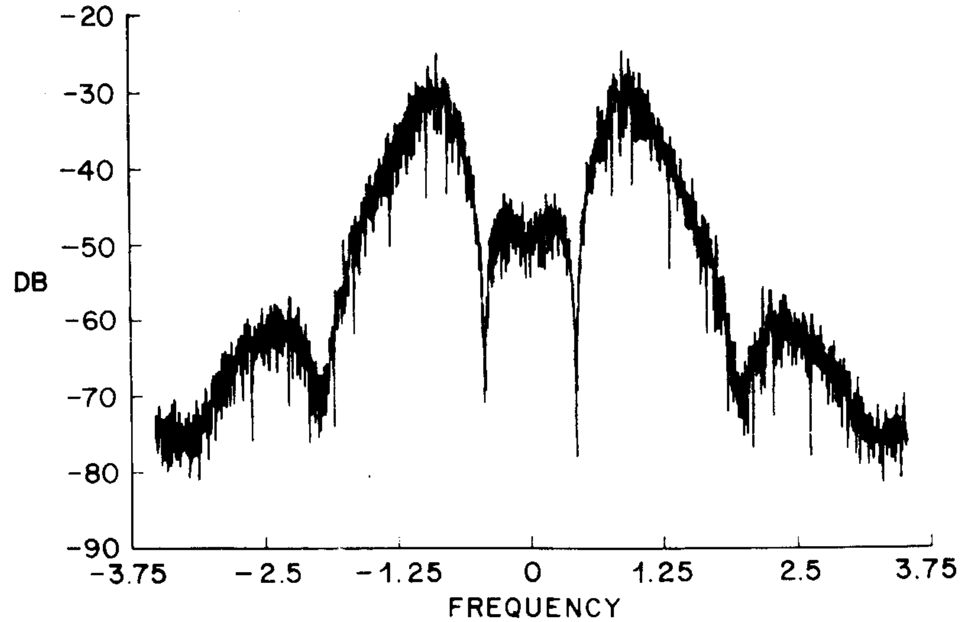

FIGURE 6 SPECTRUM OF ACI

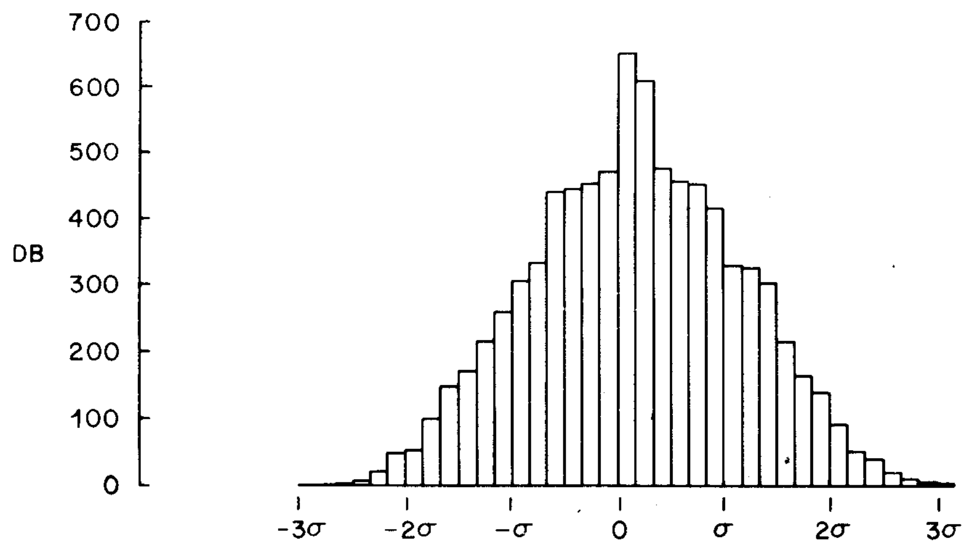

FIGURE 7 HISTOGRAM OF ACI

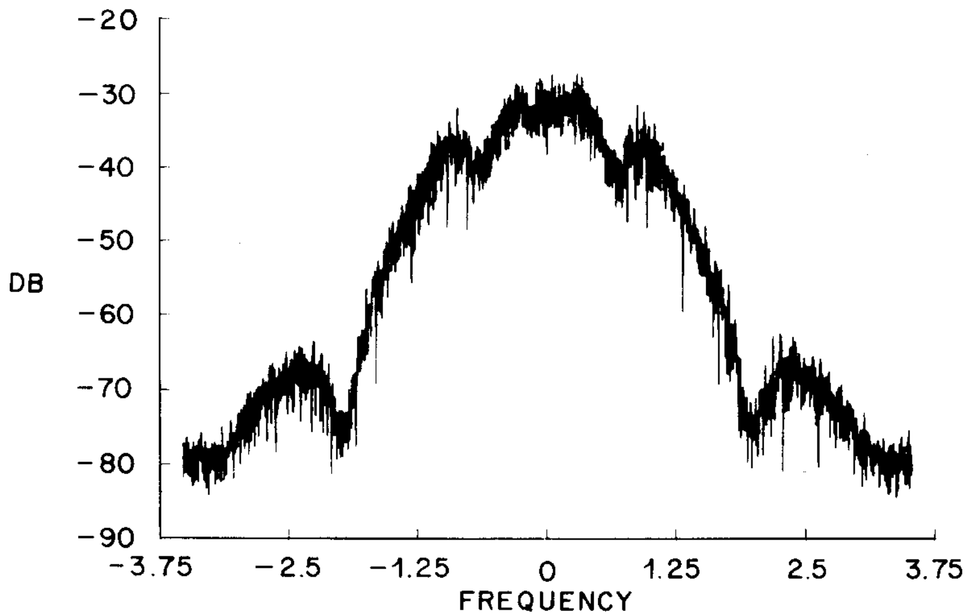

FIGURE 8 SPECTRUM OF IM AND ACI

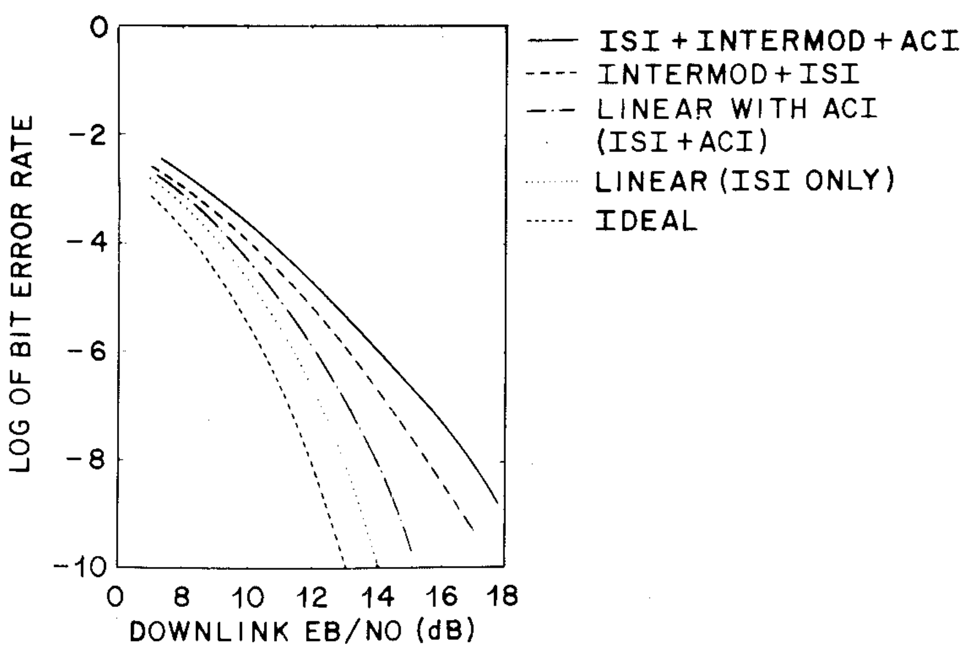

FIGURE 9 B IT ERROR RATE