Communications Research Centre

COMPUTER SIMULATION AND EXPERIMENTAL STUDIES OF THE PERFORMANCE OF A 2ϕ–DPSK MODEM OVER A SATELLITE CHANNEL

by

C. LOO AND S.M. CHOW

CRC TECHNICAL NOTE NO. 675

Department of Communications
Ministère des Communications

OTTAWA, SEPTEMBER 1975

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

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ABSTRACT

A comparison between experimental and calculated performance in terms of probability of error of a 2ϕ-DPSK over a nonlinear satellite channel is described in this paper. The channel nonlinearity is a travelling-wave tube (TWT) operated near or at saturation. The TWT is modeled by a single frequency-dependent nonlinearity whose parameters are based on results from measurement. In addition, measured frequency responses of the transmit and receive filters are used in the simulation. The results obtained in this study show that the measured and simulated values agree very well in the region of normal operation and thus indicate that the simulation technique is useful in practical situations.

1. INTRODUCTION

In digital transmission systems, the performance measure is usually the probability of error of the received digital message. The two main causes of errors are non-signal related effects such as Gaussian noise and signal related effects such as intersymbol interference. Noise exists in any communications system, and bandlimiting of the communication signal introduces intersymbol interference.

A 2-phase differential phase shift keying (2ϕ-DPSK) modulation system will be employed in the synchronization experiment which uses the Communications Technology Satellite (CTS) [1]. For this reason, the performance of the 2ϕ-DPSK digital transmission over the satellite channel should be determined with consideration of bandpass filtering, travelling-wave tube (TWT) nonlinearities and additive Gaussian noise.

Much previous work [2-6] has been based on analytical techniques and has considered only the effects of intersymbol interference, interchannel interference and Gaussian noise. The analytical evaluation of the combined effects of intersymbol and interchannel interference, additive Gaussian noise and TWT nonlinearities, is very difficult. For this reason, several investigators [7-11] have chosen to obtain particular results for this problem by computer simulations.

This paper presents simulated and measured results of a 2ϕ-DPSK system over a satellite channel. The simulation described uses the models of the CTS channels so far developed [12, 13]. The simulation method is applicable to other digital modulation schemes such as 4-phase CPSK and off-set CPSK.

The method of simulation is described in Section 2. A description of the modem and measurements procedures are given in Section 3 and 4. Results and conclusions are contained in Sections 5 and 6 respectively.

2. METHOD

The model used for the simulation of the digital transmission system is shown in Figure 1. Alternate representation in the time and frequency domains is necessary in the simulation and is accomplished by the use of the Fast Fourier Transform (FFT) algorithm [14].

The input data signal is given by:

$$e_1(t) = \sum_{k=-\infty}^{\infty} a_k \, s(t - kT) \tag{1}$$

where

a_k = a random variable with a value of 0 or 1.

$s(t)$ = waveform of the transmitted pulse in the interval 0,T

and

T = pulse duration ($R = 1/T$ = symbol rate)

This signal modulates a carrier. The output of the DPSK modulator is:

$$e_2(t) = \sum_{k=-\infty}^{\infty} A\, s(t - kT) \cos(2\pi f_c t + \phi_k) \tag{2}$$

where

A = carrier amplitude

f_c = carrier frequency

and

ϕ_k = transmitted phase (0 or π, corresponding to values of a_k of 0 or 1 and the value of 0 or π of the previous transmitted phase ϕ_{k-1}).

Equation (2) can be rewritten as:

$$e_2(t) = \mathrm{Re}\left\{ \exp[j2\pi f_c t] \sum_{k=-\infty}^{\infty} A \exp[j\phi_k]\, s(t - kT)] \right\} \tag{3}$$

where Re denotes the real part of the bracketed expression. To employ the Fourier Transform economically, it is necessary to shift the carrier frequency of the signal to zero. Thus, ignoring an arbitrary phase angle, $e_2(t)$ becomes:

$$e_2'(t) = \mathrm{Re}\left\{ \sum_{k=-\infty}^{\infty} A \exp[j\phi_k]\, s(t - kT) \right\} \tag{4}$$

The effect of the transmit filter, shown in Figure 1, can be simulated conveniently by the computation of the Fourier Transform of $e_2'(t)$ via the FFT algorithm. The spectrum of $e_2'(t)$ is then modified by the lowpass equivalent of the bandpass filter, $H_2(f)$. The time response of the signal after the filter is obtained by an inverse FFT. This signal, $e_3(t)$, shifted to a carrier frequency, f_c, may be written as:

$$e_3(t) = x(t) \cos 2\pi f_c t - y(t) \sin 2\pi f_c t \tag{5a}$$

or in complex notation:

$$e_3(t) = \mathrm{Re}\left\{ \rho(t)\ \exp[j(2\pi f_c t + \psi(t))] \right\} \tag{5b}$$

where

$$p(t) = [x^2(t) + y^2(t)]^{1/2} \tag{6}$$

$$\psi(t) = \tan^{-1}\left[\frac{y(t)}{x(t)}\right] \tag{7}$$

and $x(t)$ and $y(t)$ are the in-phase and quadrature components respectively of the modulated signal at frequency f_c at the filter output.

The input signal to the traveling-wave tube (TWT) is given by Equation (5b). The model of the TWT characteristic [12] is represented by the expression $g(\rho)\exp[jf(\rho)]$ followed by a bandpass filter $H_T(f)$.

The signal at the TWT output is given by:

$$e_4(t) = \mathrm{Re}\left\{ g(\rho)\exp[j(2\pi f_c t + \psi(t) + f(\rho))] \right\} \tag{8}$$

where the functions $g(\rho)$ and $f(\rho)$ approximate the amplitude and phase distortion of the TWT. $g(\rho)$ and $f(\rho)$ are obtained directly from a single carrier measurement of the TWT transfer characteristic. The frequency spectrum of $e_4(t)$ is shifted to a carrier frequency of zero and is modified by the lowpass equivalent of bandpass filter $H_T(f)$. Thus the TWT is modeled as a nonlinear system with a single frequency-dependent transfer function, (i.e. the nonlinear system is regarded as being composed of a zero memory nonlinear network followed by a linear time-invariant network).

Gaussian receiver noise is added to the signal at the output of the TWT and the received signal is filtered. It is assumed that the BT product for a DPSK system is sufficiently large[5] that any correlation between signal and noise can be neglected. It is further assumed that the Gaussian noise is passed through a filter of noise bandwidth B_N which is larger than the signal bandwidth. Finally, the filtered received signal $e_o'(t)$ is demodulated and the probability of error is determined.

Due to bandlimiting filters and AM/PM conversion of the TWT, the phase angle of the received signal is not discrete, but it is distributed continuously. For convenience in the simulation, the phase of the received carrier must be determined by searching the phase of the received signal. This is accomplished by multiplying $\exp[j\beta)$ and the lowpass complex signal $e_o'(t)$. β is selected by trial and error to maximize the absolute value of the real components of the received signal.

In the case of a 2ϕ-DPSK transmission, the signal is demodulated by sampling once in each message symbol the product of the received signal and its delayed version which is delayed by one bit period of duration T.

The probability of error of the received symbols is given by:

$$P_e = \frac{1}{2} \exp \left[-e_o^{*2}/2N\right] \tag{9}$$

where

e_o^* is the sampled value of the signal and N is the power of the noise at the output of a filter with noise bandwidth B_N. The average probability of error becomes:

$$A_v P_e = \frac{1}{M} \sum_{i=1}^{M} P_{ei} \tag{10}$$

where M is the number of symbols in a test message. To plot the ratio of energy-per-bit and noise-power-density (E_b/N_o) versus probability of error (P_E), the following relation in dB is used:

$$E_b/N_o = C/N + B_N/B_R \tag{11}$$

where B_R is the bit rate of the 2ϕ-DPSK and C/N is the carrier-to-noise ratio at the input to the receive filter.

3. DESCRIPTION OF THE TEST MODEM

The modulator accepts a data stream and clock pulses at a rate of 65.5 Mbps from an external source and produces a signal centered about a 500 MHz center frequency. The demodulator accepts the PSK signal and produces an output data stream and clock pulses.

A block diagram of the modem is shown in Figure 2. The data and clock from an external source are connected to a JK flip-flop in such a way that the flip-flop will toggle if the input data is "high". The flip-flop output is then lowpass filtered to eliminate any high frequency components. The resulting bandlimited signal modulates a 500 MHz carrier. In this way, the spectrum of the modulated signal is controlled by a lowpass filter. Every "high" in the data stream is represented by a phase change of 180° in the carrier.

The received signal at the demodulator is first filtered by a bandpass filter to eliminate all out of band noise. The filtered signal is then split into two components and one of the components is delayed by exactly one bit period (T). A balanced mixer is used to multiply the two components and the resulting signal is filtered by a lowpass filter to obtain the baseband signal. If there is a phase shift of 180° between two adjacent data bits, the output of the mixer will contain a negative DC component. If there is no phase change between adjacent bits, the mixer output will contain a positive DC component. The lowpass filter enhances the signal-to-noise ratio at the sampling instant and eliminates the double frequency components generated by the mixing process. The lowpass filter output is hardlimited to form a binary waveform which is sampled by the regenerated timing pulses. The recovered data stream is obtained from the output of the sampler.

The regenerated clock is obtained by the differentiation of the hardlimited waveform. The polarity of the output pulses from the differentiator is the same as the polarity of the transition. A full wave rectifier is used to convert negative-going pulses to positive-going so that a positive pulse will appear at every transition. A narrow band filter tuned to the bit rate is used to eliminate any higher harmonics in the rectified waveform and retains only the fundamental component at the bit rate. The output of this filter is passed to a phase locked loop which locks on to the fundamental component. If the noise bandwidth of the phase locked loop is small compared to the bit rate, the output frequency will not change even during periods when there are no data transitions for a number of bits.

Once the clock is recovered from the data, it can provide timing to sample the threshold circuit and reconstruct the input data stream.

4. DESCRIPTION OF THE TEST PROCEDURE

The configuration for a modem test is shown in Figure 3. A pseudorandom sequence generator, triggered from an external pulse generator is used as a data source to the modulator. The output of the modulator passes through the channel to be demodulated. White noise of 85 MHz bandwidth is added to the input of the demodulator. A precision attenuator connected in series with the noise source is used to adjust the noise level to obtain a required signal-to-noise ratio.

During the test, the noise is varied in 1 dB steps to adjust the signal-to-noise ratio at the demodulator input. An error counter is used to count the errors directly for a given signal-to-noise ratio. The errors counted are averaged over a total number of bits transmitted which range from 10^4 to 10^8 such that in each case, recorded errors range from approximately 400 to 25.

5. RESULTS

To obtain simulated results of a 2ϕ-DPSK modem at a given E_b/N_O, a sequence of length 128 bits with 16 samples per bit is used to approximate the input data sequence. The simulated results for probability of error are compared with the measured results.

A PN sequence of length 2047 repeated many times is used as the input data sequence in the measurement. The simulated transmission link is shown in Figure 1. The transmit and receive filters used in the simulation are identical and are specified as 3 pole, 0.1 dB ripple Chebyschev filters of 85 MHz bandwidth. The frequency response of this filter is shown in Figure 4. The satellite channel characteristics are shown in Figures 5 and 6.

Measured and calculated results of probability of error are shown in Figure 7 under the constraint that the 200 watt TWT is operated at saturation. The two sets of values agree to within 1 dB. Results for the cases of 2 dB above and 3 dB below saturation are shown in Figures 8 and 9 respectively. The results show that the system performs better at 2 dB above saturation than at saturation. At 3 dB input backoff, measured values do not compare as well as the previous results. Apparently during this particular test that noise in the transponder affected the results. This is caused by the uplink noise which is significant when the transponder is operated at backoff. If a correction for uplink noise is made on the measured values, the two results should be in good agreement. Thus, the simulation method can predict accurately the performance of a digital transmission system such as the 2ϕ-DPSK system. Moreover, the method can be applied to TDMA transmission in which the TWT is normally operated at saturation.

6. CONCLUSIONS

A computer simulation for predicting the probability of error of a 2ϕ-DPSK digital transmission link through a nonlinear channel has been described. The simulated results have been verified by measured results. The two sets of values are in good agreement in the region of normal operation.

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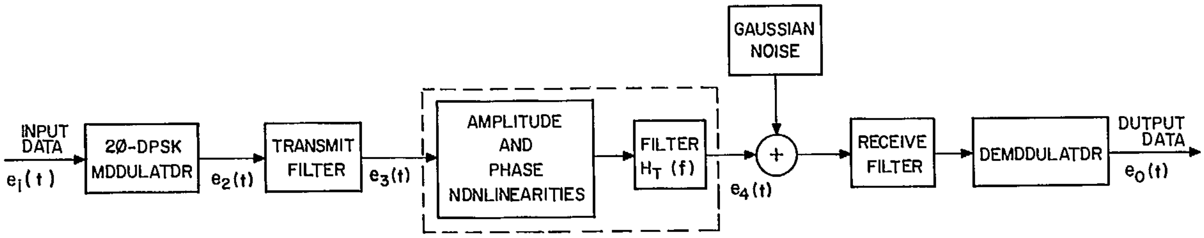

Figure 1. Satellite Link Modem used in the Simulation

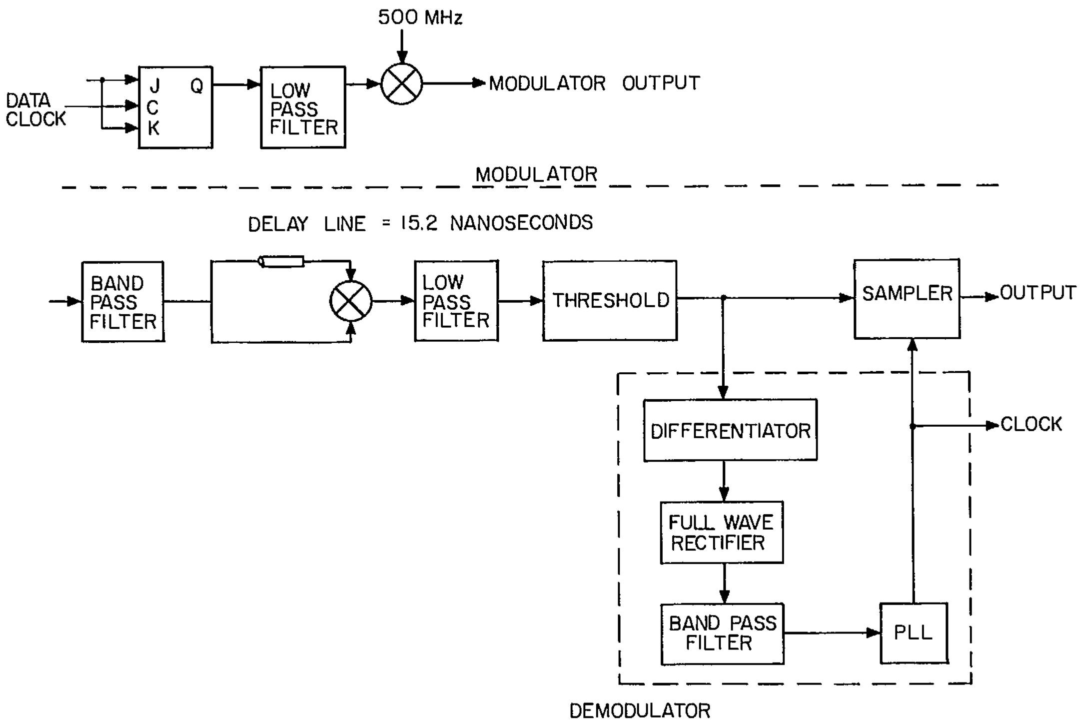

Figure 2. Block Diagram of Modem

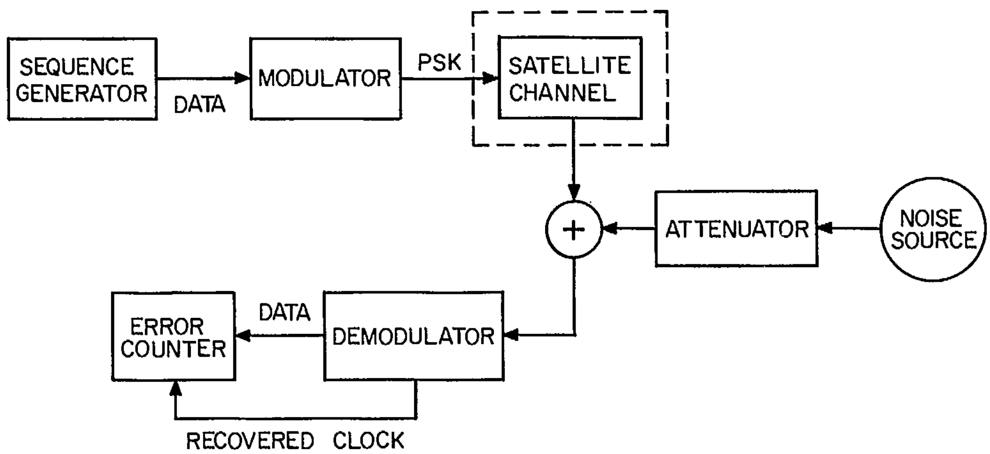

Figure 3. Measurement Set-up

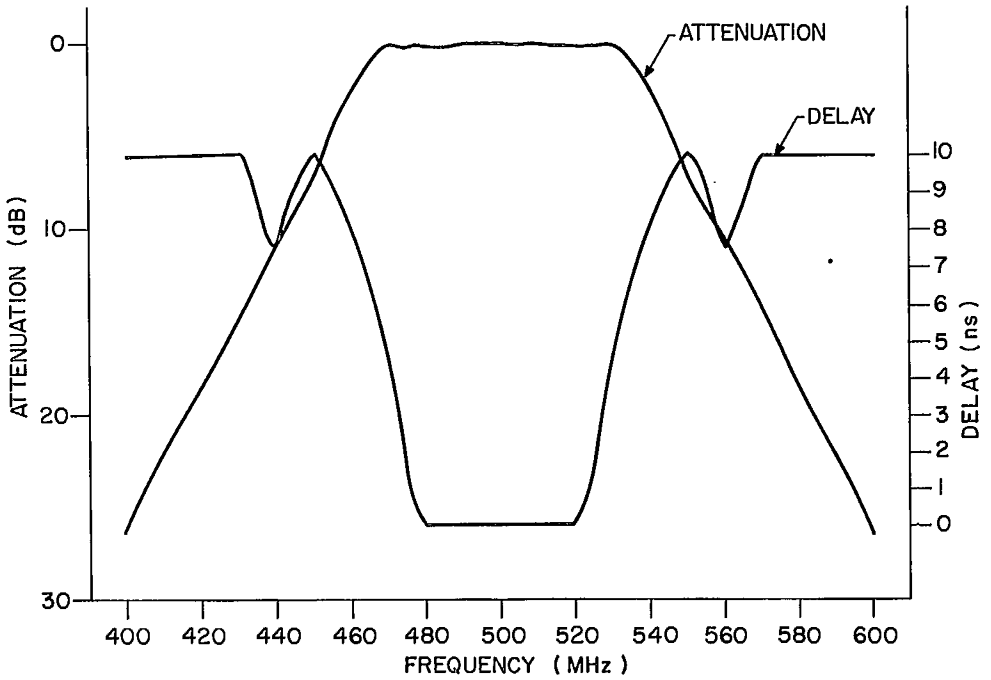

Figure 4. Frequency Response of Transmit or Receive Filter

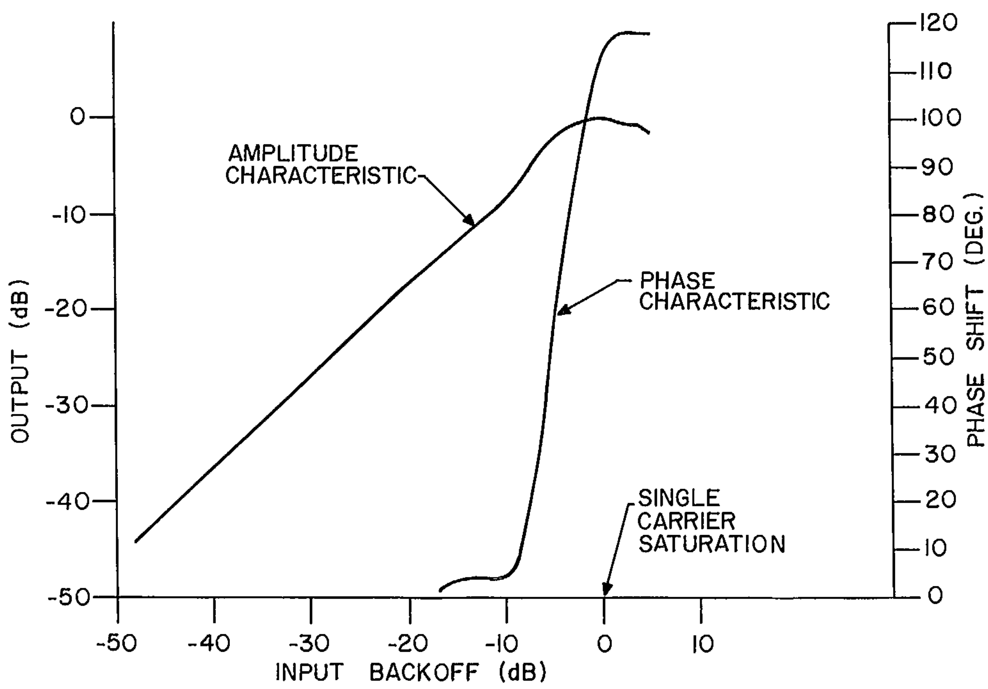

Figure 5. TWT Transfer Characteristics

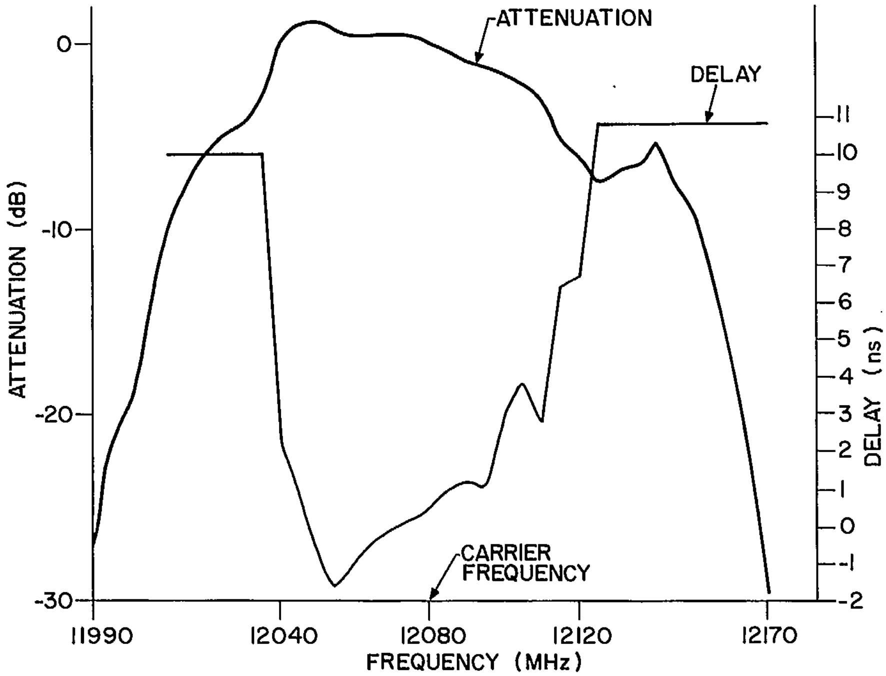

Figure 6. Frequency Response of TWT

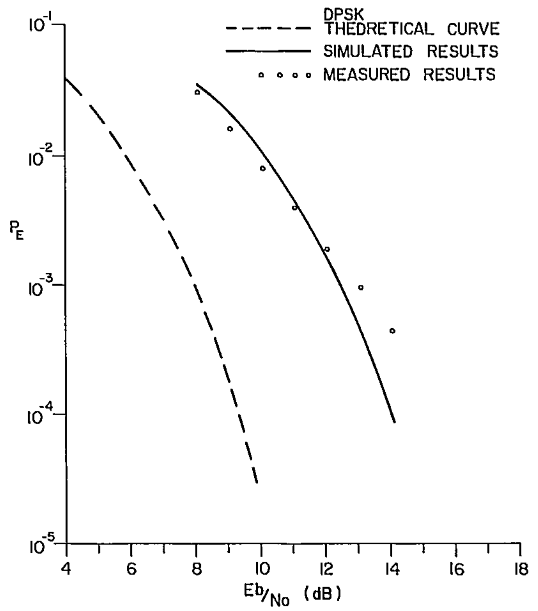

Figure 7. Bit Error Probabilities Curve
with TWT Operated at Saturation

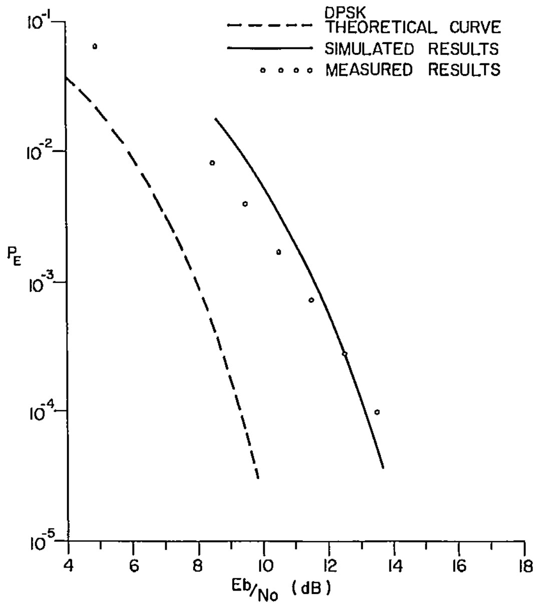

Figure 8. Bit Error Probabilities Curve with TWT Operated at 2 dB above Saturation

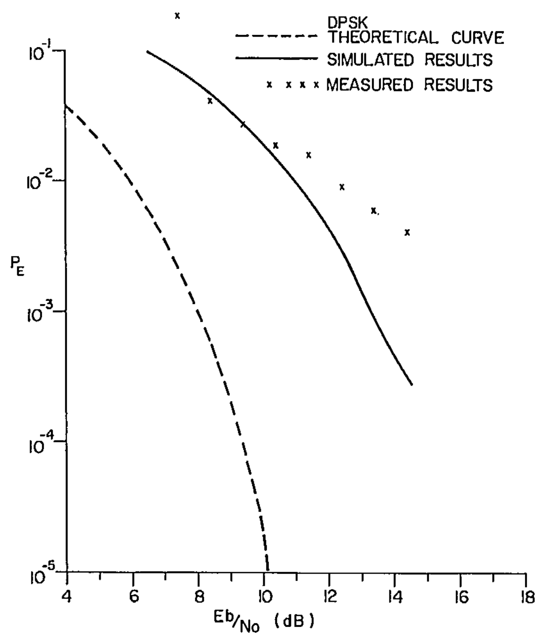

Figure 9. Bit Error Probabilities Curve with TWT Operated at 3 dB Input Backoff

CRC DOCUMENT CONTROL DATA

1. ORIGINATOR: Department of Communications/Communications Research Centre

2. DOCUMENT NO: CRC Technical Note 675

3. DOCUMENT DATE: September 1975

4. DOCUMENT TITLE: Computer Simulation and Experimental Studies of the Performance of a 2ϕ-DPSK Modem over a Satellite Channel

5. AUTHOR(s): C. Loo and S.M. Chow

6. KEYWORDS: (1) DPSK
(2) Simulation
(3) Satellite

7. SUBJECT CATEGORY (FIELD & GROUP: COSATI)

17 Navigation, Communications, Detection, and Countermeasures

17 02 Communications

8. ABSTRACT: A comparison between experimental and calculated performance in terms of probability of error of a 2ϕ-DPSK over a nonlinear satellite channel is described in this paper. The channel nonlinearity is a travelling-wave tube (TWT) operated near or at saturation. The TWT is modeled by a single frequency-dependent nonlinearity whose parameters are based on results from measurement. In addition, measured frequency responses of the transmit and receive filters are used in the simulation. The results obtained in this study show that the measured and simulated values agree very well in the region of normal operation and thus indicate that the simulation technique is useful in practical situations.

9. CITATION:

Government of Canada Gouvernement du Canada