

RECOMMENDATION ITU-R SM.1235

**PERFORMANCE FUNCTIONS FOR DIGITAL MODULATION
SYSTEMS IN AN INTERFERENCE ENVIRONMENT**

(Questions ITU-R 44/1 and ITU-R 45/1)

(1997)

The ITU Radiocommunication Assembly,

considering

- a) that the value of the performance function at the receiver input for various combinations of modulation types of interference and desired signals essentially can define spectrum utilization efficiency;
- b) that performance functions depend on the criteria for estimation of the signal reception quality and the modulation types of the interference and desired signals;
- c) that performance functions can be defined either experimentally, graphically or calculated by means of formulae,

recommends

- 1 that for the performance estimation of various digital modulation systems, receiving interference from one emitter, calculated graphs presented in Annex 1 should be used;
- 2 that for the performance estimation of multiple digital phase shift keying (MPSK) systems, receiving interference from one or more emitters, calculated graphs or the analytical method presented in Annex 2 should be used.

ANNEX 1

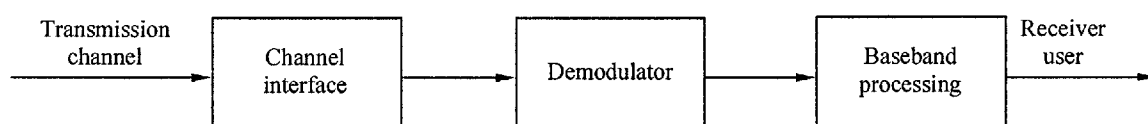
**Performance function for various digital modulation
systems with only one interfering system**

1 Digital receiver model

A simplified model of a communications receiver is shown in Fig. 1. The input to the channel interface is the superposition of the desired and undesired signals appearing at the receiver antenna output. The channel interface is composed of a number of circuit elements and is characterized by a receiver selectivity and by desired and undesired signal characteristics. Several Reports provide means to determine the nature of desired and undesired signals at the input to the demodulator given channel interface characteristics. The most important channel interface characteristics to consider are the bandwidth relationship between the undesired signal and the channel interface, off-tuning between the receiver and the undesired signal, and non-linear effects.

FIGURE 1

General communication system receiver model



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Undesired signals are characterized as follows:

– *Undistorted:*

The ideal waveform transmitted by the interfering transmitter. The signal may be specified in the frequency domain in terms of power spectral density.

– *Noiselike:*

The signal varies in amplitude according to a normal (Gaussian) distribution. The signal may have a flat spectrum and is referred to as additive white Gaussian noise (AWGN).

– *Continuous wave (CW):*

A constant frequency sinusoid whose phase with respect to the receiver is assumed to be a uniformly distributed random variable.

– *Impulsive:*

A sequence of periodic or randomly spaced pulses, each of which is of short duration compared to the time between pulses.

Undesired signals may be either continuous or intermittent. An intermittent undesired signal may be defined as a signal whose statistics such as amplitude distribution function, mean and variance are time-varying when observed at a victim receiver. Interference due to a co-located frequency hopper is an example of an intermittent undesired signal in the sense that the victim receiver will typically exhibit time-varying performance degradation. The recommended analysis procedure for the case of intermittent undesired signals involves partitioning the observation interval into contiguous time segments, or epochs, during each of which the undesired signal statistics are (approximately) constant. A separate degradation analysis is performed for each epoch, and the results are time-averaged. It is important that the time-averaging not be performed on signals until they have been demodulated.

For electromagnetic compatibility (EMC) analyses using the performance curves in this Recommendation, the undesired signal at the receiver input can usually be assumed to be either undistorted (i.e., the output of an interfering transmitter with known waveform characteristics) or noiselike. The channel interface characteristics are then used to determine the undesired signal at the demodulator input. The curves show the demodulator output bit error rate as a function of the ratio of the desired symbol energy-to-noise power spectral density (E/N_0) or the ratio of the desired symbol energy-to-interference energy (E/I_e) at the demodulator input. The noise is assumed to be Gaussian, and the interference is assumed to be continuous-wave. The analyst must determine whether the undesired signal at the input to the demodulator more closely resembles noise or CW interference or some combination of the two. This determination may include a prediction regarding the nature of the interfering signal spectrum at the demodulator input based on the passband of the channel interface and the interfering signal RF characteristics.

The remainder of the Recommendation addresses the individual sections of the receiver model shown in Fig. 1 following the channel interface. The output of any particular section may be found by concatenating the effects of that section and any preceding sections.

2 Performance of digital demodulators

Typical M -ary digital demodulator performance is given in terms of P_s versus E/N_0 and E/I_e . These terms are defined as follows:

M : number of possible distinct symbols. For binary signalling, $M = 2$

P_s : symbol-error probability. The bit error probability P_b , which is also often used, cannot exceed P_s . When $M = 2$, $P_b = P_s$

E/N_0 : ratio of average signal energy (J)-to-noise power spectral density (W/Hz) as specified at the demodulator input (dB)

E/I_e : ratio of average signal energy per symbol (or per bit)-to-interference energy per symbol (or per bit), as specified at the demodulator input (dB).

Power ratios, in particular the signal-to-noise ratio (S/N), may be used instead of energy ratios by noting that:

$$E/N_0 = (S/N) (B T) \quad (1)$$

where:

B : receiver bandwidth (Hz)

T : symbol duration (s)

S/N : measured at the demodulator input.

Table 1 summarizes the types of modulation presented, which curve to use for each, and the undesired signal (CW or noise) for which probabilities of bit or symbol errors may be obtained. The curves identified in Table 1 are provided in Figs. 2 through 24. These curves relate receiver performance in terms of symbol or bit error rate in the presence of noise and/or interference. The noise is assumed to be Gaussian, and the interference is assumed to be CW. The curves have been developed assuming optimum receiver design, i.e., bandwidths associated with the demodulator were designed for the associated system bit durations and data rates.

TABLE 1
Summary of digital modulation types considered

Modulation type	Plot of	Interfering signal ⁽¹⁾	Figure number
CPSK, M -ary	P_s versus E_b/N_0	N	2
CPSK, $M = 2$	P_s versus $E/N_0, E/I_e$	I_e	3
CPSK, $M = 4$	P_s versus $E/N_0, E/I_e$	I_e	4
CPSK, $M = 8$	P_s versus $E/N_0, E/I_e$	I_e	5
CPSK, $M = 16$	P_s versus $E/N_0, E/I_e$	I_e	6
QPSK	P_s versus $E/N_0, E/I_e$	I_e	4
O-QPSK (offset-QPSK)	P_s versus $E/N_0, E/I_e$	I_e	4
DPSK, $M = 2$	P_s versus $E/N_0, E/I_e$	N, I_e	7
DPSK, $M = 4$	P_s versus $E/N_0, E/I_e$	N, I_e	8
DPSK, $M = 8, 16$	P_s versus $E/N_0, E/I_e$	I_e	9
CFSK, M -ary	P_b versus E_b/N_0	N	10
CFSK, $M = 2$	P_s versus $E/N_0, E/I_e$	I_e	11
MSK	P_s versus $E/N_0, E/I_e$	I_e	4
NCFSK, M -ary	P_s versus E_b/N_0	N	12
NCFSK, $M = 2$	P_s versus $E/N_0, E/I_e$ (interference in one channel)	I_e	13
NCFSK, $M = 2$	P_s versus $E/N_0, E/I_e$ (equal interfering tones in each channel)	I_e	14
NCFSK, $M = 4$	P_s versus $E/N_0, E/I_e$	I_e	15
NCFSK, $M = 8$	P_s versus $E/N_0, E/I_e$	I_e	16
CASK, M -ary, bipolar	P_s versus E_b/N_0	N	17
CASK, $M = 16$, bipolar	P_s versus $E/N_0, E/I_e$	I_e	18
CASK, M -ary, unipolar	P_s versus E_b/N_0	N	19
CASK, $M = 2$, unipolar (also called OOK or on off keying)	P_s versus $E_b/N_0, E/I_e$	I_e	20
NCASK, M -ary	P_s versus E_b/N_0	N	21
QAM, M -ary (quadrature amplitude modulation)	P_s versus E_b/N_0	N	22
QAM, $M = 4$	P_s versus $E/N_0, E/I_e$	I_e	4
QAM, $M = 16$	P_s versus $E/N_0, E/I_e$	I_e	23
QAM, $M = 64$	P_s versus $E/N_0, E/I_e$	I_e	24

⁽¹⁾ N : AWGN; I_e : CW interference.

When using the curves, be alert to the parameters used. Bit energy-to-noise ratio (E_b/N_0) rather than symbol energy-to-noise (E/N_0) was used in most of the figures comparing M -ary schemes for different values of M in order to simplify the graphs. The value E represents the average symbol energy. The relationship between symbol energy and the equivalent bit energy is:

$$E = E_b \log_2 M \quad (2)$$

Some of the figures presented have the probability of a bit error, P_b , rather than the probability of a symbol error, P_s . The relationship between the two, for orthogonal signalling (coherent frequency shift keying (CFSK), non-coherent frequency shift keying (NCFSK), minimum shift keying (MSK)), is:

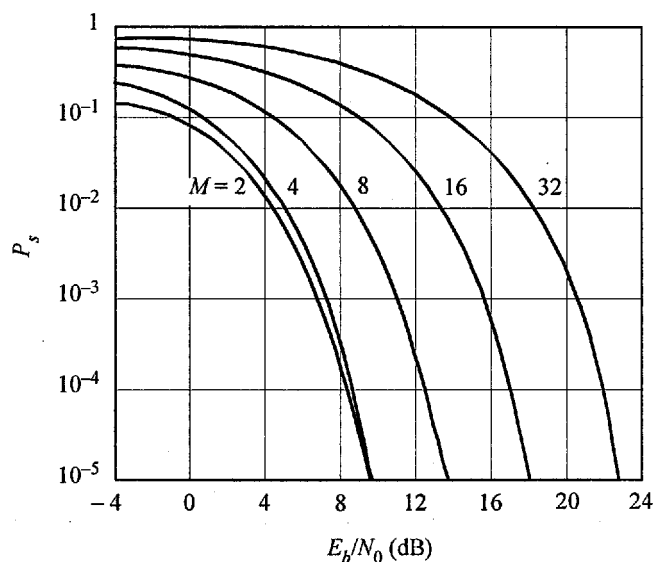
$$P_b = \frac{2^{k-1}}{2^k - 1} P_s \quad (3)$$

where $k = \log_2 M$ (number is equivalent bits).

For M -ary coherent phase shift keying (CPSK) and differential phase shift keying (DPSK) (Gray encoding is assumed) and for coherent amplitude shift keying (CASK) and non-coherent amplitude shift keying (NCASK) the relationship is:

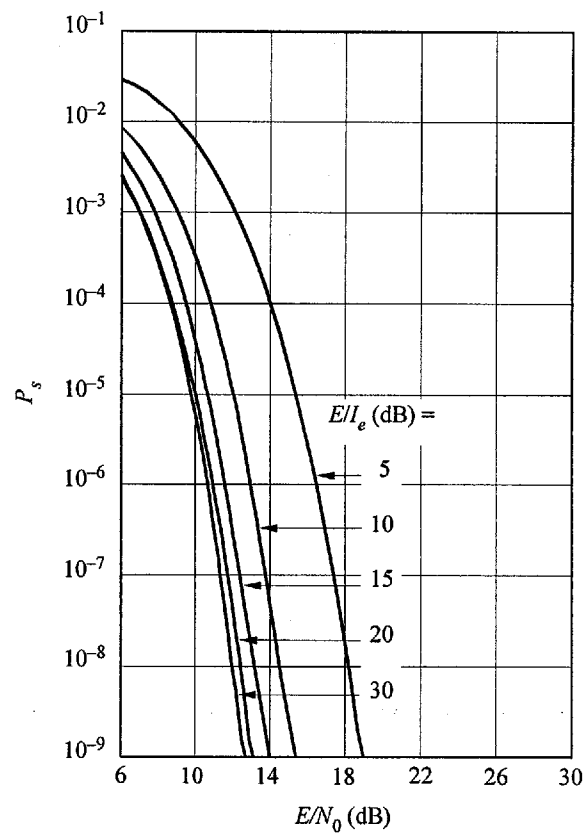
$$P_b = P_s/k \quad (4)$$

FIGURE 2
 P_s versus E_b/N_0 for M -ary CPSK



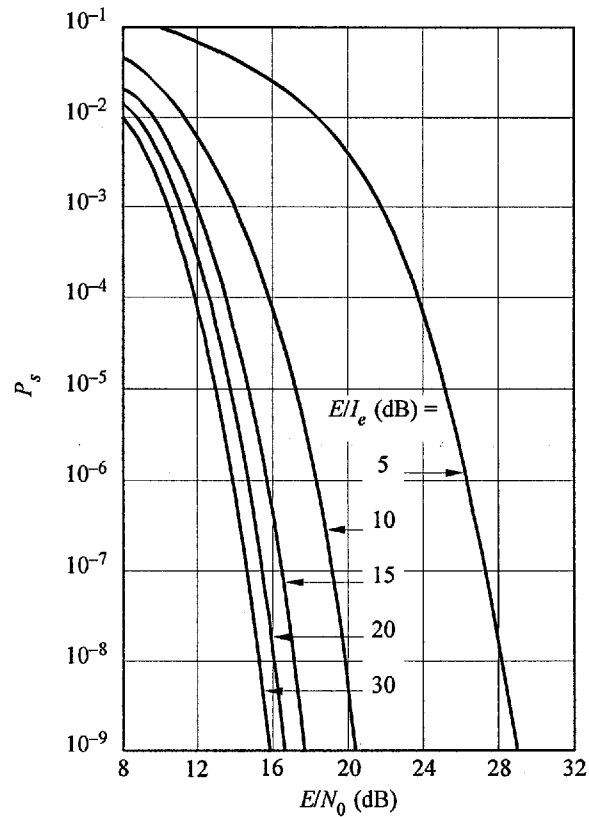
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FIGURE 3

 P_s versus E/N_0 and E/I_e for binary CPSK

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FIGURE 4

 P_s versus E/N_0 and E/I_e for 4-ary CPSK, QPSK, O-QPSK, MSK and 4-ary QAM

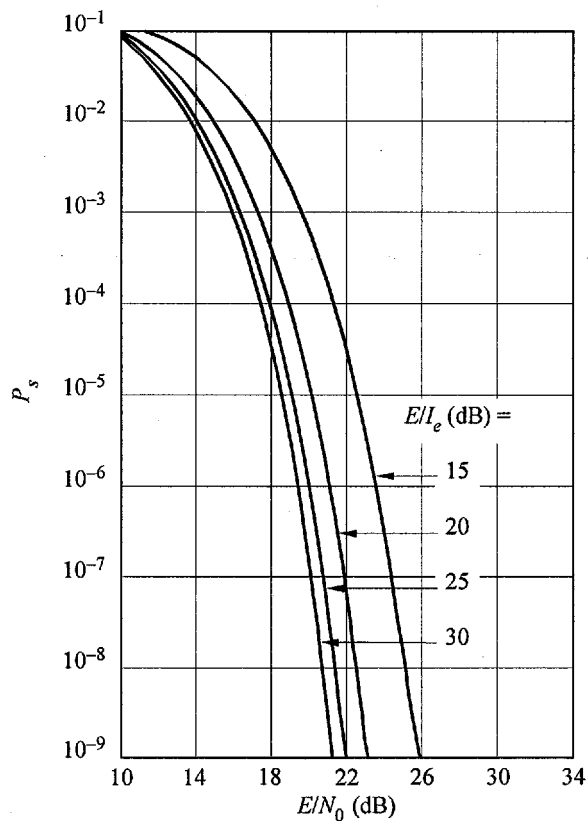
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FIGURE 5

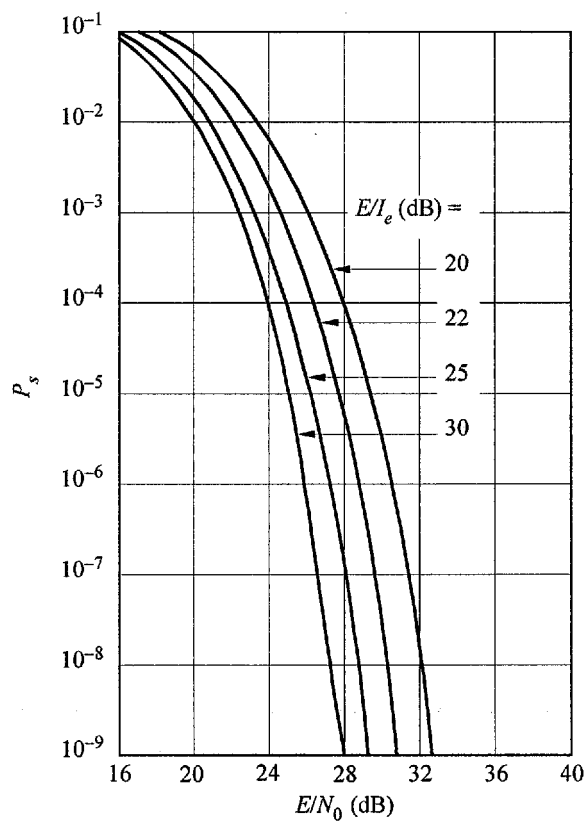
P_s versus E/N_0 and E/I_e for 8-ary CPSK



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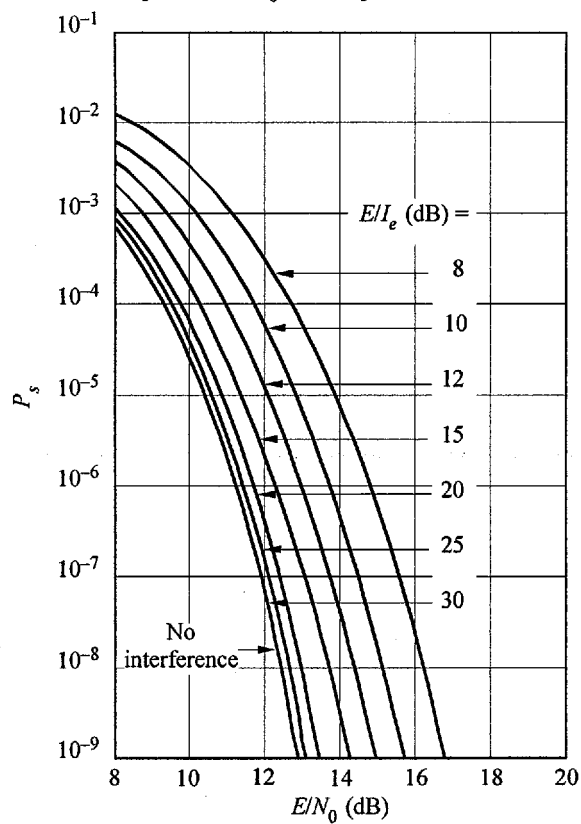
FIGURE 6

P_s versus E/N_0 and E/I_e for 16-ary CPSK



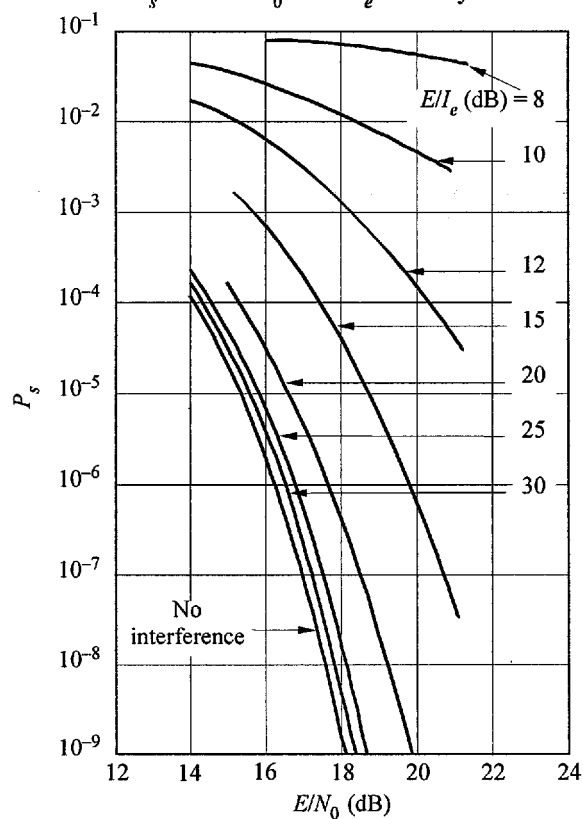
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FIGURE 7

 P_s versus E/N_0 and E/I_e for binary DPSK

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FIGURE 8

 P_s versus E/N_0 and E/I_e for 4-ary DPSK

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FIGURE 9

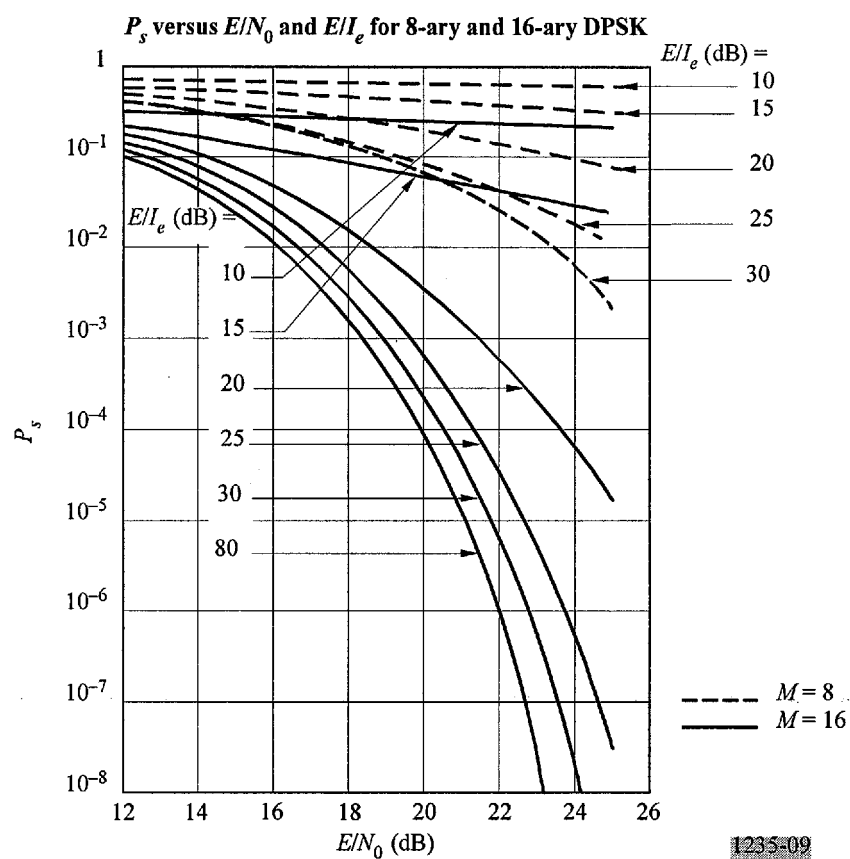


FIGURE 10

 P_b versus E_b/N_0 for M -ary CFSK