REPORT ITU-R SM.2022-1

The effect on digital communications systems of interference from other modulation schemes

(Question ITU-R 202/1)

(2000-2004)

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PART A

Theoretical investigation

1 Introduction

This Part A considers the situation where a digital fixed link receives interference from radio (natural) noise plus an unwanted interferer of power set at 6 dB above the natural noise.

Current fixed link assignment strategies are commonly noise limited. This means that the minimum receiver signal level under fading is set to a particular level with respect to the system noise floor and the ambient noise. The assignments are then planned such that the maximum level of an unwanted signal is set by a protection ratio that results in the unwanted signals typically being approximately 6 dB below the noise.

This approach is relatively safe and easy to define, but suffers from being sub-optimum. It is advantageous in maximizing the number of links that can be accommodated in a given band and geographical area to arrange that systems are interference limited. In other words, that the unwanted signals, not natural noise, set the environmental noise floor.

Such a strategy brings forth the need to assess the performance of fixed-link receivers in the presence of unwanted signals of other modulation schemes as well as Gaussian noise.

This study to considered three types of digital fixed link modulation schemes of frequency-shift keying (FSK), 4-level phase-shift keying (4-PSK) and 16-level quadrature amplitude modulation (16-QAM) affected by noise and interference from one source of dissimilar modulation scheme, FSK, 4-PSK 8-PSK and 16-QAM.

The theoretical investigation was carried out using the signal processing work system (SPW).

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The Report concludes, through analysis of results of computer simulations, that planning and assignment of fixed-links in an interference limited environment (i.e., interference 6 dB above noise) will provide closer physical packing of fixed-link assignments with increased efficiency.

2 Project work objectives and plan

It was intention of this project work to carry out theoretical study according to the agreed objectives and work plan with the sponsor, but additional work was added during the investigative study.

2.1 Project work objectives

The objective of the study was to simulate the effect on a typical microwave link of unwanted energy consists of both noise and interference (of other modulation schemes) with their signal levels in a defined proportion. Then through analysis assess the potential of spectrum planning and assignment strategies based on interference limited scenarios that are more likely to be more efficient.

For the purpose of this project work a symbol error ratio (SER), or a bit error ratio (BER), was measured/calculated for a various values of signal to (noise + interference) ratios, $S/(N+I)$, where noise = additive white Gaussian noise (AWGN) and interference = other specified modulation schemes. In all cases, unless specified, the interference level was chosen to be 6 dB above the noise.

2.2 Project work test plan

Table 1 lists the tasks that were to meet the specified objectives in § 2.1.

TABLE 1

Agreed project test cases

Task No.	Wanted fixed link modulation scheme of	Noise and unwanted fixed link type with their signal levels in varying proportions
1	4-PSK modulation format	Noise (AWGN) to SER 1×10^{-6}
2	4-PSK modulation format	Noise + 4-PSK interference level 6 dB above the level of noise
3	4-PSK modulation format	Noise + 16-QAM interference level 6 dB above the level of noise
4	4-PSK modulation format	Noise + FSK interference level 6 dB above the level of noise
5	16-QAM modulation format	Noise (AWGN) to SER 1×10^{-6}
6	16-QAM modulation format	Noise + 4-PSK interference level 6 dB above the level of noise
7	16-QAM modulation format	Noise + 6-QAM interference level 6 dB above the noise
8	16-QAM modulation format	Noise + FSK interference level 6 dB above the level of noise
9	FSK modulation format	Noise (AWGN) to SER 1×10^{-6}
10	FSK modulation format	Noise + FSK interference level = level of noise
11		Noise + FSK interference level 6 dB above the level of noise
12		Noise + 4-PSK interference level 6 dB above the level of noise
13		Noise + 8-PSK interference level 6 dB above the level of noise
14		Noise + 16-QAM interference level 6 dB above the level of noise

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2.3 Additional project work developed during the project

During the project work, it became necessary to know two things. One is how wanted fixed links of 4-PSK, 16-QAM and FSK modulation formats are affected by unwanted fixed link of FSK modulation format with its varying modulation index.

The other, is how wanted fixed-link of FSK modulation format is affected by unwanted fixed-links of FSK, 4-PSK and 16-QAM formats whilst the wanted FSK fixed-link's modulation index is varied.

TABLE 2

Additional project work

Task No.	Wanted fixed link modulation scheme of	Noise and Unwanted FSK fixed link modulation index varying from 0.0 to 1
1	FSK modulation format	Noise + FSK interference of at a fixed $S/(N+I)$ ratio of 8 dB with the interference level 6 dB above the noise
2	4-PSK modulation format	Noise + FSK interference at a fixed $S/(N+I)$ ratio of 15 dB with the interference level 6 dB above the noise
3	16-QAM modulation format	Noise + FSK interference at a fixed $S/(N+I)$ ratio of 15 dB with the interference level 6 dB above the noise

3 SPW simulation methodology

The objective of the project work is to compare, the effect on symbol, or bit, error probability of pure Gaussian noise (as reference) and interfering signal plus noise for a variety of test cases specified in Tables 1 and 2.

The chosen methodology was to generate SPW simulation designs for a typical fixed-link employing 4-PSK, 16-QAM and FSK modulation formats respectively, validate each design against expected theoretical results and then proceed with simulation for the specified test cases.

Subsequent paragraphs give details of simulation design set up, error counting method, justification for its validity and results of required computer simulations for fixed-links of 4-PSK, 16-QAM and FSK modulation format with their power spectrum density (PSD) plots. Scatter and eye diagrams for wanted fixed-links of 4-PSK and 16-QAM modulation formats with interference signal and noise varied in proportions are also given.

3.1 SPW simulation set up and designs

A typical fixed link simulation design set up consists of wanted signal and an interference signal of required modulation formats that combined into the receiver with a facility to add and vary AWGN to wanted signal to give required signal-to-noise ratio, S/N, or $S/(N+I)$, at the input of a demodulator, for calculations, or measurements, of BER and SER.

Figure 1 shows a generic simulation set up for 4-PSK and 16-QAM wanted fixed-links that consist of a transmitter (Tx), a receiver (Rx) and interference source (Ix). Figure 2 shows the simulation set up FSK wanted fixed-link.

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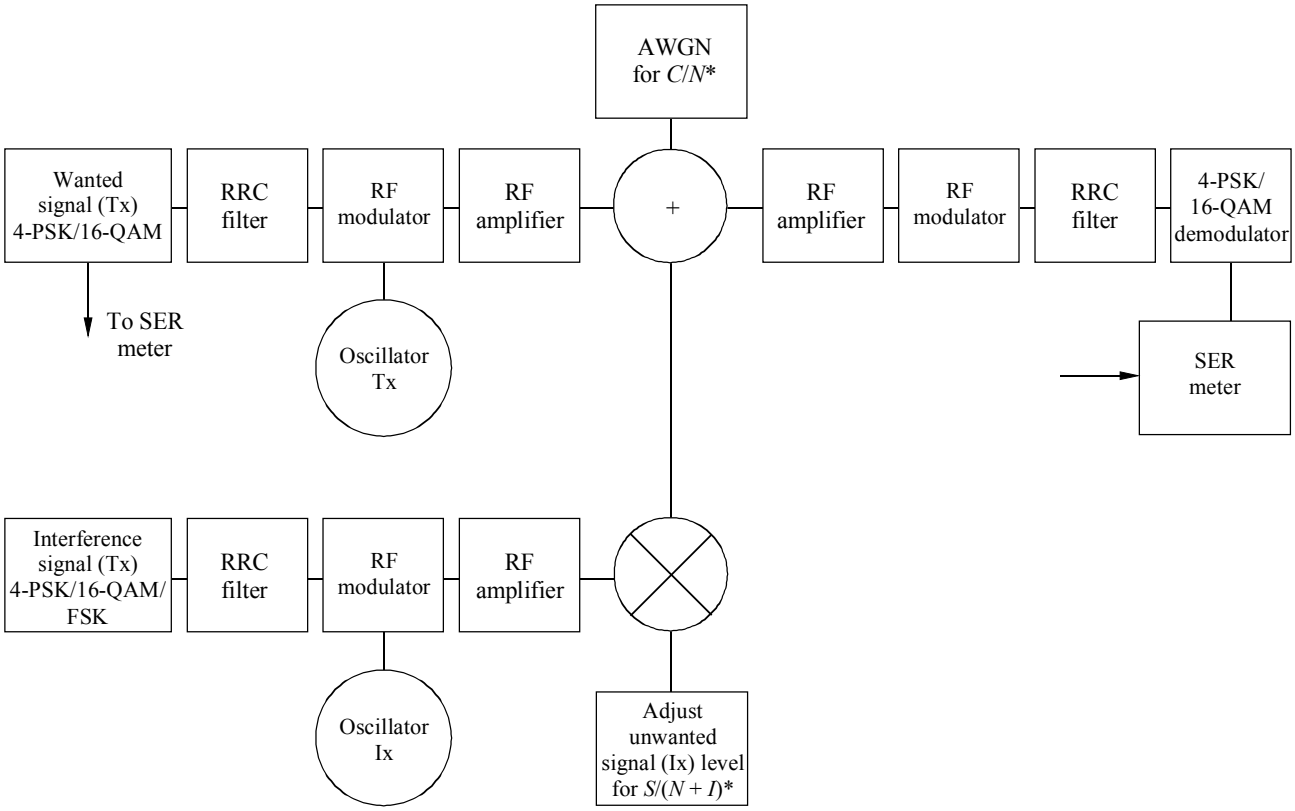
3.1.1 SPW design wanted fixed link of 4-PSK modulation format with a receiver

A wanted fixed-link employing 4-PSK modulation scheme consists of a transmitter and receiver.

For simplicity, Fig. 3 shows SPW design of 4-PSK transmitter and Fig. 4 shows the design of 4-PSK receiver.

FIGURE 1

Generic simulation set up for wanted fixed links of 4-PSK and 16-QAM modulation schemes with noise and interference



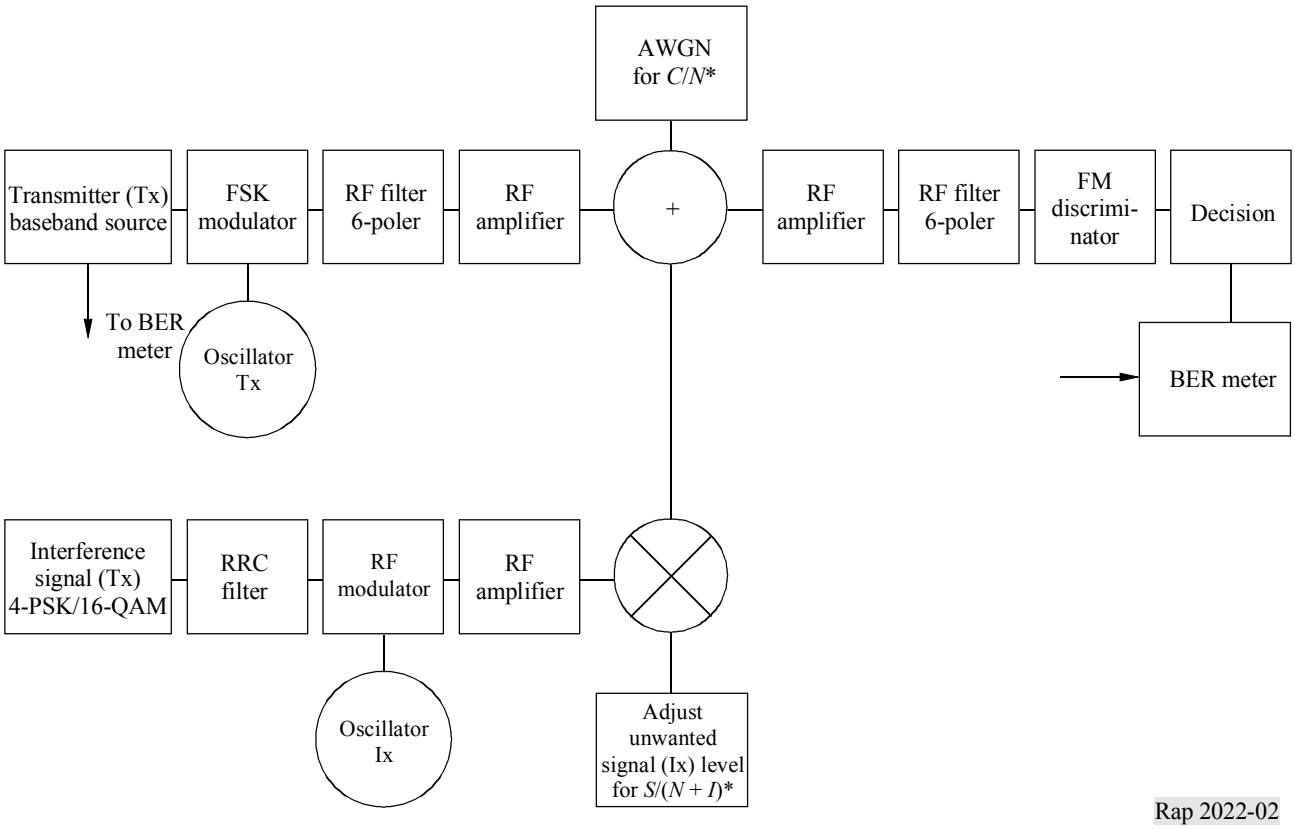
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RRC: root-raised cosine filter

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FIGURE 2

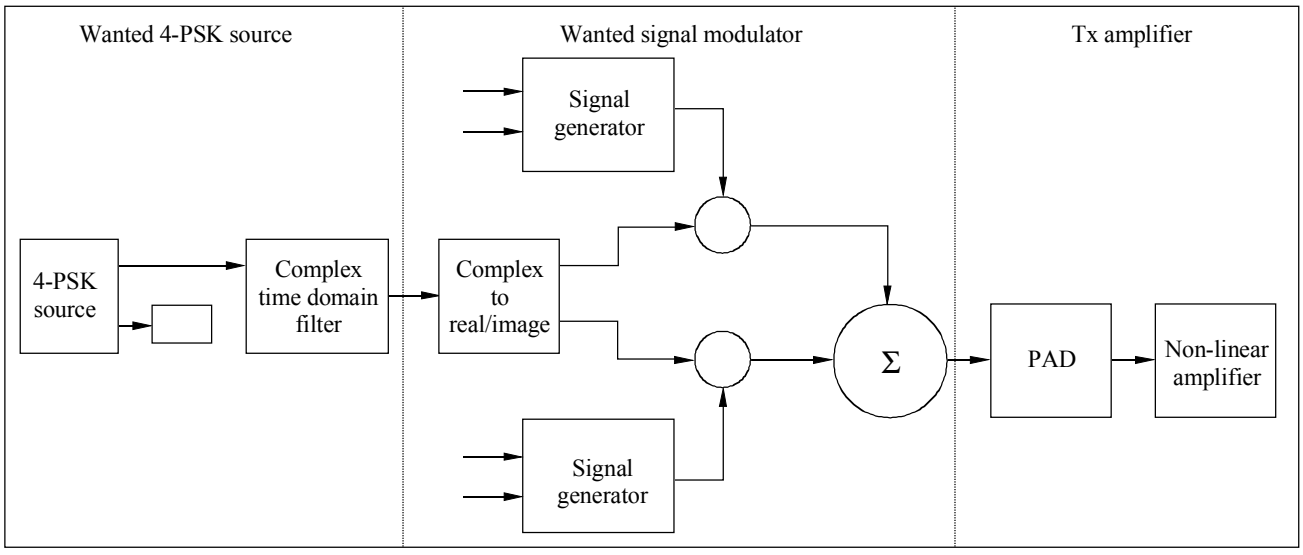
Simplified simulation set up for wanted fixed links of FSK modulation schemes with noise and interference



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FIGURE 3

4-PSK transmitter

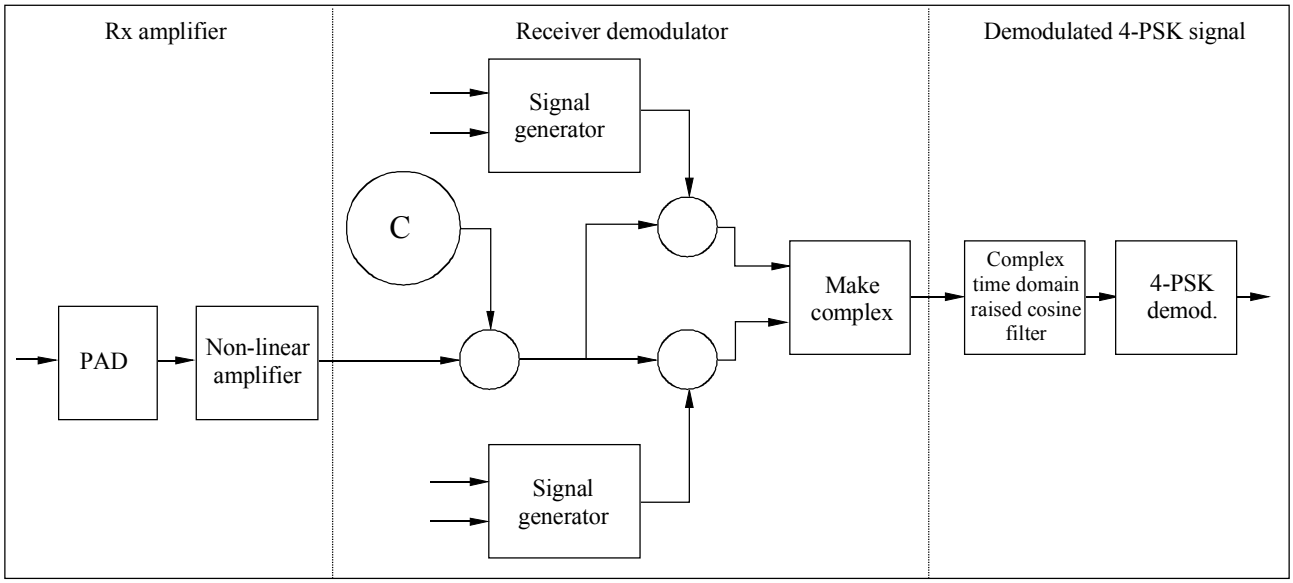


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FIGURE 4

4-PSK receiver



4-PSK transmitter: The 4-PSK transmitter is comprised of a 4-PSK source, a RRC, a radio frequency (RF) modulator and an RF amplifier. The output of the amplifier is then combined into the receiver with unwanted interference of similar and other modulation formats and AWGN. The Figures given in Part B show how unwanted interference and AWGN are combined. The same 4-PSK transmitter design was also used to generate 4-PSK and 8-PSK unwanted signals.

4-PSK transmitter simulation parameters: During each SPW simulation the following parameters were set:

a) *4-PSK source symbol rate*: 1.024 Msymbols/s.

b) *RRC filter*: roll-off factor of 0.5 (512 number of delay-taps used to achieve the specified roll-off factor).

c) *RF modulator*: 2.5 MHz.

d) *RF amplifier*:

- Operating at 10 dB below 1 dB compression point;
- 3rd order intercept point is set at 6 dB above 1 dB compression point value;
- 2nd order intercept point set at 16 dB above 1 dB compression point value;
- RF amplifier's noise figure of 10 dB.

4-PSK receiver: The 4-PSK receiver is consisted of an RF amplifier, RF demodulator, RRC filter with roll-off factor of 0.5 and 4-PSK coherent demodulator. The RF amplifier was set to operate linearly and the RF demodulator down converts 2.5 MHz carrier, and the 4-PSK demodulator is of matched filter type. The output of the 4-PSK demodulator is fed into the SER counter.

3.1.2 SPW design wanted fixed link of 16-QAM-modulation format with a receiver

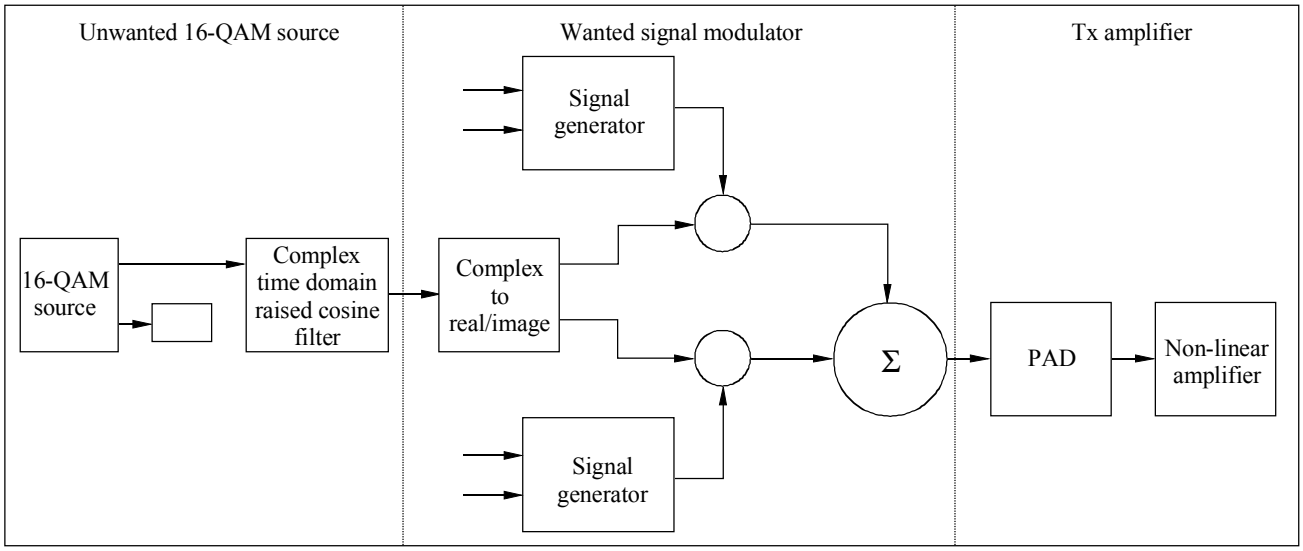
A wanted fixed-link employing a 16-QAM-modulation scheme consists of a transmitter and receiver. For simplicity, Fig. 5 shows SPW design of 16-QAM transmitter and Fig. 6 shows the design of 16-QAM receiver.

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16-QAM transmitter: The transmitter is comprised of a 16-QAM source, a RRC filter, an RF modulator and an RF amplifier. The output of amplifier is then combined into the receiver with unwanted interference of similar and other modulation formats and AWGN. The Figures given in Part B show how unwanted interference and AWGN are combined. The same 16-QAM-transmitter design was also used to generate unwanted signal.

FIGURE 5

16-QAM transmitter



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16-QAM transmitter simulation parameters: During each SPW simulation the following parameters were set:

a) *16-QAM-source symbol rate*: 1.024 Msymbols/s.

b) *RRC filter*: roll-off factor of 0.5 (512 number of delay-taps used to achieve the specified roll-off factor).

c) *RF modulator*: 2.5 MHz.

d) *RF amplifier*:

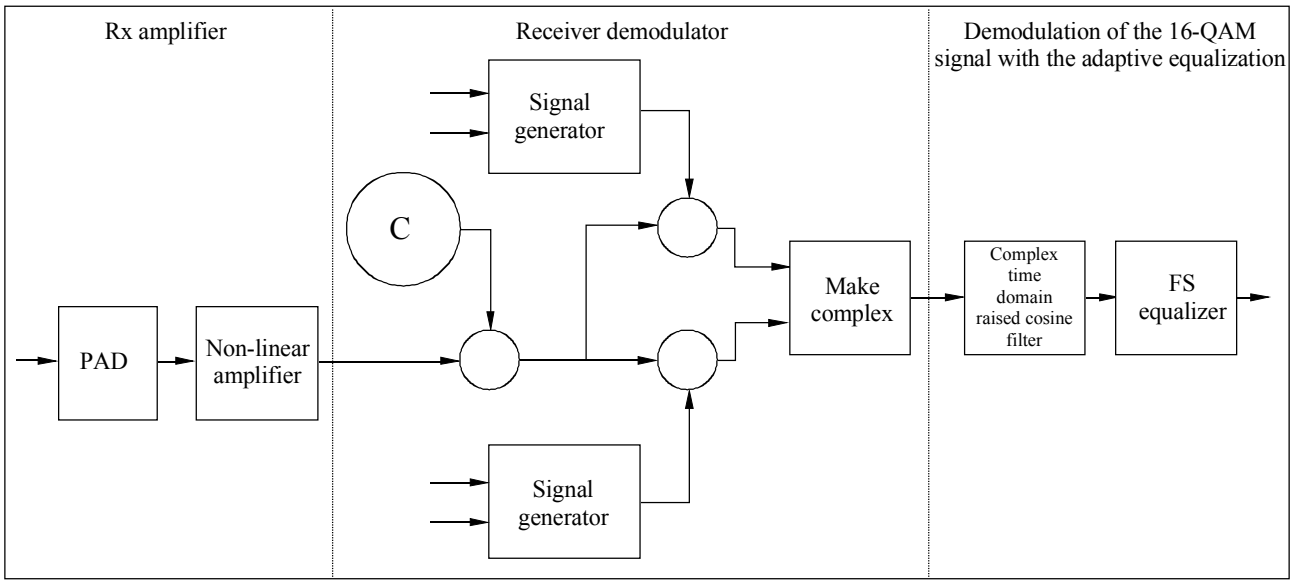
- operating at 10 dB below 1 dB compression point;
- 3rd order intercept point is set at 6 dB above 1 dB compression point value;
- 2nd order intercept point set at 16 dB above 1 dB compression point value;
- amplifier's noise figure of 10 dB.

16-QAM receiver: The receiver is consisted of an RF amplifier, RF demodulator, RRC filter with roll-off factor of 0.5 and an adaptive equalization with 16-QAM demodulator. The RF amplifier was set to operate linearly and the RF demodulator down converts 2.5 MHz carrier filter type. The output of the demodulator is fed into the SER counter.

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FIGURE 6

16-QAM receiver



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It was necessary to use an adaptive equalization in the demodulation process because the RRC filter caused significant amplitude and phase distortion to the 16-QAM wanted signal.

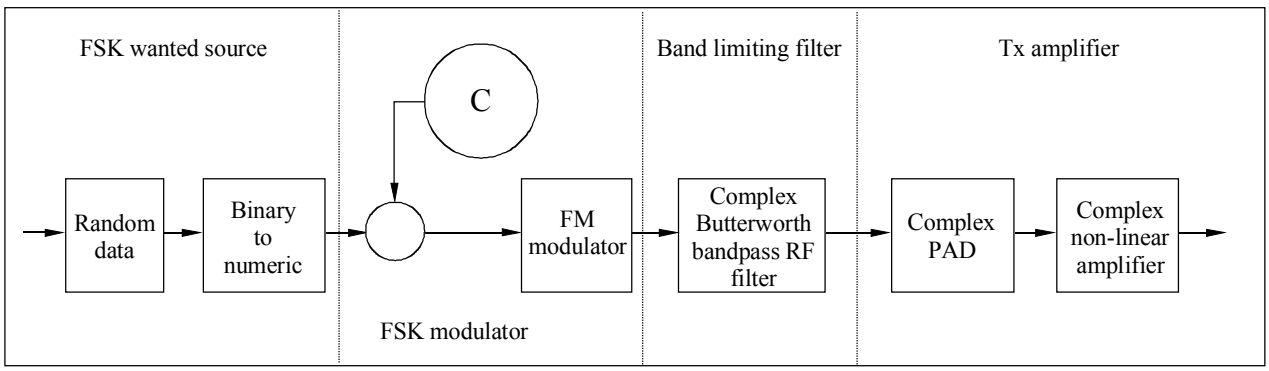
3.1.3 SPW designs of FSK modulation format with a receiver

A wanted fixed-link employing an FSK modulation scheme consists of a transmitter and a receiver. For simplicity, Fig. 7 shows SPW design of FSK transmitter and Fig. 8 shows the design of FSK receiver. The same FSK transmitter design was used to generate an unwanted signal.

FSK transmitter: The FSK transmitter is comprised of a data source, an FSK modulator, an RF bandpass filter and an RF amplifier. The output of the amplifier is then combined into the receiver with unwanted interference of similar and other modulation formats and AWGN the Figures given in Part B show how unwanted interference and AWGN are combined.

FIGURE 7

FSK transmitter



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FSK transmitter simulation parameters: during each SPW simulation the following parameters were set:

a) *Random data source bit rate*: 1.024 Mbit/s.

b) *Butterworth filter*: 6-pole Butterworth bandpass RF filter centred at a carrier frequency of 2.048 MHz. Its bandwidth (BW) set by BW = 2 (Bitrate) · (1 + Modulation index).

c) *FM modulator*: set to operate at a carrier frequency of 2.048 MHz with a modulation index of 0.45 for wanted signal and 0.35 modulation index for unwanted signal.

d) *RF amplifier*:

– operating at 10 dB below 1 dB compression point;

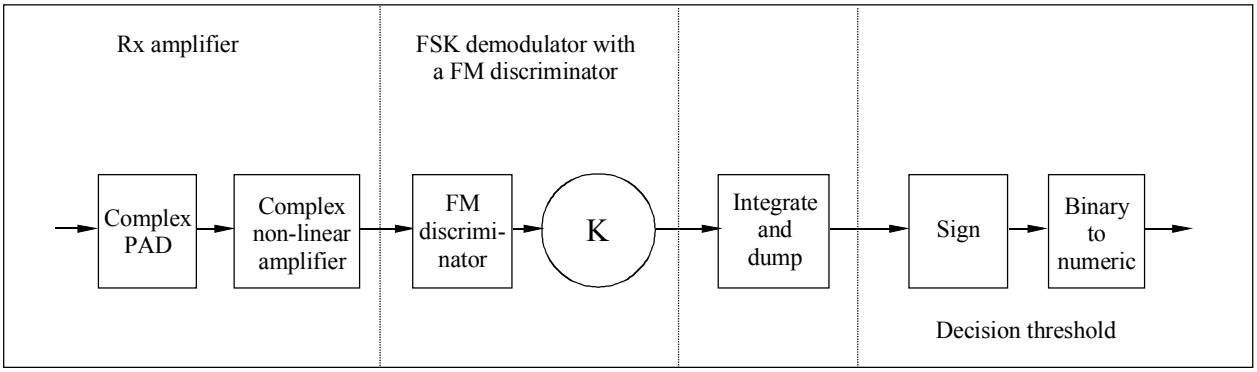
– 3rd order intercept point is set at 6 dB above 1 dB compression point value;

– 2nd order intercept point set at 16 dB above 1 dB compression point value;

– amplifier's noise figure of 10 dB.

FIGURE 8

FSK receiver



FSK receiver: The receiver is consisted of an RF amplifier, a bandpass filter, FM discriminator to demodulate FSK modulated wanted signal and a decision-making circuit to regenerate transmitted random data. The RF amplifier was set to operate linearly. The output of the demodulator is fed into the BER counter.

3.2 SER or BER measurement using Monte Carlo method

Evaluation of BER, or SER, performance of digital communication systems is done here via SPW simulation on SUNSparc Station. The traditional method of extracting a numerical estimate of the BER from the simulation is the Monte Carlo method, which, consists of counting errors.

The definition of BER use here is the fractional number of errors in a transmitted sequence. Since an error can be expected to occur every p^{-1} bits, or symbols, where p, is the BER. The length of a Monte Carlo run must increase as P decreases to a point where for a sufficiently small p, the running time will be prohibitively long. Currently it is only practical to verify BER requirements as low as about 1×10^{-5} using the Monte Carlo simulation.

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For lower values of BER, it becomes necessary to consider variance reducing, extrapolation, or semi-analytical techniques. The objective of these techniques is to obtain reliable estimates using fewer numbers of symbols, or bits, than would be required with the Monte Carlo method. However, the modified Monte Carlo method makes an assumption about the system itself and type of interference (noise), but not other types of interference (i.e. FSK, 4-PSK and 16-QAM).

3.2.1 Selecting a method for an evaluation of BER/SER performance of fixed links

The Monte Carlo method was chosen for evaluation of BER and SER performance of wanted fixed-links interfered with combinations of noise and unwanted interference of other modulation schemes because it requires no assumptions about the input process and or the system.

To keep each SPW simulation time to a minimum, the maximum numbers of 50 errors and 1×10^7 symbols or bits counted. This will to lead to numbers of:

– 50 errors counted to SER/BER 1×10^{-5};

– 10 to 50 errors counted from SER/BER 1×10^{-5} to 1×10^{-6}.

3.2.2 BER/SER measurement uncertainty

For each SPW simulation relating to test cases in Tables 1 and 2, the measurement uncertainty to:

– SER/BER 1×10^{-5} with 95% confidence level is ±20%;

– from SER/BER 1×10^{-5} to 1×10^{-6} with 95%, confidence level is ±20% to ±62%.

3.3 Validation of SPW simulation designs for wanted fixed links of 4-PSK, 16-QAM and FSK modulation schemes

3.3.1 Methodology

Each transmitter and receiver SPW simulation designs for wanted fixed links of 4-PSK, 16-QAM and FSK modulation formats were validated by evaluating their SER, or BER, performance with AWGN, using the Monte Carlo method. Each SPW receiver design was fine-tuned to achieve the best possible SER/BER performance against either theoretical results or previous simulation results.

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The criteria adopted for the validation of:

a) *4-PSK wanted fixed-link receiver*

FIGURE 9

4-PSK wanted fixed-link receiver SER performance against AWGN

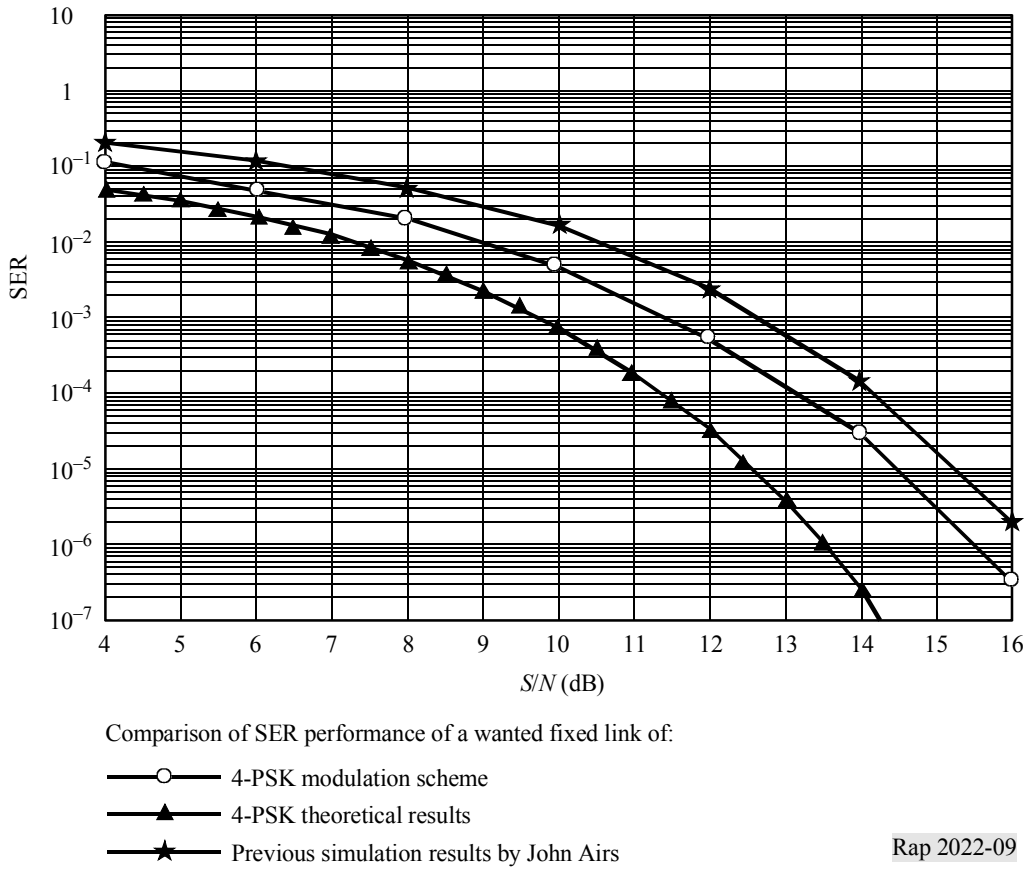


Figure 9 shows that the designed 4-PSK receiver SER performance is about 1 dB better than the previous simulation results and 2 dB worse than the theoretical results, which one would expect using a narrow-band filter and amplifier causing phase and amplitude distortion. It is possible that by using an adaptive equalization in the receiver, its performance could be further improved by 1 dB.

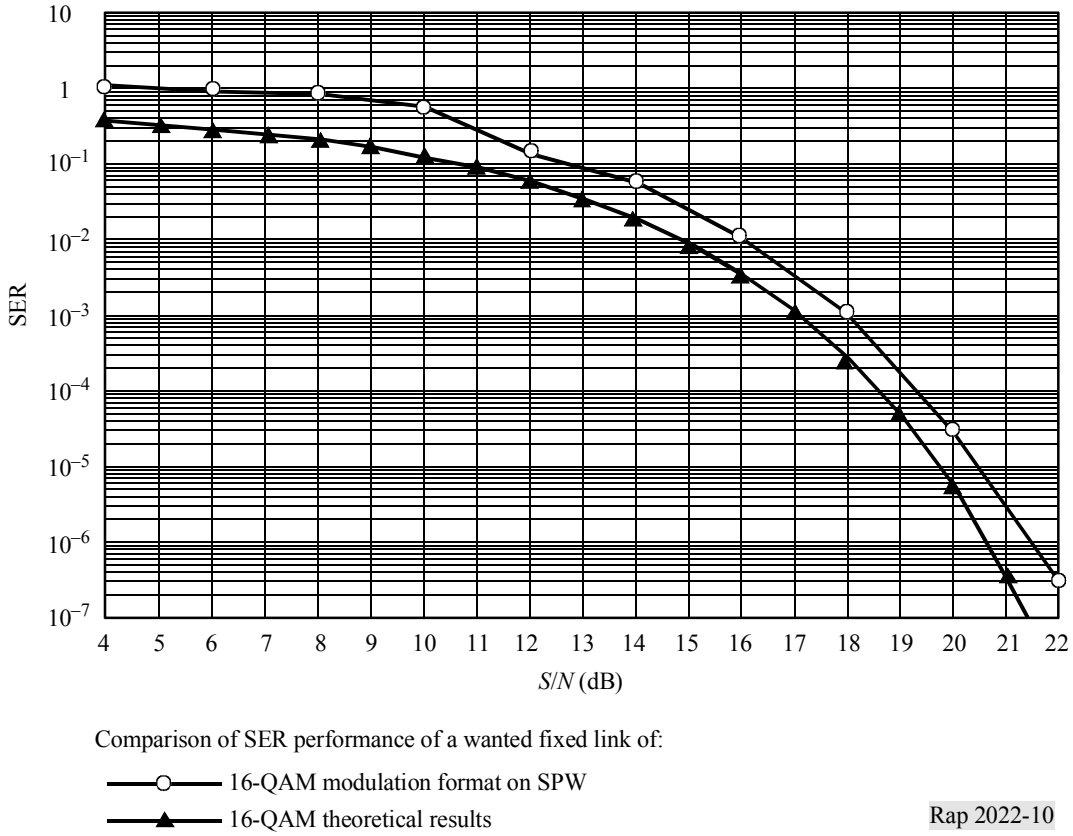
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b) *16-QAM wanted fixed-link receiver*

Figure 10 shows that the designed 16-QAM receiver performance is about 1 dB worse than the theoretical results that could only be achieved using an adaptive equalization.

FIGURE 10

16-QAM wanted fixed-link receiver SER performance against AWGN



c) *FSK wanted fixed-link receiver*

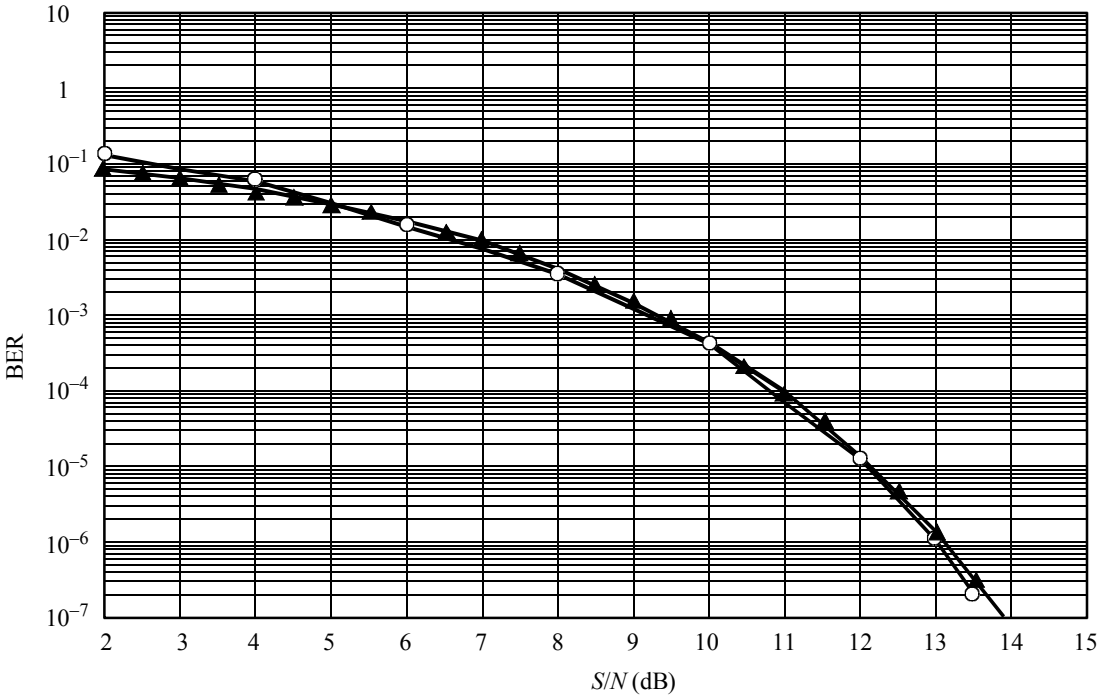
Figure 11 shows that the designed FSK receiver BER performance almost matches the theoretical results. This was achieved a FM discriminator and RF filters with bandwidth set to:

$$BW = 2\ (\text{Bitrate}) \cdot\ (1 +\ \text{Modulation index})$$

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FIGURE 11

FSK wanted fixed-link receiver BER performance against AWGN



4 Results

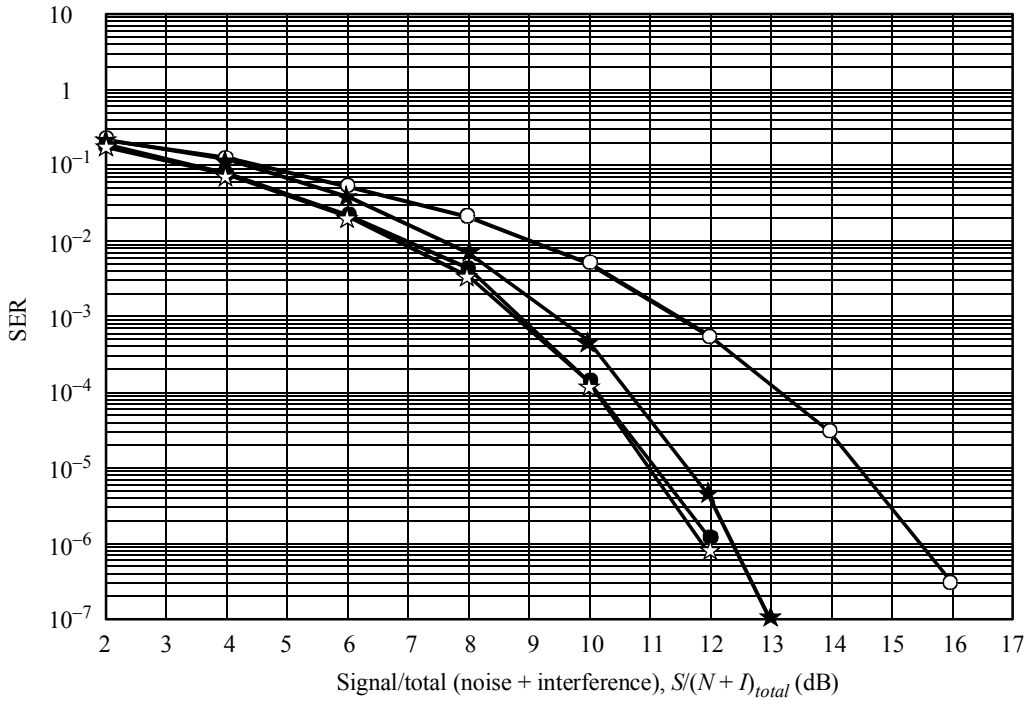
4.1 BER/SER performance of wanted fixed links of 4-PSK, 16-QAM and FSK modulation formats

Figures 12 to 17 contain SPW simulation results. Each graph has been plotted to show the effect on SER/BER of AWGN as a reference and interference signals of other modulation formats plus AWGN for a variety of test cases specified in Tables 1 and 2.

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FIGURE 12

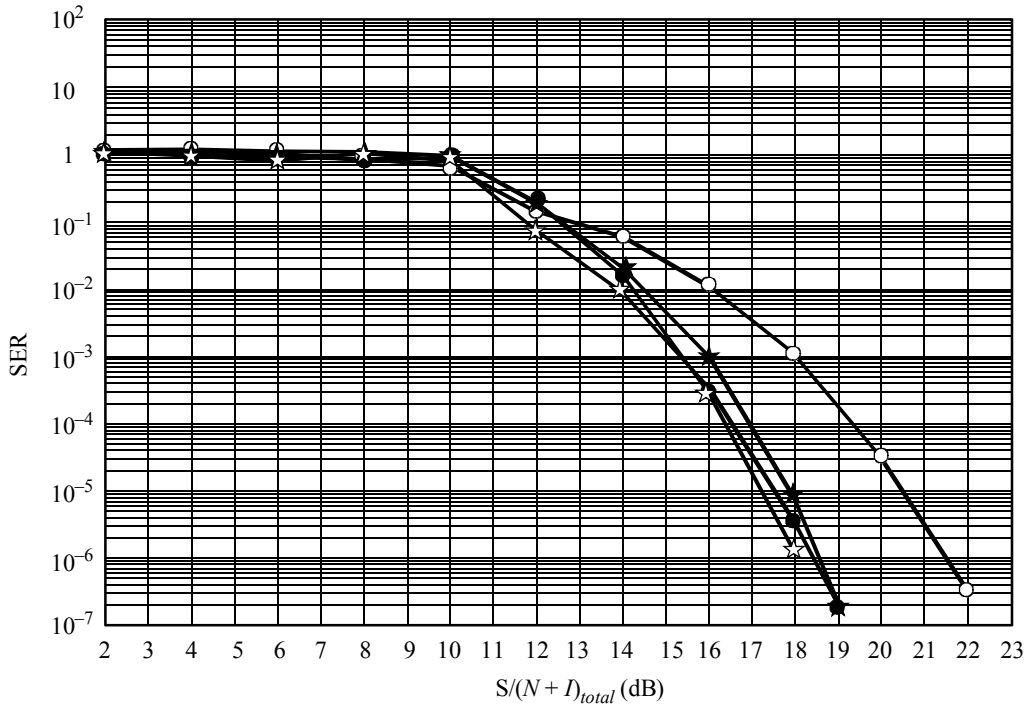
SER performance of a wanted fixed-link receiver of 4-PSK modulation format interfered by an unwanted fixed link of other modulation format with AWGN in a specified proportion



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FIGURE 13

SER performance of a wanted fixed-link receiver of 16-QAM modulation format interfered by an unwanted fixed link of other modulation format with AWGN in a specified proportion

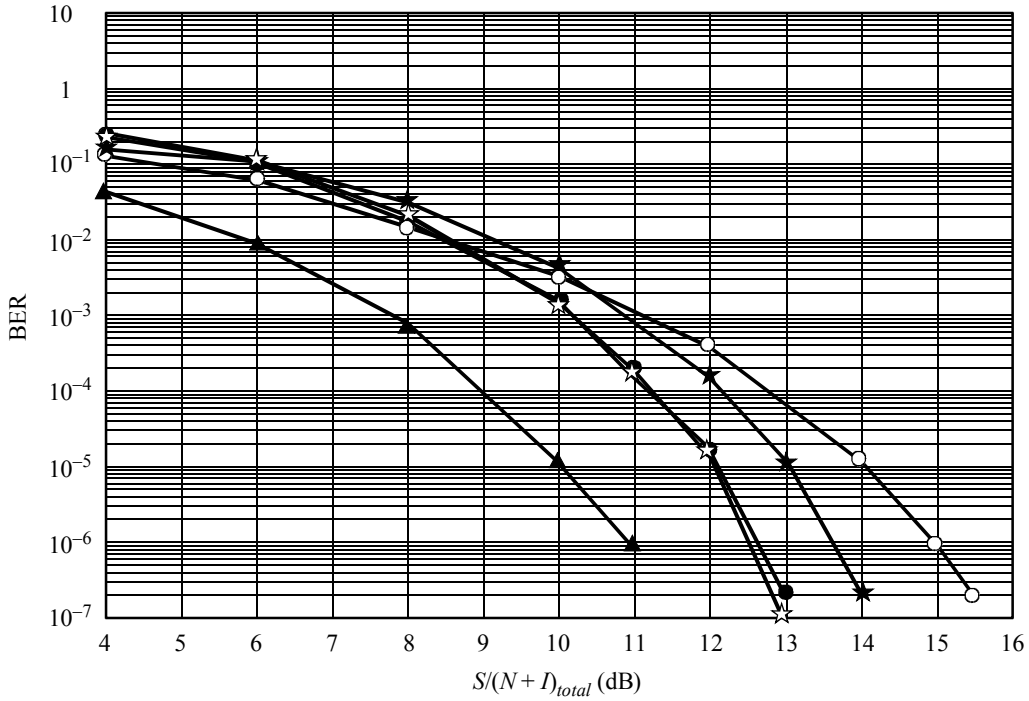


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FIGURE 14

BER performance of a wanted fixed-link receiver of FSK modulation format interfered by an unwanted fixed link of other modulation format with AWGN in a specified proportion



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