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).

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

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.

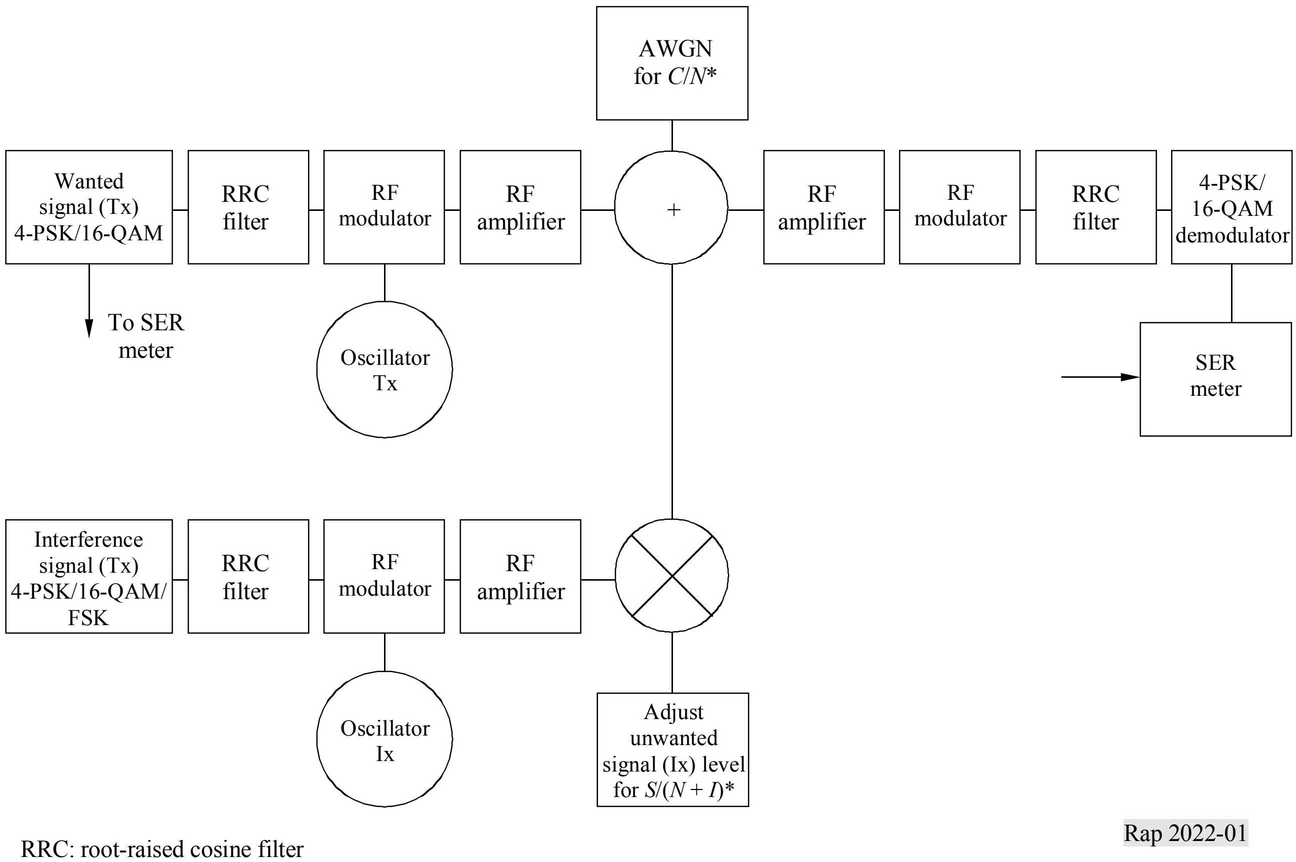
3.1.1 SPW design wanted fixed link of 4-PSK modulation format with a receiver

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



RRC: root-raised cosine filter

FIGURE 2

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

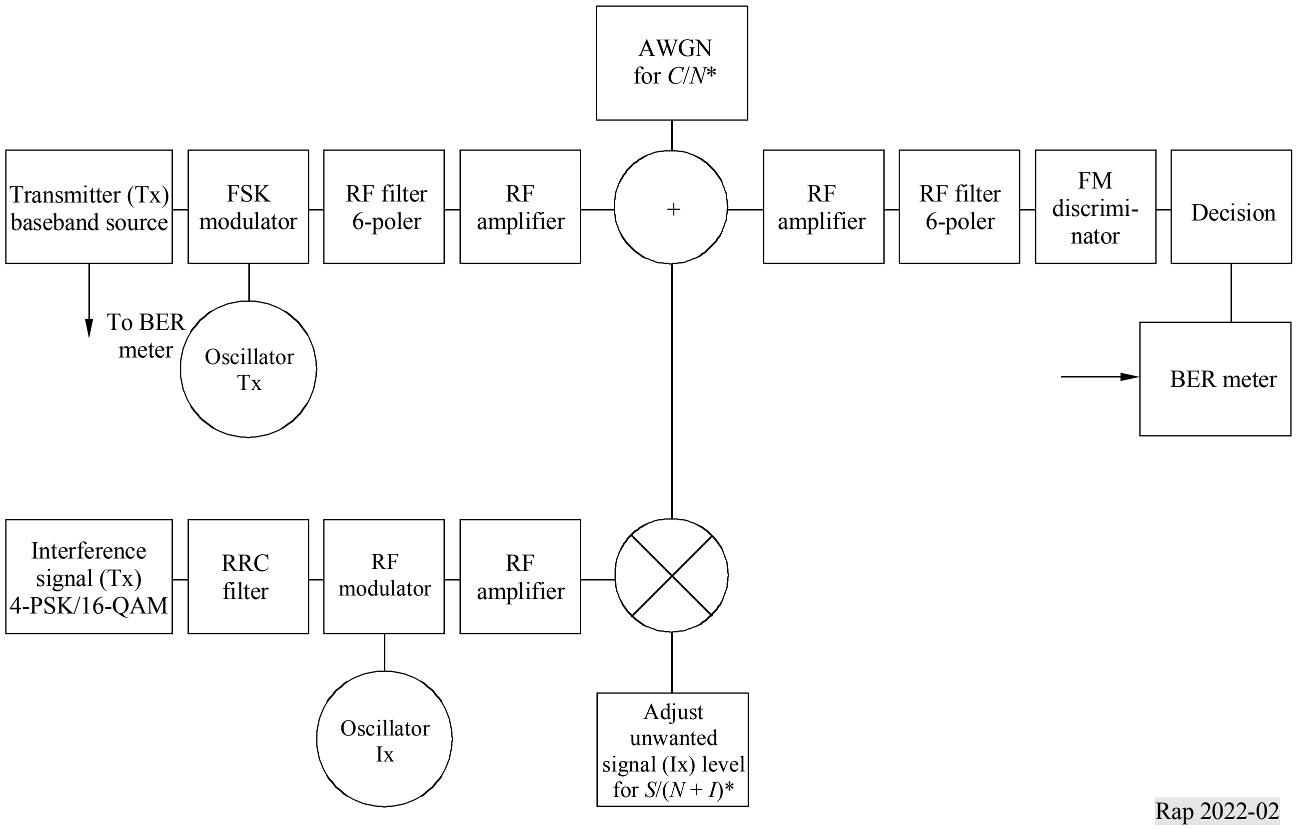


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FIGURE 3

4-PSK transmitter

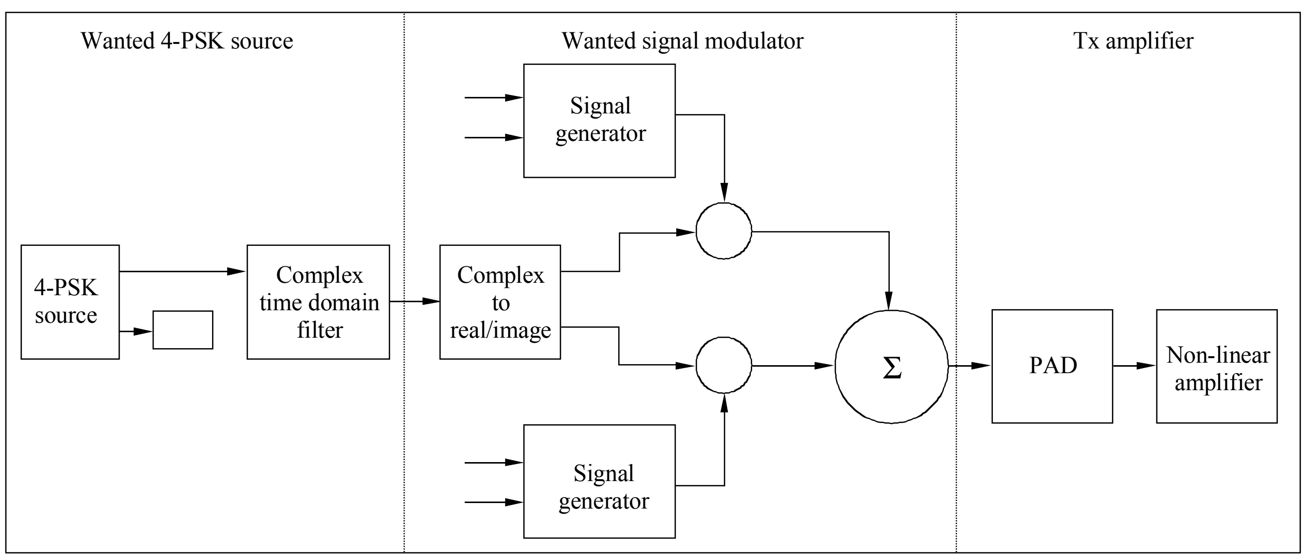

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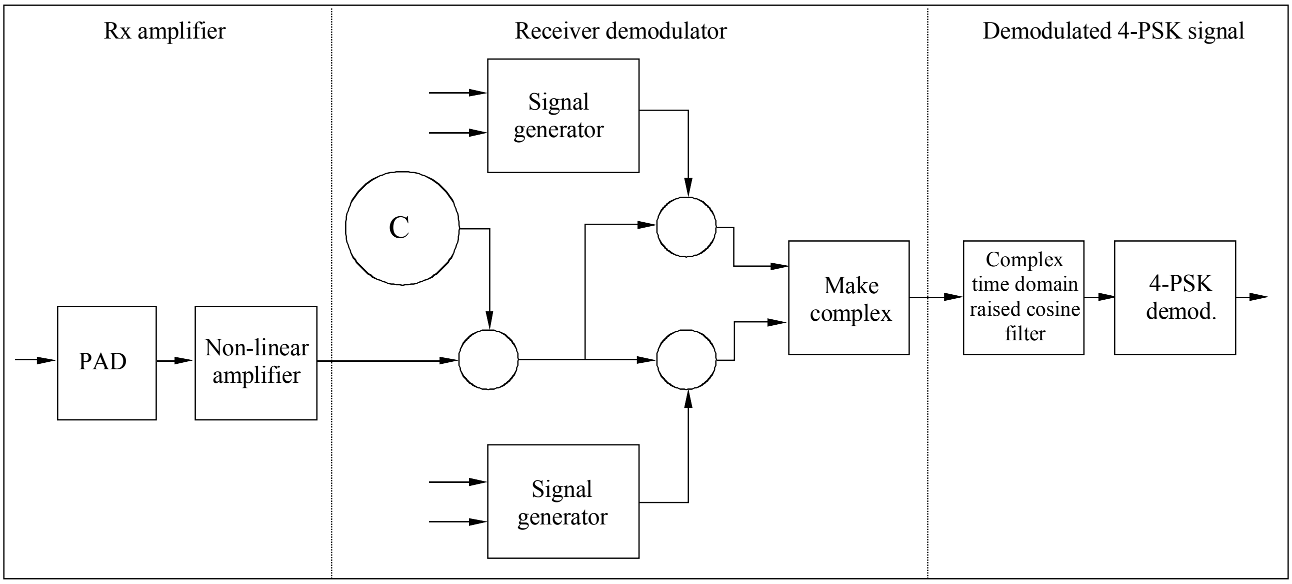
FIGURE 4

4-PSK receiver



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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.

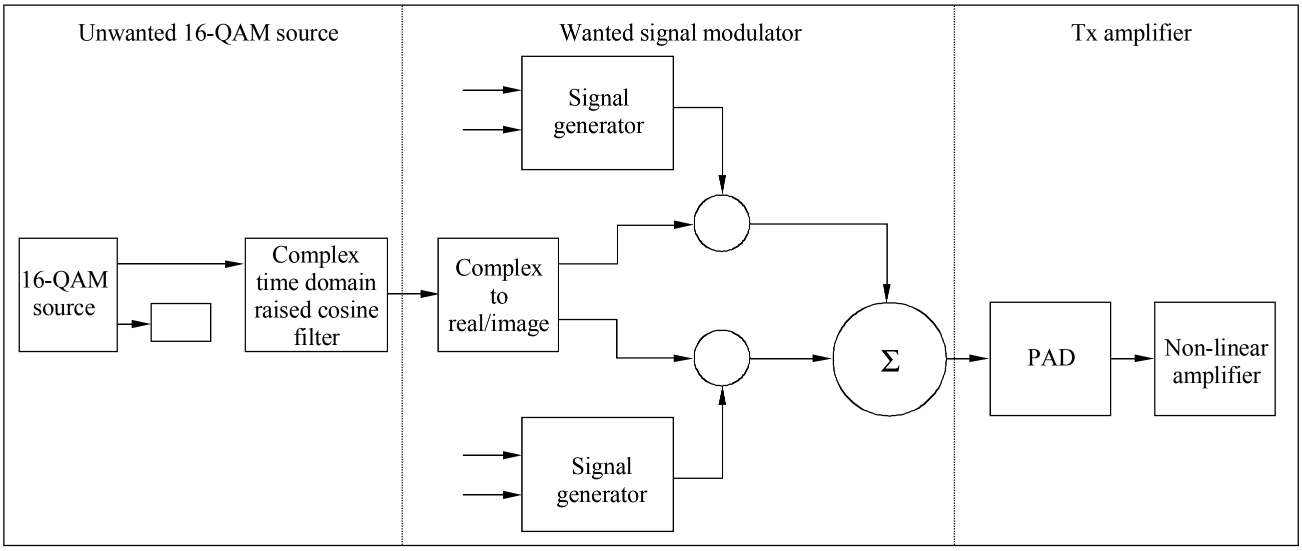
3.1.2 SPW design wanted fixed link of 16-QAM-modulation format with a receiver

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.

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;

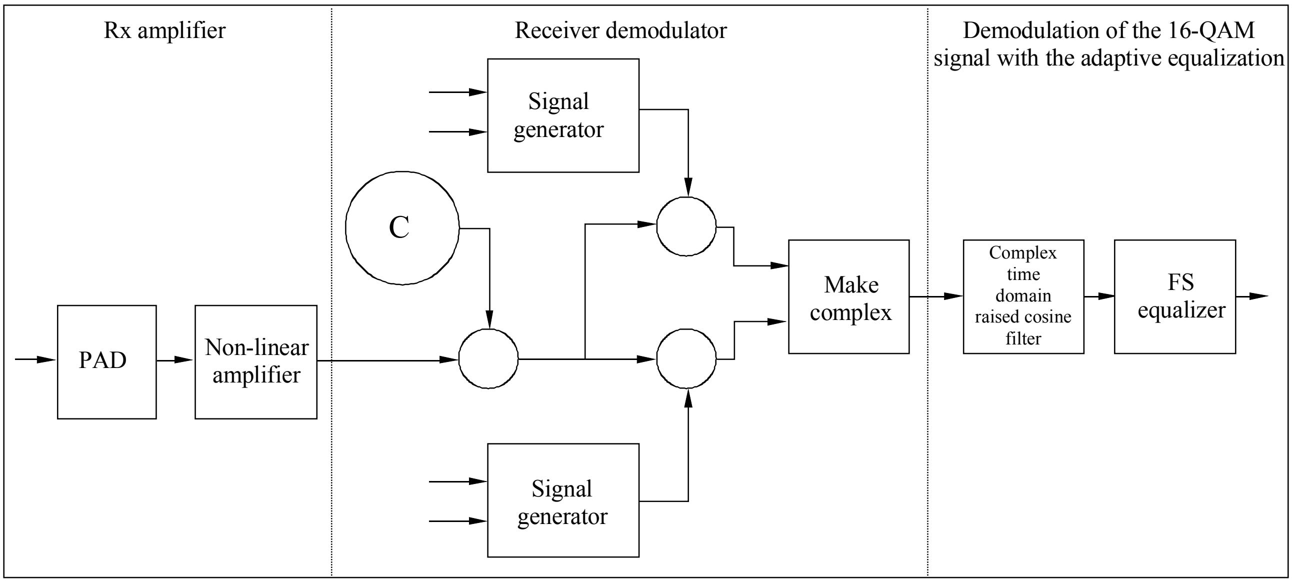
– 2nd order intercept point set at 16 dB above 1 dB compression point value;

– 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.

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.

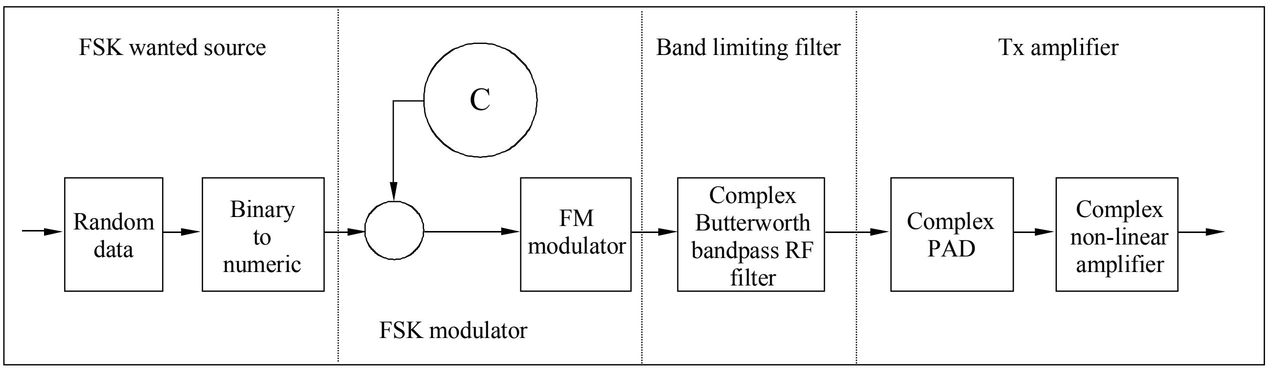
3.1.3 SPW designs of FSK modulation format with a receiver

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).

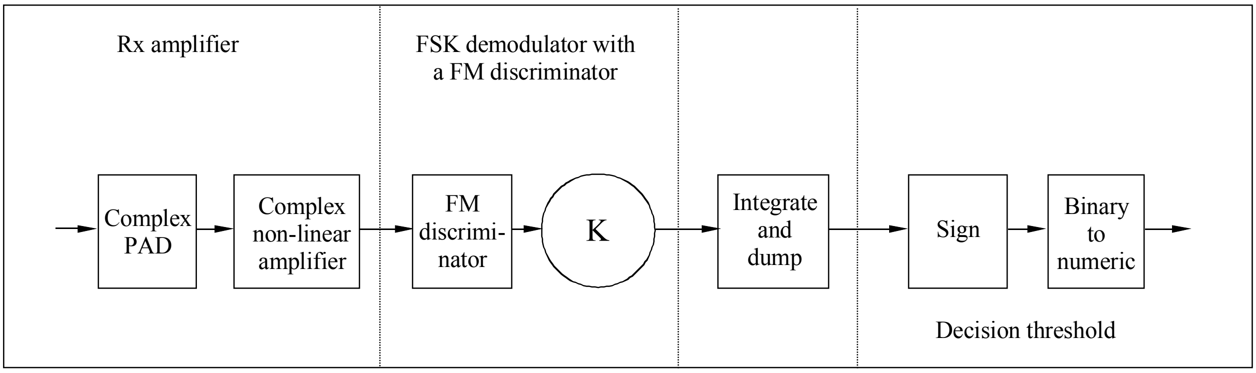
c) *FM modulator*: set to operate at a carrier frequency of 2.048 MHz with a modulation index of 0.45 for wanted signal and 0.35 modulation index for unwanted signal.

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



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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.

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 $1 \times 10^{–5}$;

– 10 to 50 errors counted from SER/BER $1 \times 10^{–5}$ to $1 \times 10^{–6}$.

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 $1 \times 10^{–5}$ with 95% confidence level is ±20%;

– from SER/BER $1 \times 10^{–5}$ to $1 \times 10^{–6}$ 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.

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

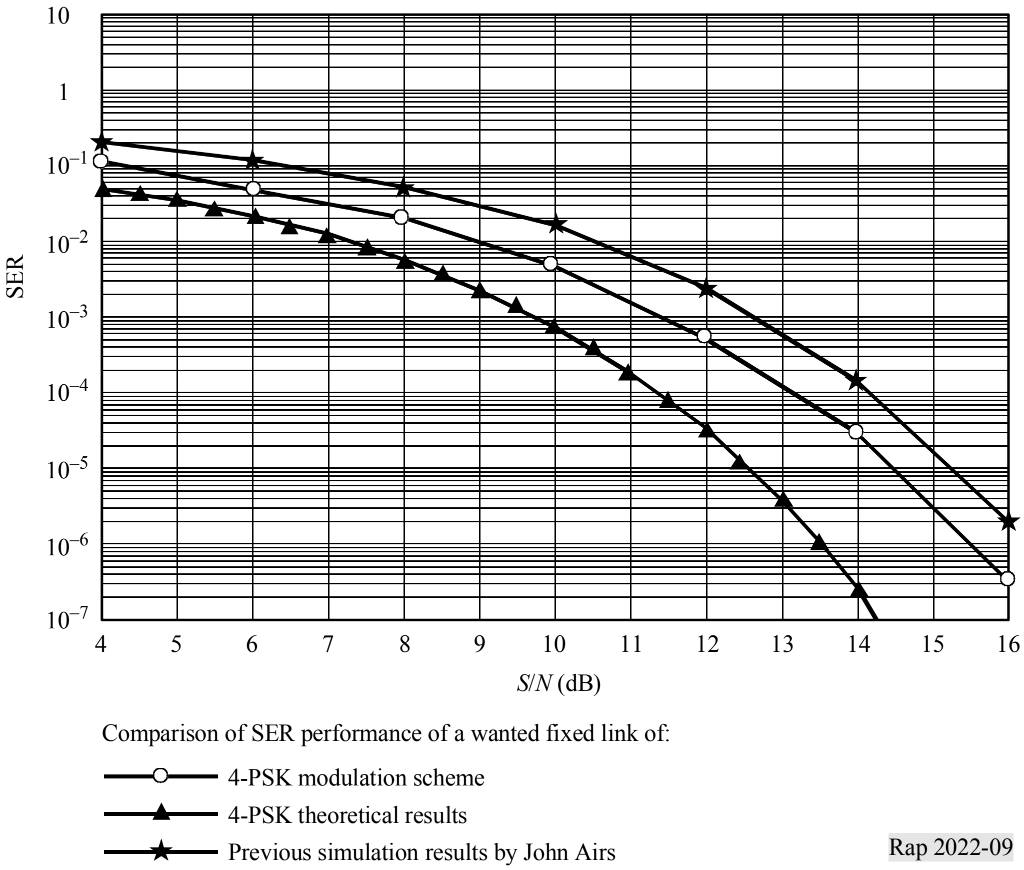


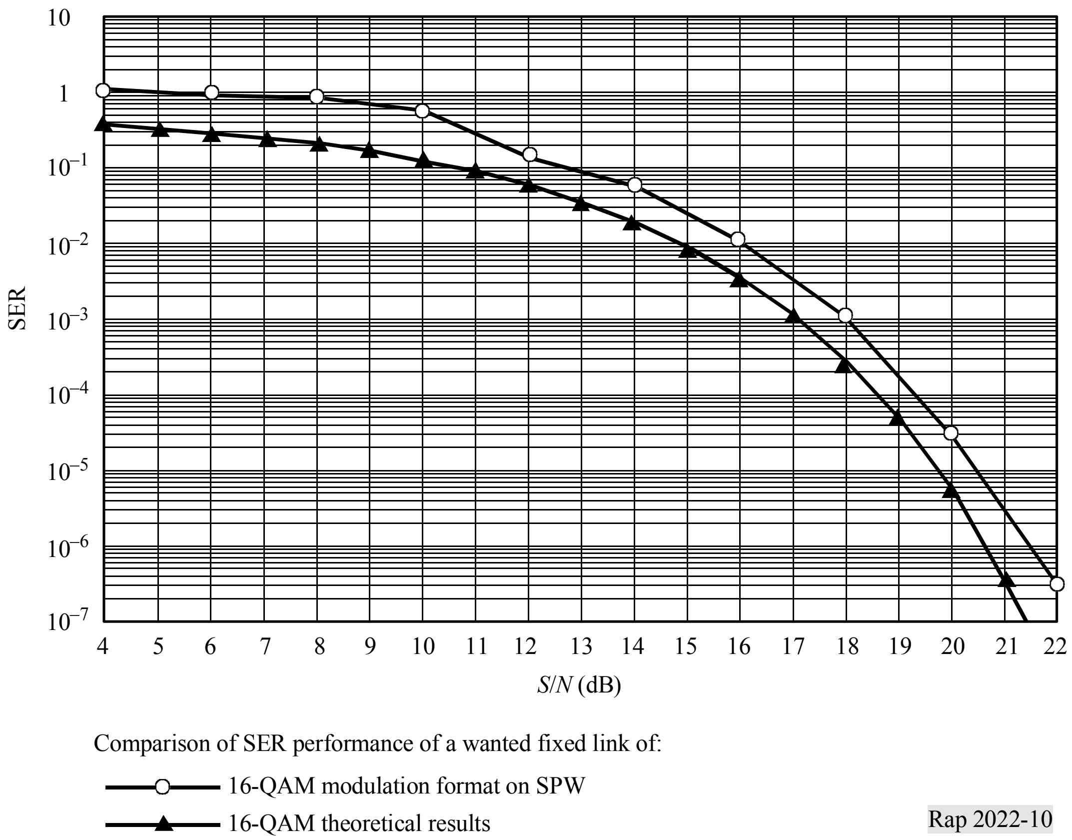
Figure 9 shows that the designed 4-PSK receiver SER performance is about 1 dB better than the previous simulation results and 2 dB worse than the theoretical results, which one would expect using a narrow-band filter and amplifier causing phase and amplitude distortion. It is possible that by using an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

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



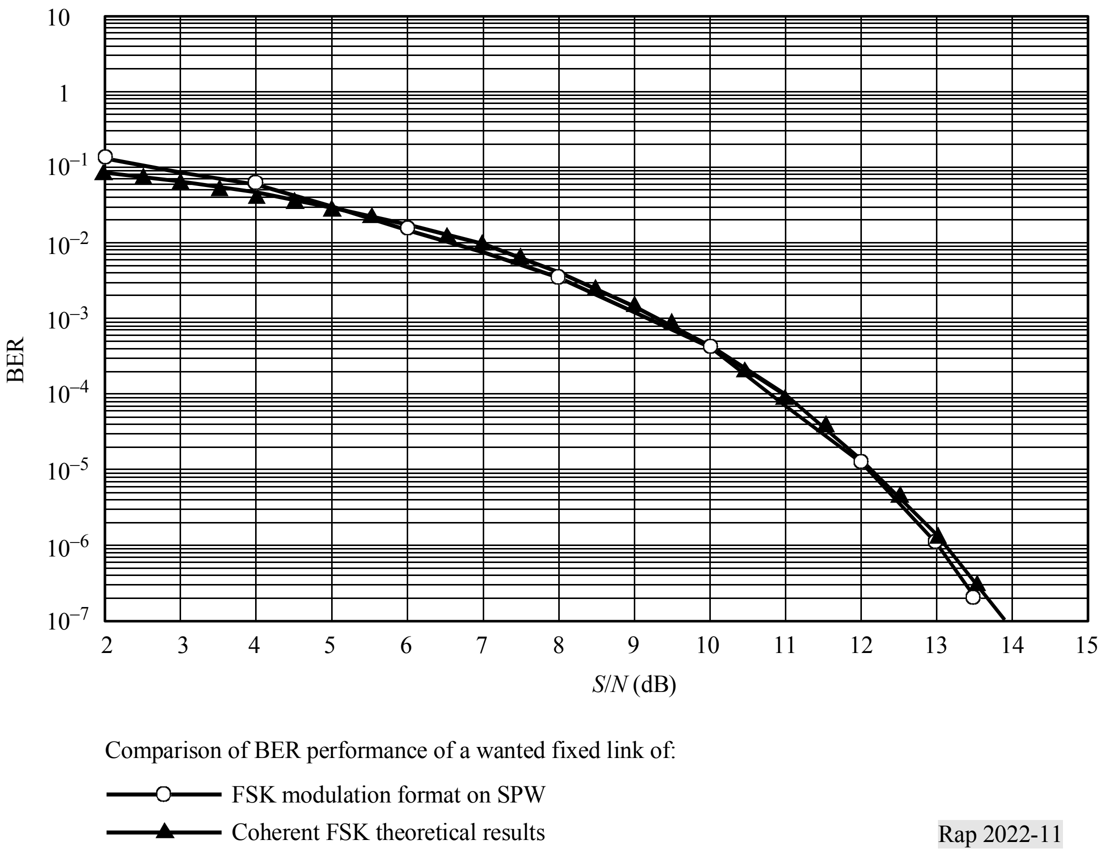
c) *FSK wanted fixed-link receiver*

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:

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

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.

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

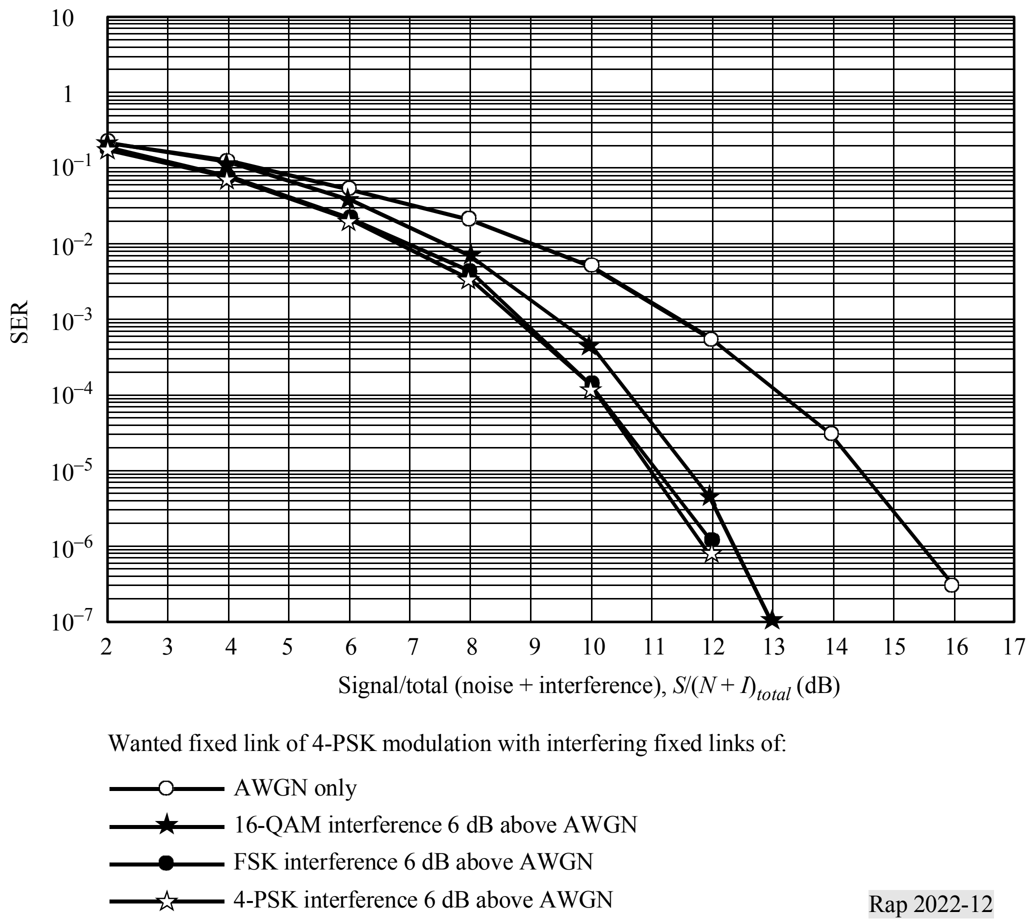


FIGURE 13

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

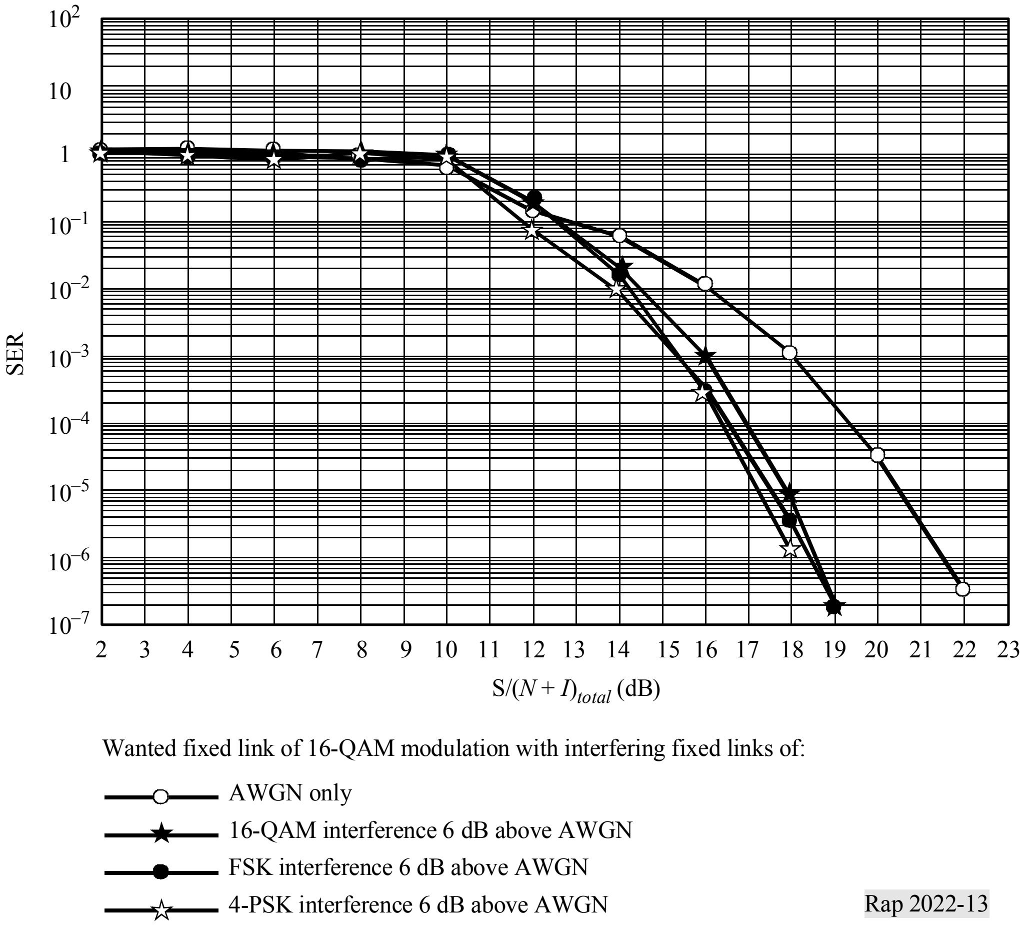
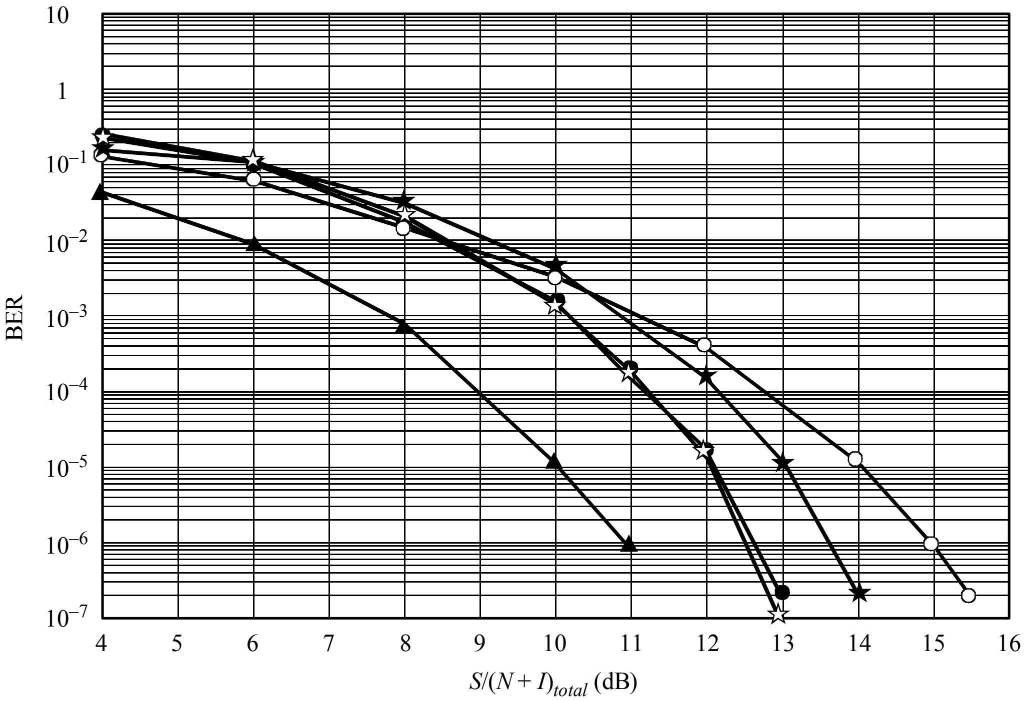


FIGURE 14

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



Wanted fixed link of FSK modulation with interfering fixed links of:

- AWGN
- 16-QAM interference 6 dB above AWGN
- 8-PSK interference 6 dB above AWGN
- 4-PSK interference 6 dB above AWGN
- FSK interference 6 dB above AWGN

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FIGURE 15

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

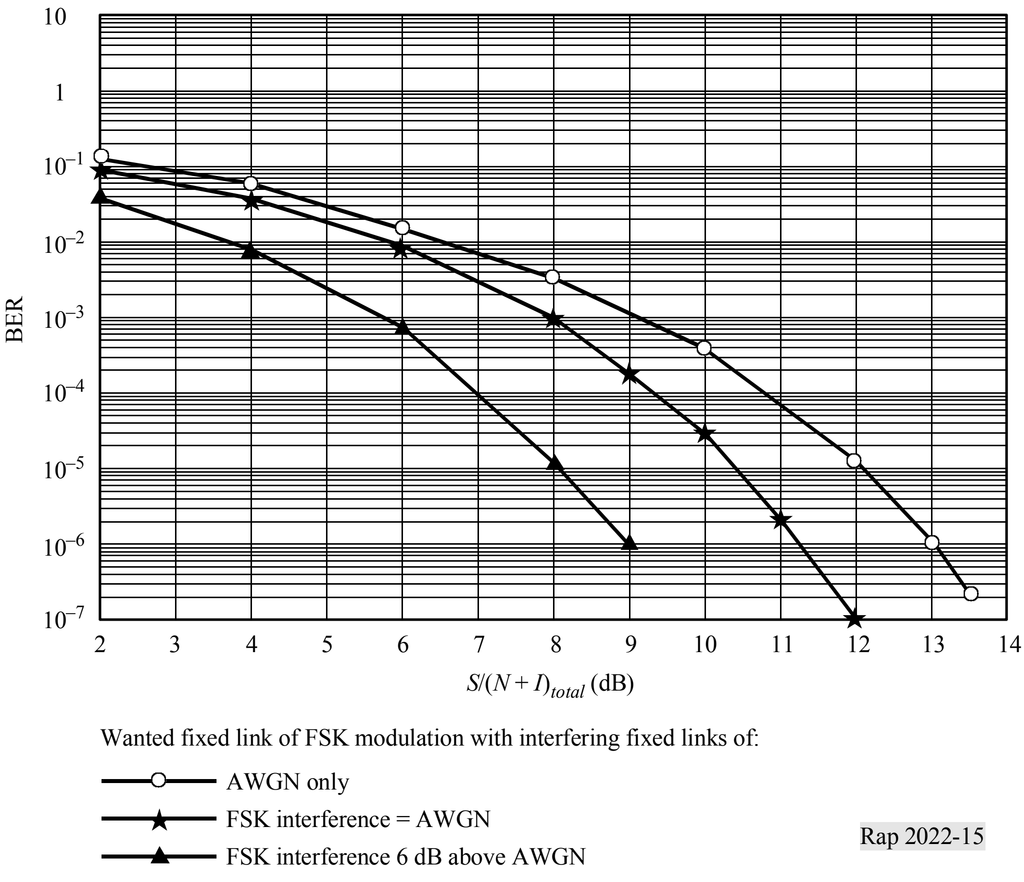
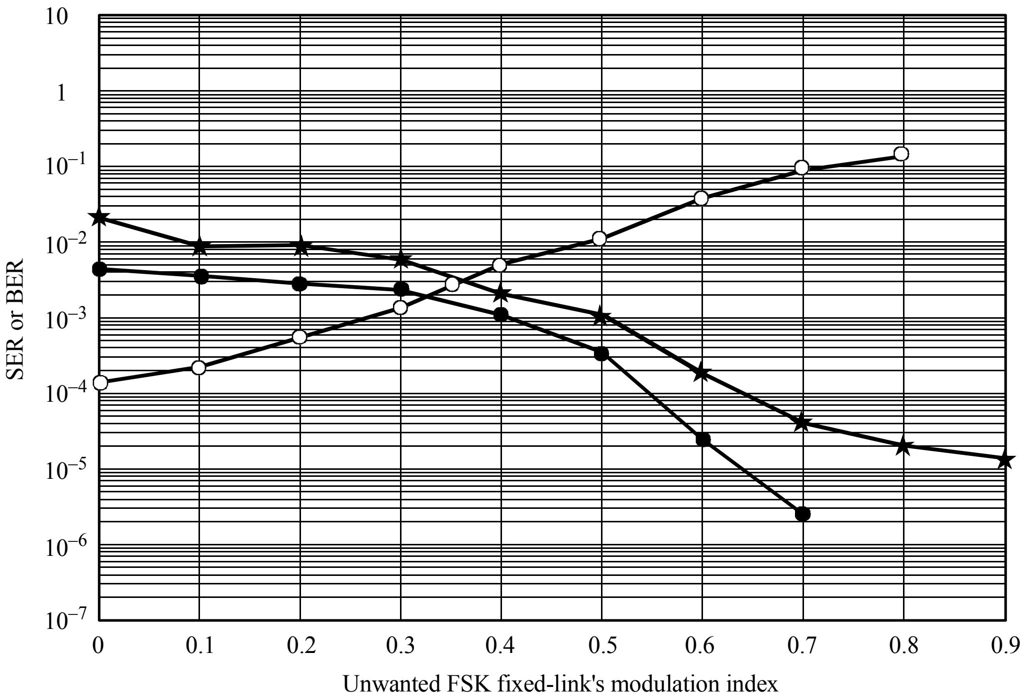


FIGURE 16

BER performance of wanted fixed-link receivers of FSK, 4-PSK and 16-QAM modulation formats interfered by an unwanted fixed link of FSK modulation format with its modulation index varied



Wanted fixed links of specified modulation formats with interfering fixed link of varying FSK modulation index:

Wanted fixed-link with FSK modulation format with modulation index = 0.45

Wanted fixed-link with 4-PSK modulation format

Wanted fixed-link with 16-QAM modulation format

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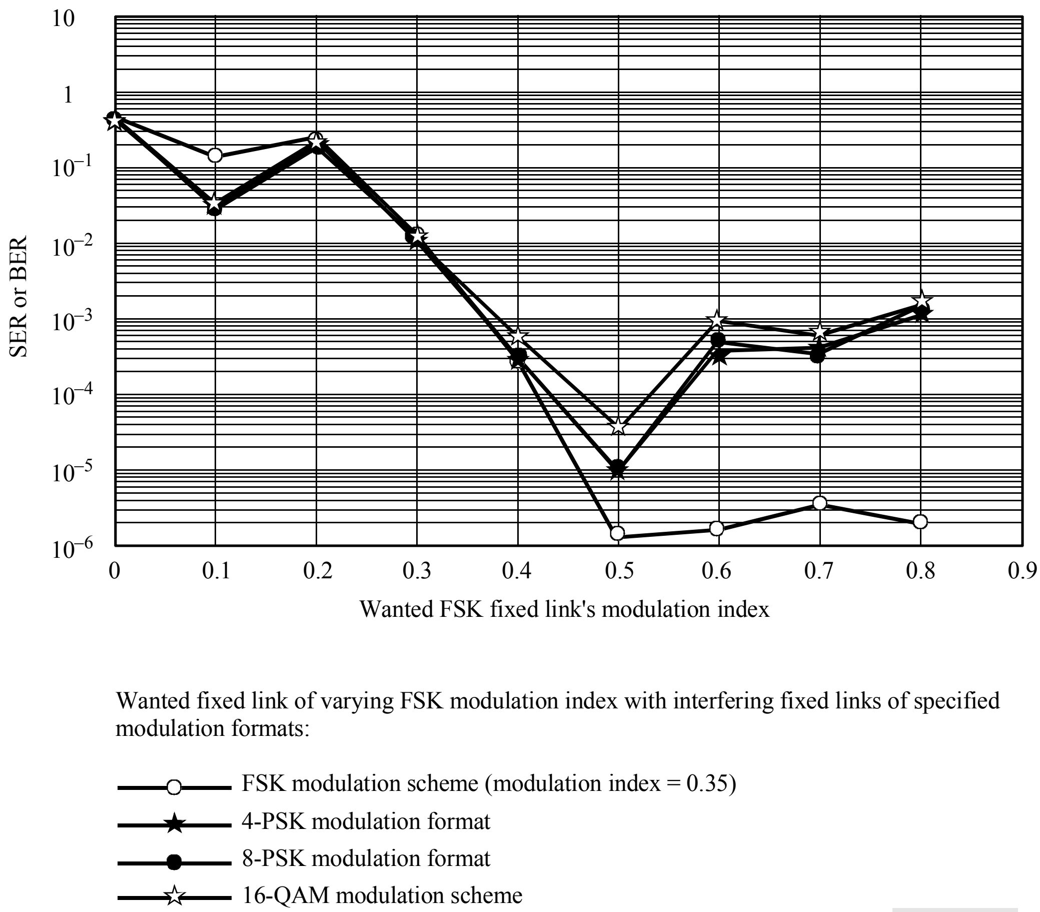
FIGURE 17

BER performance of a wanted fixed-link receiver of FSK modulation format with its transmitter modulation index varied and interfered by unwanted fixed links of FSK, 4-PSK and 16-QAM modulation formats



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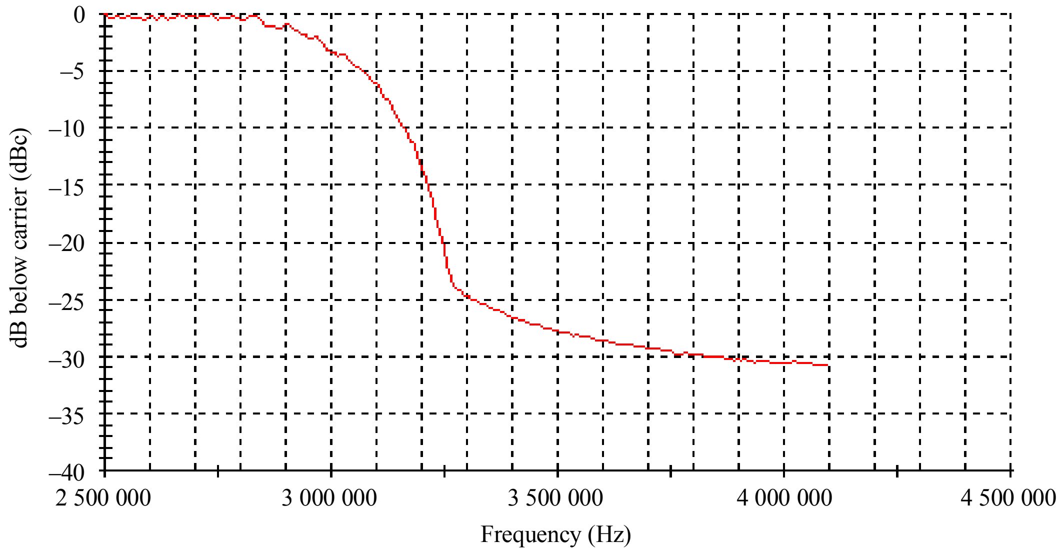
4.2 PSD plots of wanted and unwanted sources

Figures 18 to 21 show PSD plots for wanted or unwanted sources of 4-PSK, 16-QAM and FSK modulation formats.

These give a visual impression of the (baseband) transmitted signal and out-of-band components.

FIGURE 18

PSD plot of wanted, or unwanted,
fixed link of 4-PSK modulation format



PSD plot for 4-PSK wanted and interference sources

No. of points: 1 025
Frequency: 2.992 MHz
Bin No.: 374
Magnitude: –3.12977

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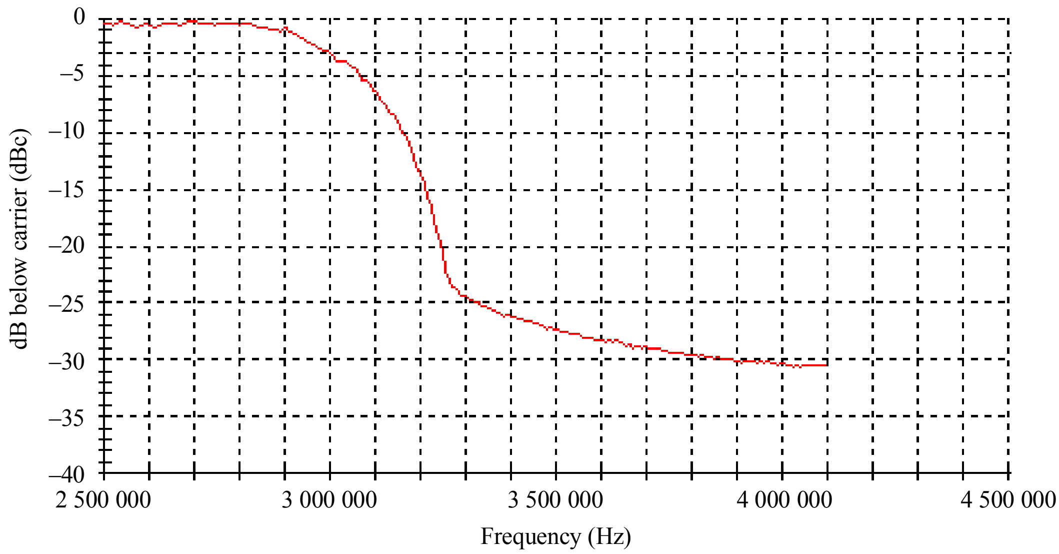
FIGURE 19

PSD plot of wanted, or unwanted,
fixed link of 16-QAM modulation format



PSD plot for 16-QAM wanted and interference sources

No. of points: 1 025
Frequency: 3 MHz
Bin No.: 375
Magnitude: –2.91409

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FIGURE 20

PSD plot of wanted fixed link of FSK modulation format with a modulation index of 0.45

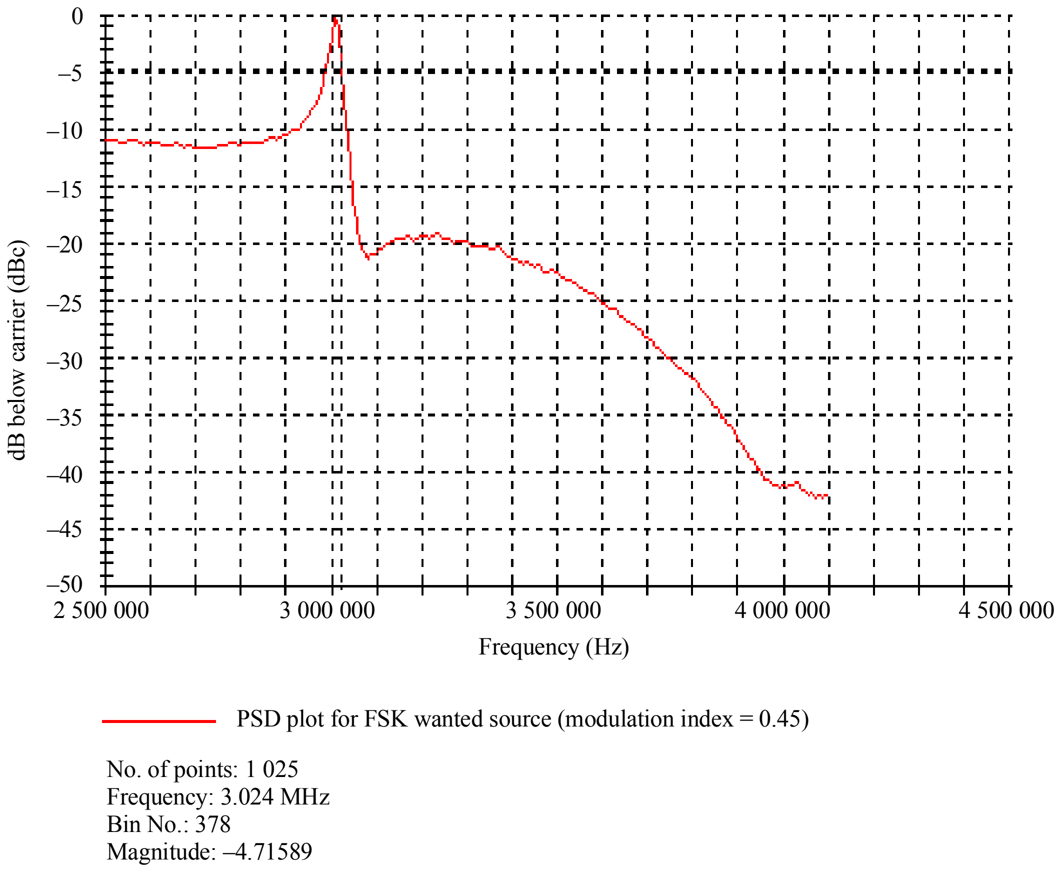

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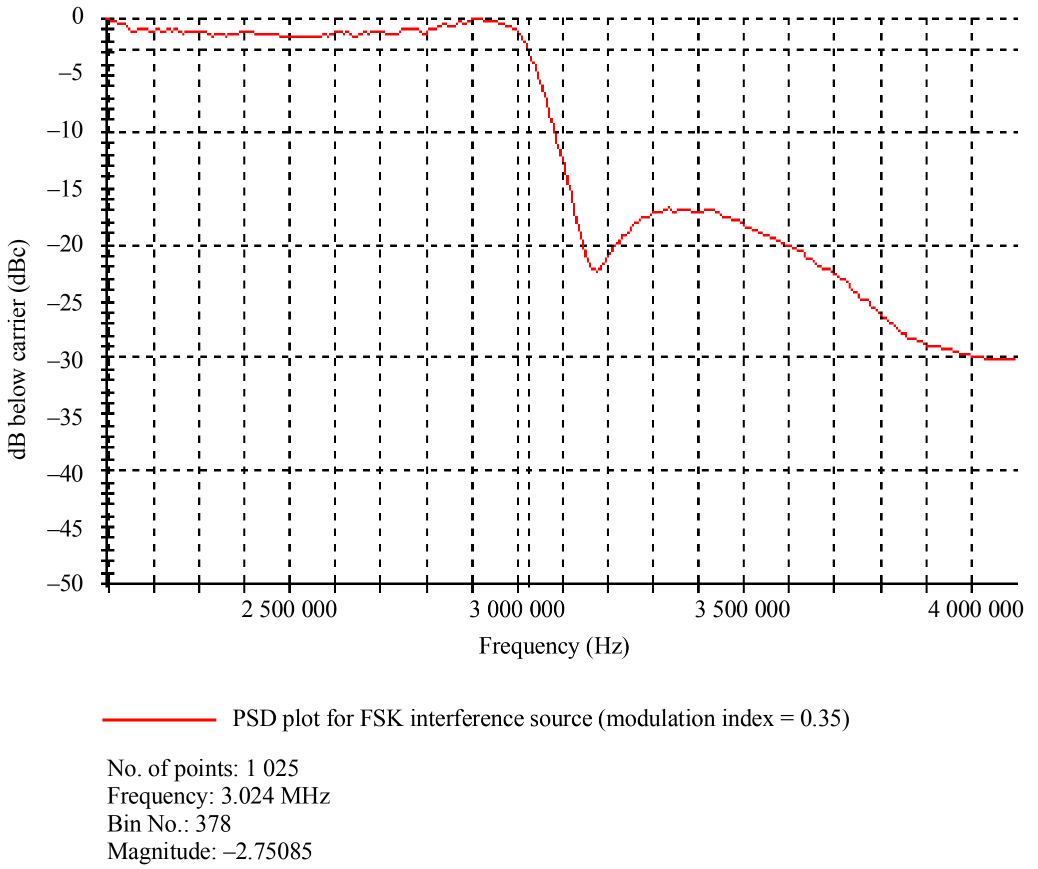
FIGURE 21

PSD plot of wanted fixed link of FSK modulation format with a modulation index of 0.35



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4.3 Eye and scatter plots for 4-PSK and 16-QAM fixed links with interference and noise

Figures 22 to 35 allow us to see how combined interference signal of a given modulation format plus AWGN in a given proportion effect the SER/BER performance of wanted fixed links of 4-PSK and 16-QAM modulation formats.

These show how the eye diagram and scatter or constellation plots will appear at a $S/(N+I)$ appropriate at an SER of approximately 1×10^{-5}.

The degree of eye closure or the extent of the scatter around each constellation point indicates visually the effect of noise and interference. A clear (low noise) signal will show a clear wide eye and minimal scatter of the constellation points.

FIGURE 22

Eye and scatter plots for a wanted fixed link of 4-PSK-modulation format with AWGN at a *S*/*N* of 14.5 dB (measured SER of 1 × 10^{-5})

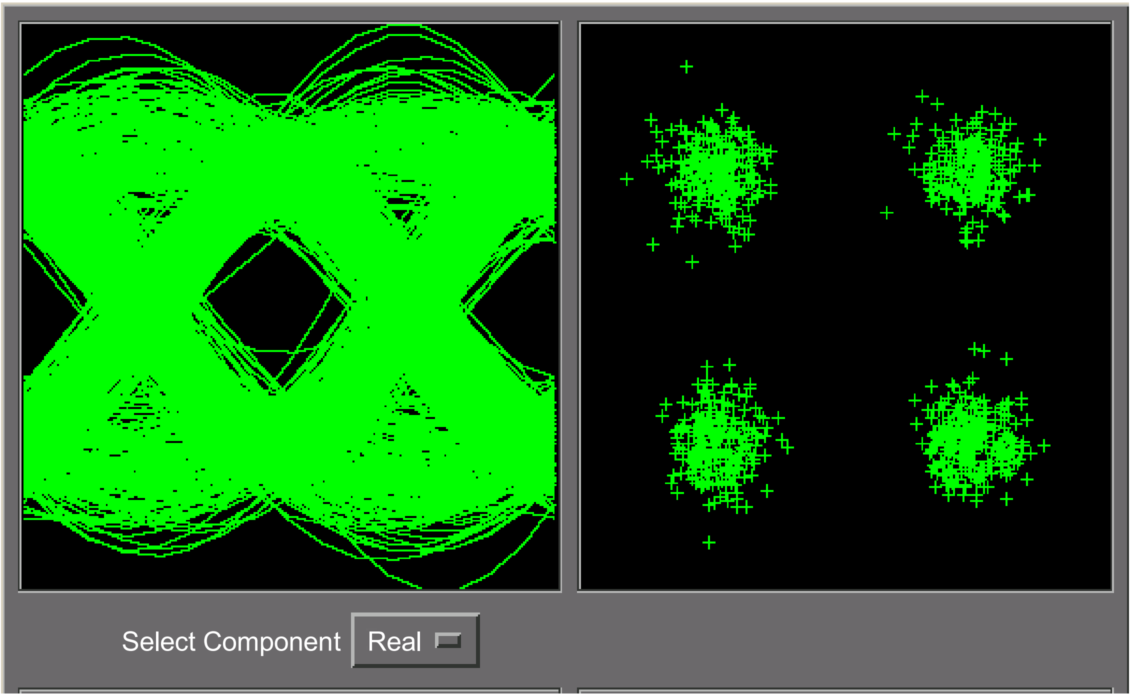

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FIGURE 23

Eye and scatter plots for a wanted fixed link of 4-PSK-modulation format with FSK interference 6 dB above AWGN at a total *S*/(*N* + *I*) of 14.5 dB

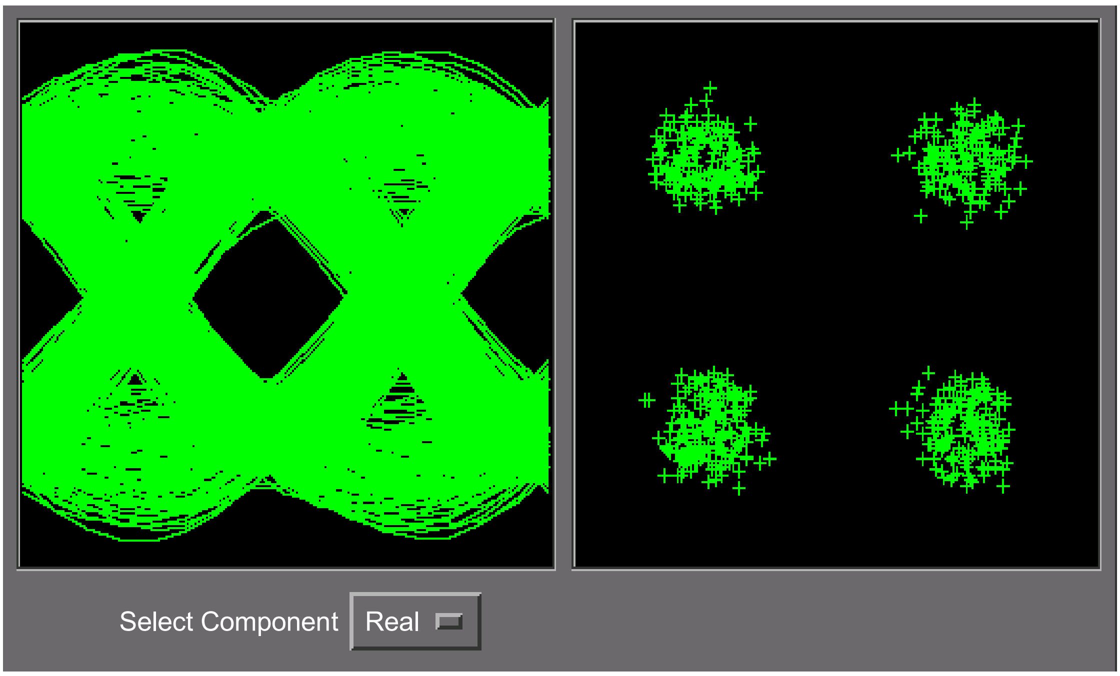

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FIGURE 24

Eye and scatter plots for a wanted fixed link of 4-PSK-modulation format with 4-PSK interference 6 dB above AWGN at a total *S*/(*N* + *I*) of 14.5 dB

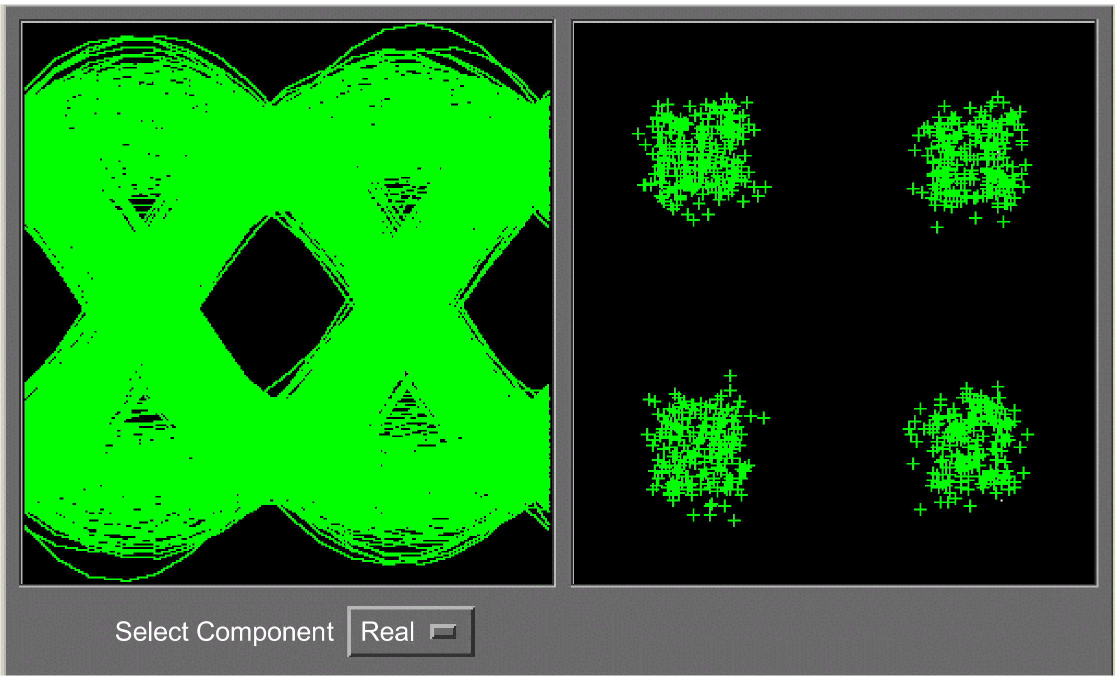

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FIGURE 25

Eye and scatter plots for a wanted fixed link of 4-PSK-modulation format with 16-QAM interference 6 dB above AWGN at a total *S*/(*N* + *I*) of 14.5 dB

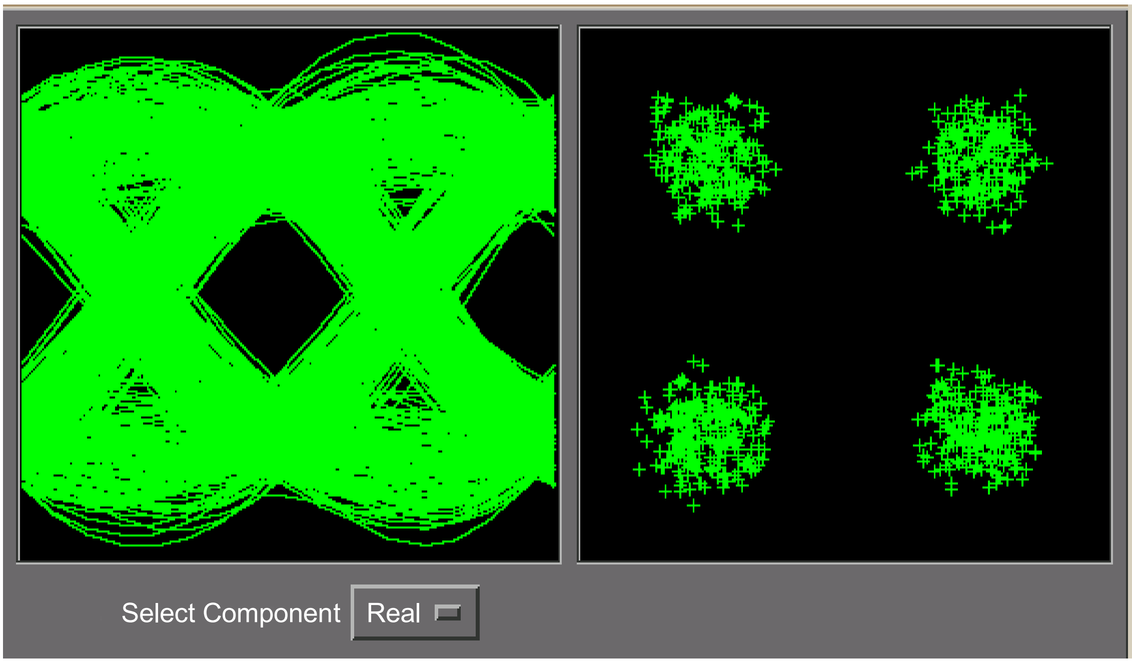

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FIGURE 26

Eye and scatter plots for a wanted fixed link of 4-PSK-modulation format with FSK interference at a *S/N* of 14.5 dB

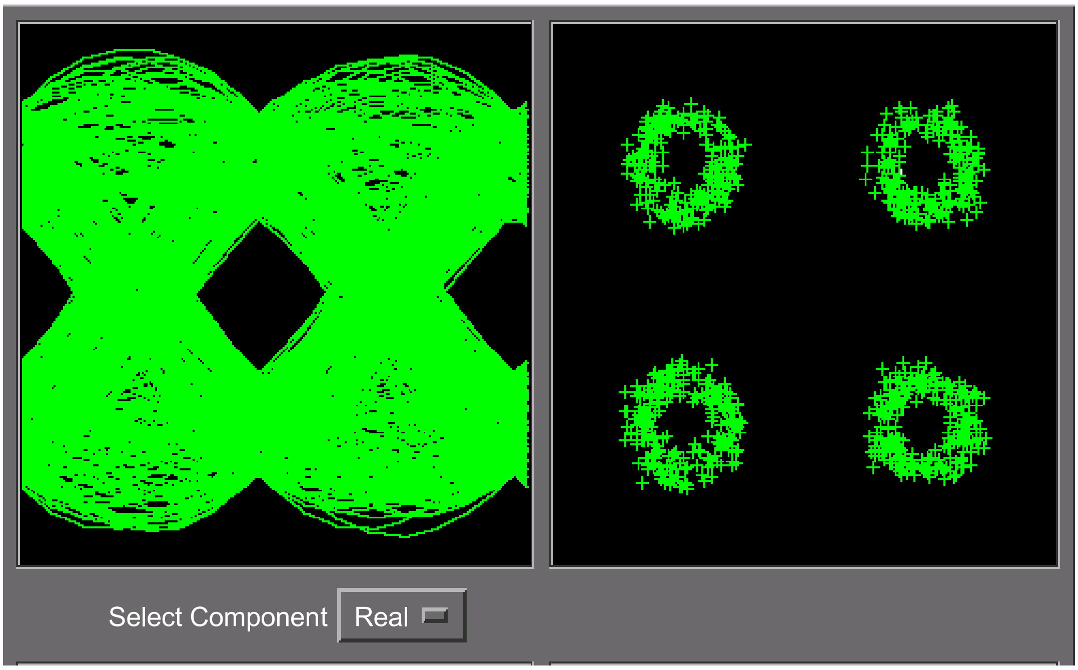

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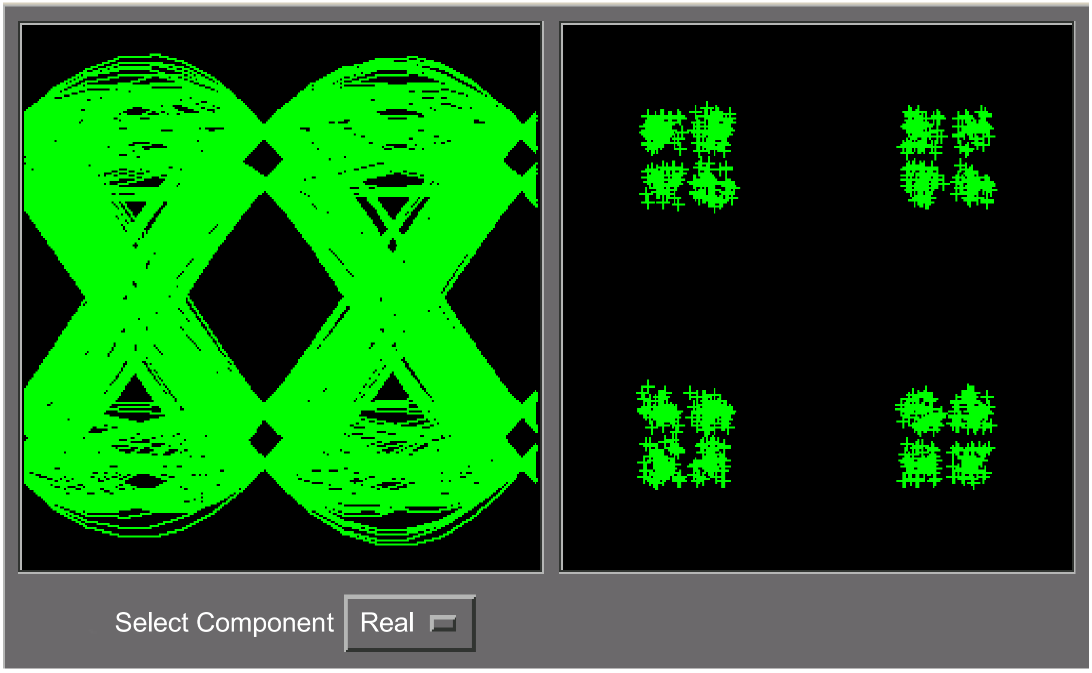
FIGURE 27

Eye and scatter plots for a wanted fixed link of 4-PSK-modulation format with 4-PSK interference at a *S/N* of 14.5 dB



Rap 2022-27sc

FIGURE 28

Eye and scatter plots for a wanted fixed link of 4-PSK-modulation format with 16-QAM interference at a *S*/*N* of 14.5 dB

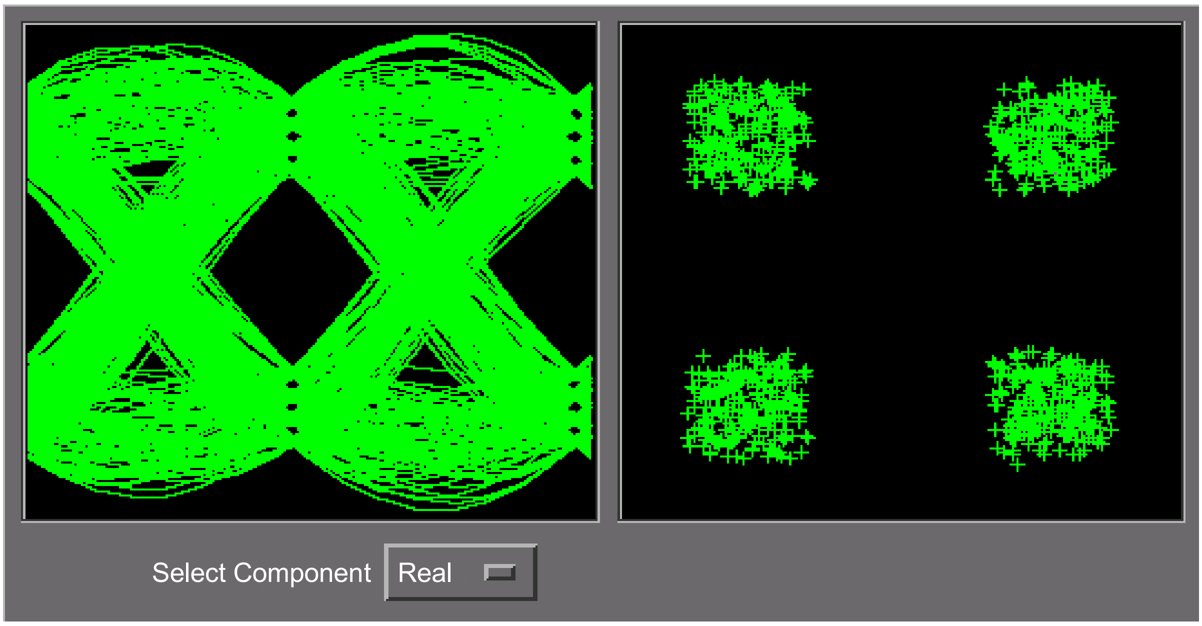


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FIGURE 29

Eye and scatter plots for a wanted fixed link of 16-QAM-modulation format with AWGN only at a *S*/*N* of 22.5 dB (SER of 1 × 10^{-5})

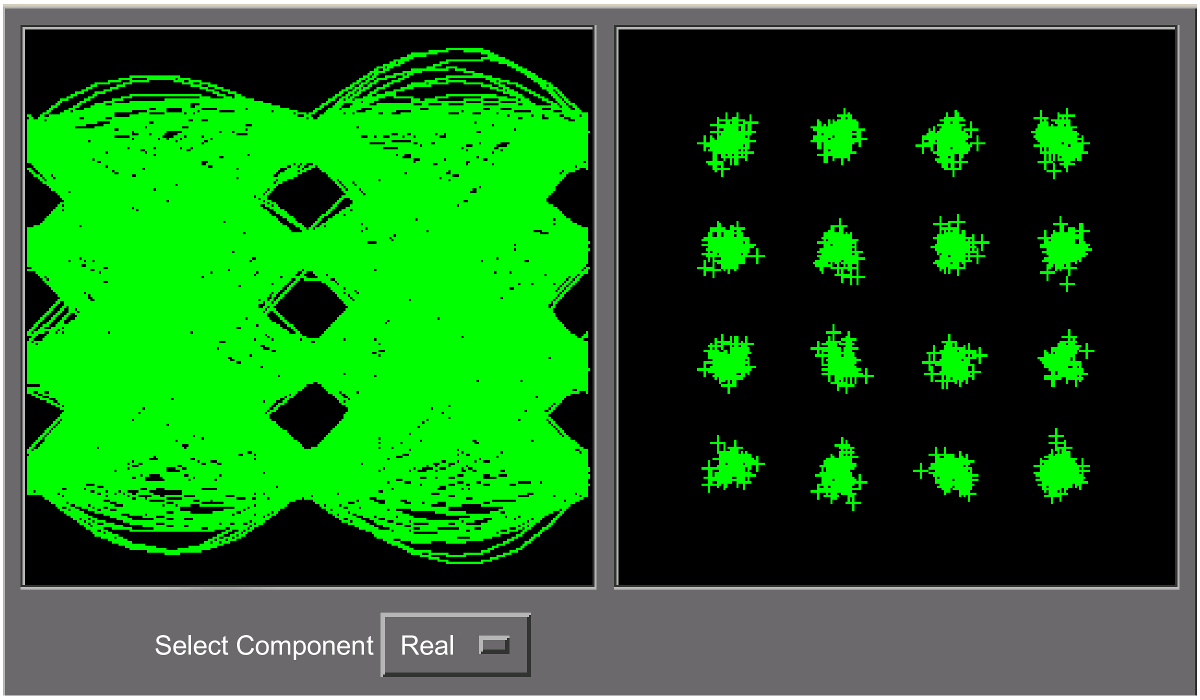

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FIGURE 30

Eye and scatter plots for a wanted fixed link of 16-QAM-modulation format with FSK interference 6 dB above AWGN at a total *S*/(*N* + *I*) of 22.5 dB

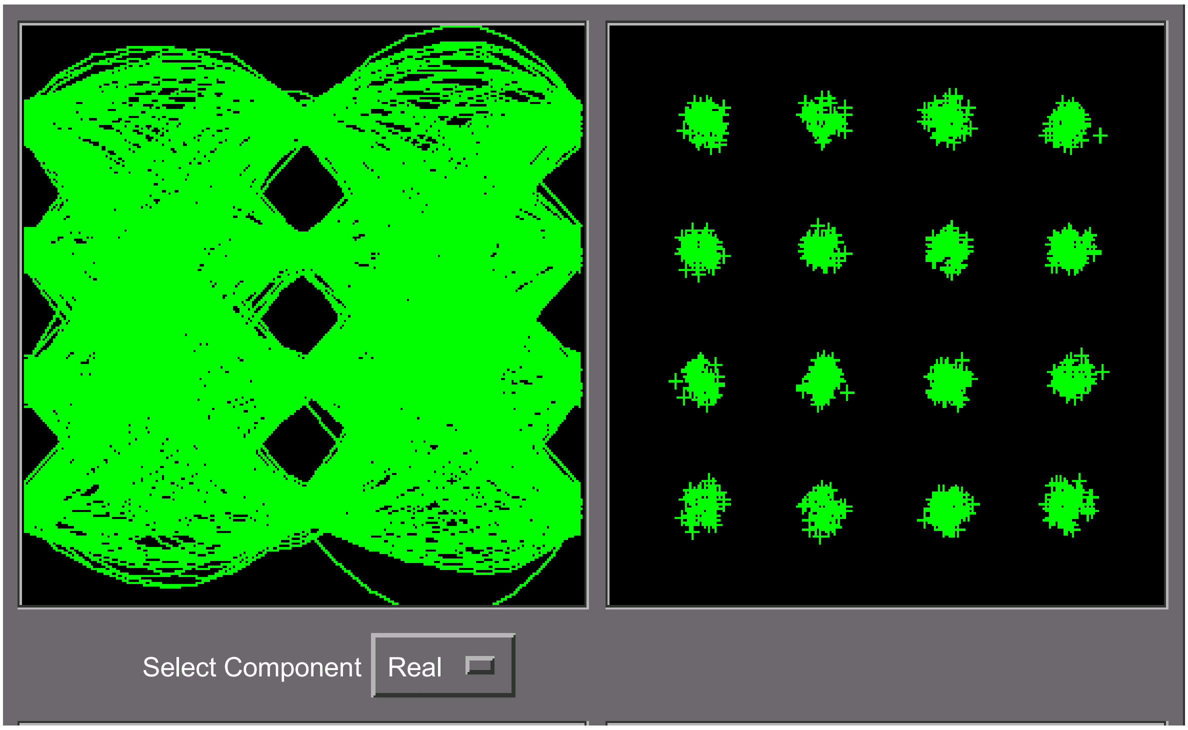

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FIGURE 31

Eye and scatter plots for a wanted fixed link of 16-QAM-modulation format with 4-PSK interference 6 dB above AWGN at a total *S*/(*N* + *I*) of 22.5 dB

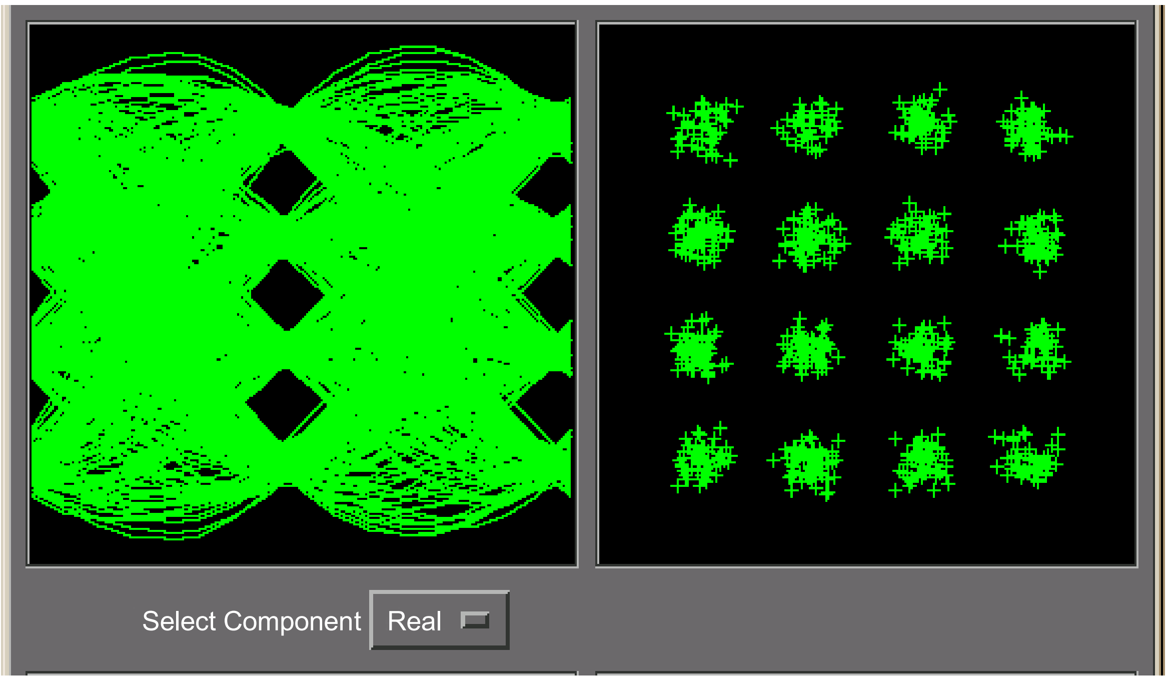

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FIGURE 32

Eye and scatter plots for a wanted fixed link of 16-QAM-modulation format with 16-QAM interference 6 dB above AWGN at a total $S/(N + I)$ of 22.5 dB

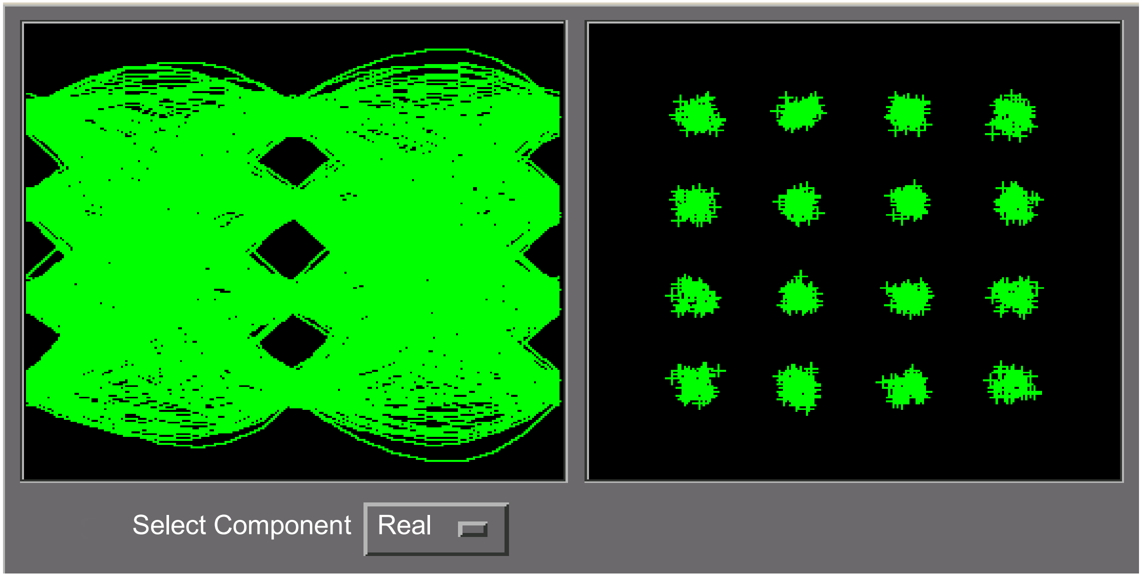

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FIGURE 33

Eye and scatter plots for a wanted fixed link of 16-QAM-modulation format with FSK interference at a S/N of 22.5 dB

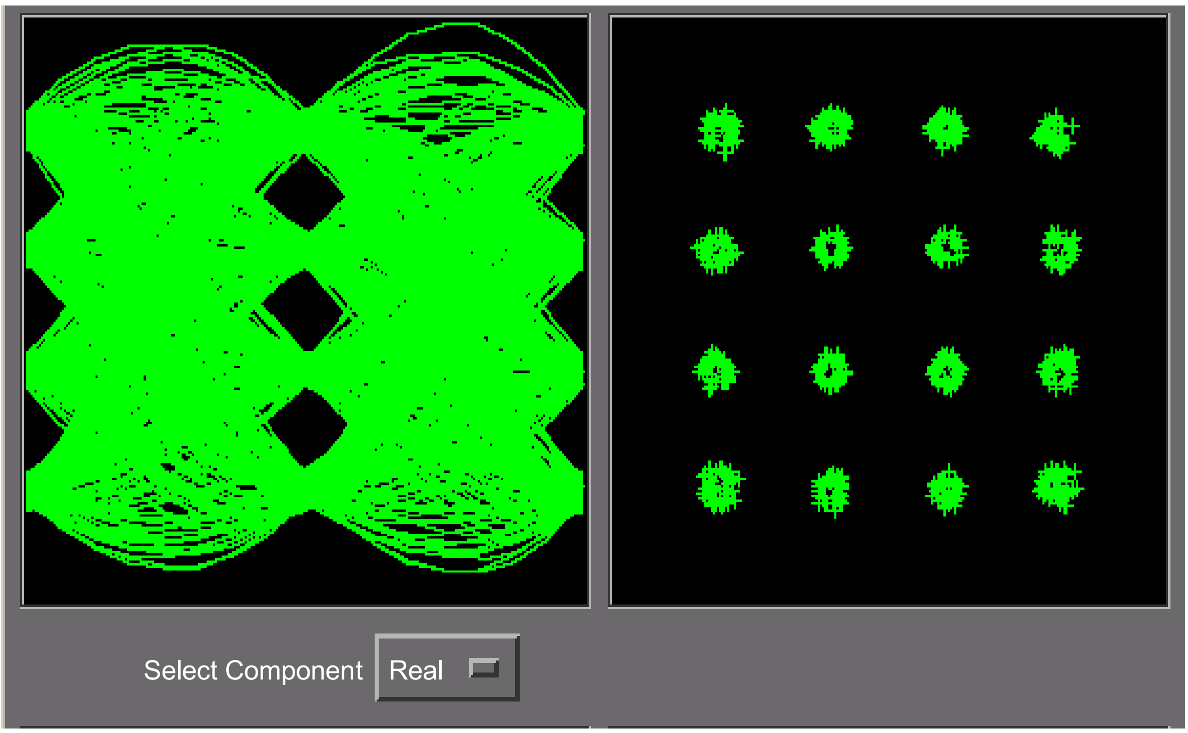

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FIGURE 34

Eye and scatter plots for a wanted fixed link of 16-QAM-modulation format with 4-PSK interference at a *S*/*N* of 22.5 dB

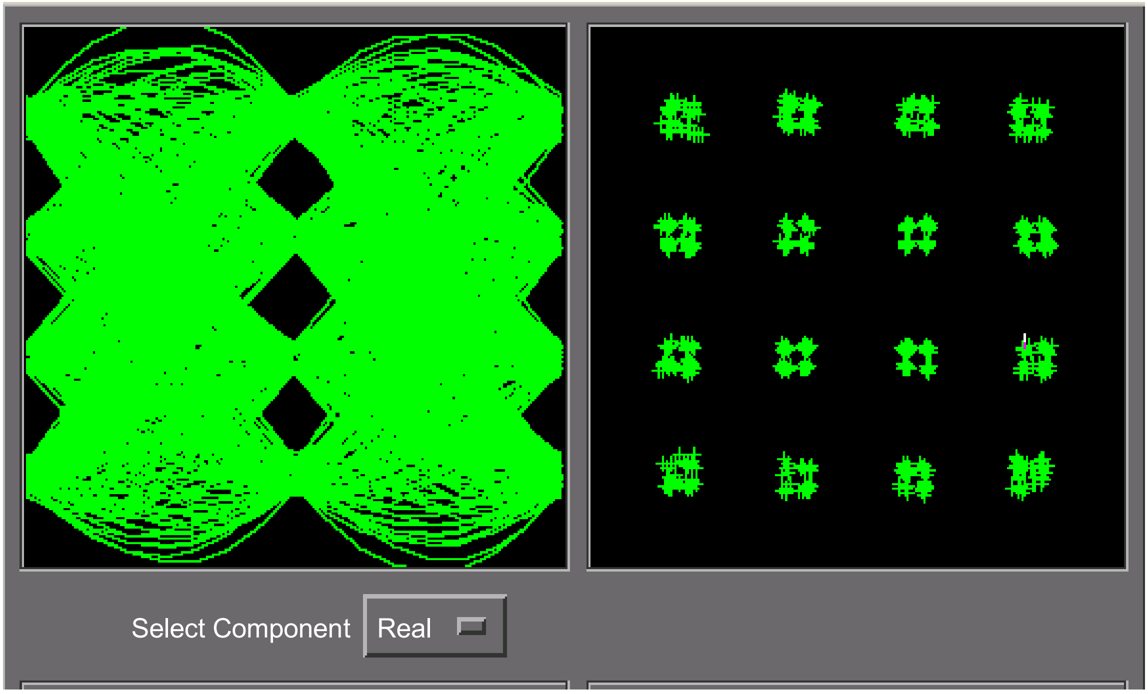

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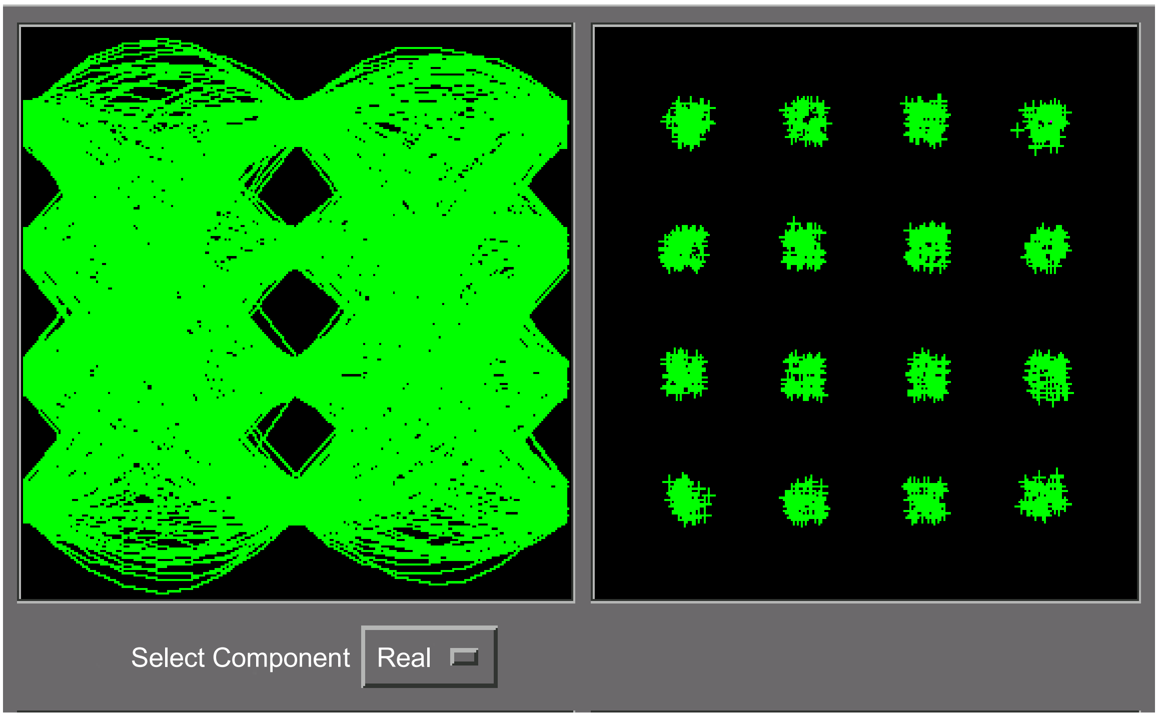
FIGURE 35

Eye and scatter plots for a wanted fixed link of 16-QAM-modulation format with 16-QAM interference at a *S*/*N* of 22.5 dB



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5 Summary and conclusions

The objective of the study was to simulate the effect on a typical microwave link of unwanted energy consisting of both noise and interference (from other modulation schemes) with their relative signal levels in a defined proportion.

Through analysis assess the potential spectral efficiency and assignment strategies based on interference limited scenarios that are likely to be more efficient.

5.1 Improvement obtained in frequency assignment and planning by interference limited environment relative to noise limited environment

The following results show the improvement obtained by planning interference limited environment where interference is 6 dB above noise for fixed links of 4-PSK, 16-QAM and FSK modulation formats.

5.1.1 Wanted fixed link of 4-PSK modulation format

From Fig. 12, 4-PSK wanted signal with interference signal 6 dB above AWGN at SER of 1×10^{-5}:

Interference signal	Noise limited (dB)	Interference limited (dB)	Improvement (dB)
4-PSK	14.5	11	3.5
16-QAM	14.5	11.6	3
FSK	14.5	11	3.5

5.1.2 Wanted fixed link of 16-QAM modulation format

From Fig. 13, 16-QAM wanted signal with interference signal 6 dB above AWGN at SER of 1×10^{-5}:

Interference signal	Noise limited (dB)	Interference limited (dB)	Improvement (dB)
4-PSK	20.6	17.2	3.4
16-QAM	20.6	17.8	2.8
FSK	20.6	17.6	3

5.1.3 Wanted fixed link of FSK modulation format

From Fig. 14, FSK wanted signal with interference signal 6 dB above AWGN at BER of 1×10^{-5}:

Interference signal	Noise limited (dB)	Interference limited (dB)	Improvement (dB)
8-PSK	12.2	10.2	2
4-PSK	12.2	10.2	2
16-QAM	12.2	11	1.2
FSK	12.2	8	4.2

5.2 The effect on 4-PSK and 16-QAM receiving systems has shown them to be 2.8 to 3.5 dB more tolerant of the total unwanted power entering the demodulator when that power is comprised of unwanted interference from typical modulation schemes at a level 6 dB above AWGN.

5.3 The effect on FSK receiving systems has been shown to be 1.2 to 4.2 dB more tolerant of the total unwanted power entering the demodulator when that power is comprise of unwanted interference from a typical modulation schemes at level 6 dB above AWGN.

5.4 The above leads to the conclusion that planning in an interference limited environment will be approximately 2.8 to 3.5 dB more advantageous than planning on the basis of AWGN only for 4-PSK and 16-QAM receiving systems.

For FSK receiving system, planning in an interference limited environment will be approximately 1.2 to 4.0 dB more advantages than planning on the basis of AWGN.

5.5 The PSK and 16-QAM receiving systems perform well with FSK interference that has a higher value of modulation index (>0.35).

5.6 The FSK receiving system's BER performance degrades with FSK interference, as its modulation index is increased.

5.7 The FSK receiving system with modulation index of 0.5 performs well with interference signals of 4-PSK, 16-QAM and FSK (modulation index 0.35) modulation formats.

5.8 The effect of a 3 dB relaxation in the ratio of wanted signal to interference signal is to allow closer physical packing of fixed link assignments. Assuming average terrain and path loss distance term of 35 log (distance), then a 3 dB relaxation corresponds to a reduction in distance to the nearest unwanted co-channel transmitter by a factor of 1.218. Assuming further a homogeneous large-scale environment, this equates to an increase in packing density almost 50%. This increase is in addition to the 130% improvement [CISPR, 1993] obtainable simply by changing to interference limited planning but continuing to assume that the total unwanted energy is still Gaussian in nature.

PART B

Measurements

1 Introduction

This Part B considers the situation where a digital fixed link receives interference which is impulsive (both broadband and narrow-band) in nature rather than the classic case of AWGN and an unmodulated sinewave.

For the measurement of interference with respect to its effect on digital communication systems, we have to acquire some knowledge on the interference effect. The effect on communication services will depend on the type of interference, e.g. broadband or narrow-band, pulse rate etc. The present Part starts by explaining the classical concept of pulse weighting to analogue radio systems, introduces a concept for weighting of interference to digital communication systems and gives experimental results of weighting curves.

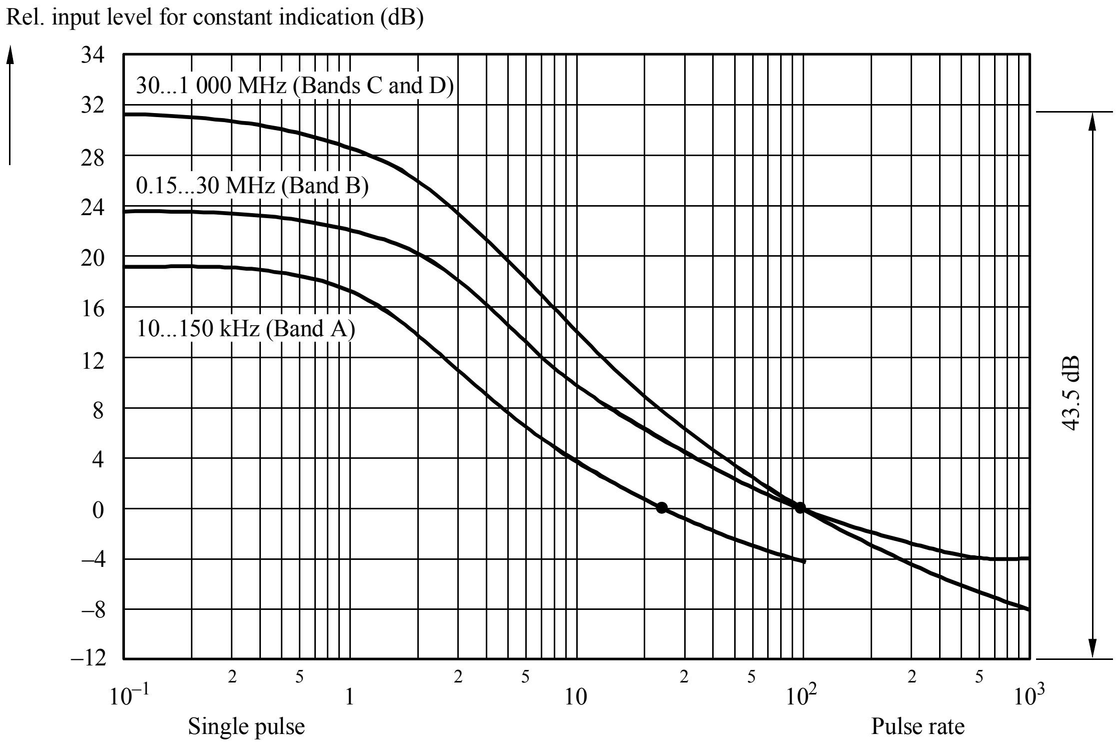
2 An introduction to available detectors

2.1 Characteristics of the International Special Committee on Radio Interference (CISPR) quasi-peak (QP) detector

The definition of the QP detector is based on the application of the laws of psycho-physics (psycho-acoustics for sound radio and psycho-optics for TV). Especially it is necessary to weight impulsive noise from e.g. electric motors and spark-ignited engines. The interference effect at a high pulse repetition frequency is stronger than at a low pulse repetition frequency. This results in the weighting curves of Fig. 36.

FIGURE 36

Weighting curves of the QP measuring receivers for the different frequency ranges as defined in CISPR 16-1



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It should be added that the effect of narrow-band interference is typically 10 dB higher compared to that of impulsive interference, which has been taken into account in different limits for narrow-band and broadband disturbances (now limits for the average and the QP detector).

The realization of the QP detector is described in CISPR 16-1. It requires different values for the resolution bandwidth, the charge and discharge times of the detector and the time constant of the indicating meter.

2.2 Characteristics of other detectors

Other detectors are described in CISPR 16-1, the peak, the average and the r.m.s. detector (see Fig. 37).

The peak detector follows the signal at the output of the IF envelope detector and holds the peak value until discharge is forced. The indication is independent of the pulse repetition frequency. By aid of the peak detector, the peak value of a signal can be measured within a given observation time.

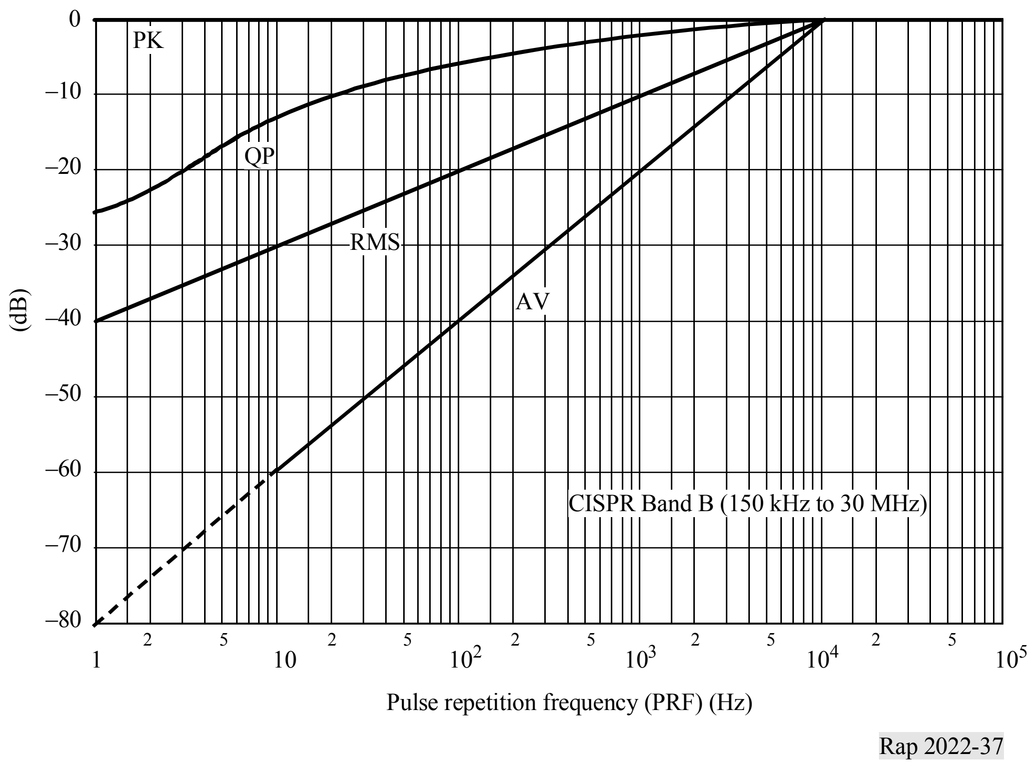
With today's components it is well feasible and has the advantage of short reaction times. This is the reason why it is well accepted for pre-scanning the emissions before the proper weighting detector is applied to critical emissions.

The average detector determines the linear average of the signal at the output of the IF envelope detector. Since 1985 the CISPR specifies emission limits with the average detector in addition to limits with the QP detector for conducted emissions measured with a LISN and an absorbing clamp. Due to the application of emission limits with the average detector, the problematic narrow-band/broadband discrimination procedure has been omitted. An average detector time constant (100 ms) for slow changing emissions is under discussion. This is to prevent short time narrow-band signals from being suppressed by averaging.

The r.m.s. detector determines the r.m.s. of the signal at the output of the IF envelope detector. It is described in CISPR 16-1, but it has no practical use in EMI measurements up to now. The 2nd edition (1972) of CISPR 1 indicates that due to the early work of CISPR the QP detector has been retained, but subsequent experience has shown that an r.m.s. voltmeter might give a more accurate assessment (of the interference effect on analogue radio).

FIGURE 37

Weighting curves of peak (PK), QP, RMS and average (AV) detectors in CISPR Band B



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2.3 Amplitude probability distribution (APD)

For the computation of the interference effect on a radio channel, the APD is a suitable basis. APD [Uchino *et al*., 1997] is however not a weighting detector because it does not give one measurement result per frequency but the probability of occurrence of certain amplitudes as a function of the amplitude. The APD has been proposed for standardization in CISPR recently.

3 Digital communication services

3.1 General

All modern radio services use digital modulation schemes. This is not only true for mobile radio but also for future audio and TV. Procedures for data compression and processing of analogue signals (voice and picture) are used together with data redundancy for error correction. Usually, up to a certain BER, the system can correct errors so that perfect reception occurs.

3.2 System characteristics

Whereas analogue radio systems require S/N of as much as 40 dB for satisfactory operation, in general, digital radio communication systems allow error-free operation down to S/N of e.g. 10 dB. However the transition region from error-free operation to malfunction is small. Therefore planning guidelines for digital radio are based on almost 100% coverage. When the digital radio receiver operates at low input levels, the sensitivity to radio interference is important. In mobile reception, the sensitivity to radio interference is combined with the problem of multi-path propagation.

4 Weighting of disturbance to digital communication systems

The importance of this topic has been recognized by the CISPR and ITU-R. Work in ITU has just begun. There is still work to do: determine the interference effect, find a compromise solution for a weighting detector including measurement bandwidth, define limits, etc.

4.1 Measurement principle

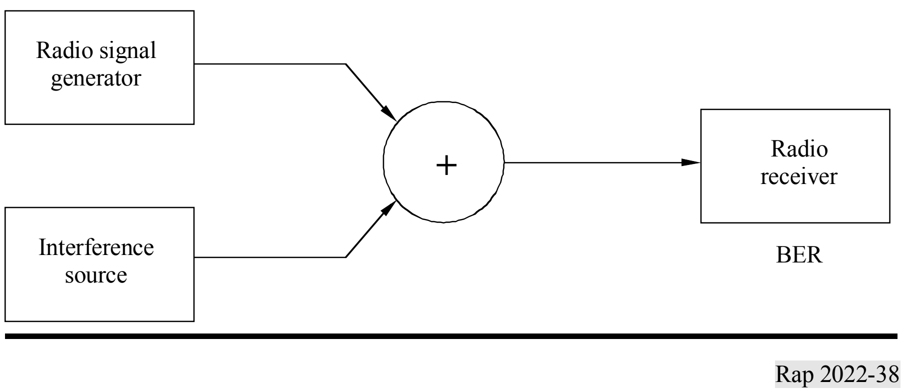
We recall the significance of the weighting curve in Fig. 36: the effect of a 100-Hz pulse on a radio listener is equal to the effect of a 10-Hz pulse, the level of which is increased by an amount of 10 dB. In analogy to the above, an interference source with certain characteristics would produce a certain BER, e.g. 1×10^{-3} when the interfering signal is received in addition to the radio signal. The BER will depend on e.g. the pulse repetition frequency and similar characteristics of the interfering signal. In order to keep the BER constant, the level of the interfering signal will have to be varied. This level variation vs. pulse repetition frequency determines the weighting function.

This can be measured in two steps:

Step 1: Determine the required level of the interfering signal for a constant BER (see Fig. 38).

FIGURE 38

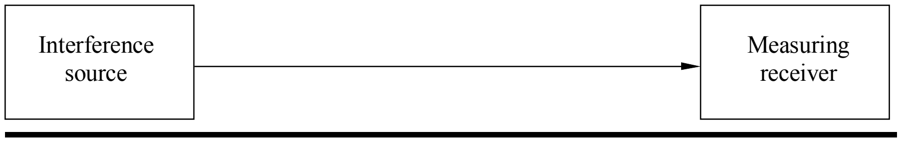
Test set-up for the determination of the interference signal level for a certain BER



Step 2: Measure the level of the interfering signal with a measuring receiver using a specified weighting method (see Fig. 39).

FIGURE 39

Test set-up for the measurement of the interference signal level



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If the level indication of the measuring receiver remains constant for all interference signal levels that produce the constant BER, then we have found the ideal weighting curve.

Different digital communication systems will of course not respond in the same way to different types of interference signals. Therefore a compromise will have to be found for the most important digital communication systems.

4.2 Interference signals

A signal generator with pulse-modulation capability can be used to generate the interference signal. For correct measurements, the pulse modulator requires a high on/off ratio of more than 60 dB. Using the appropriate pulse width, the interference spectrum can be broadband or narrow-band, where the definition of broadband and narrow-band is relative to the communication channel. Figures 40 and 41 give examples of interference spectra used for the determination of weighting functions.

FIGURE 40

Interference signal consisting of a pulse width of 0.1 μs with a pulse repetition frequency of 1 MHz. The signal generator level is 47 dBμV. The spectrum above was measured with a pulse bandwidth of 1 MHz and the peak detector

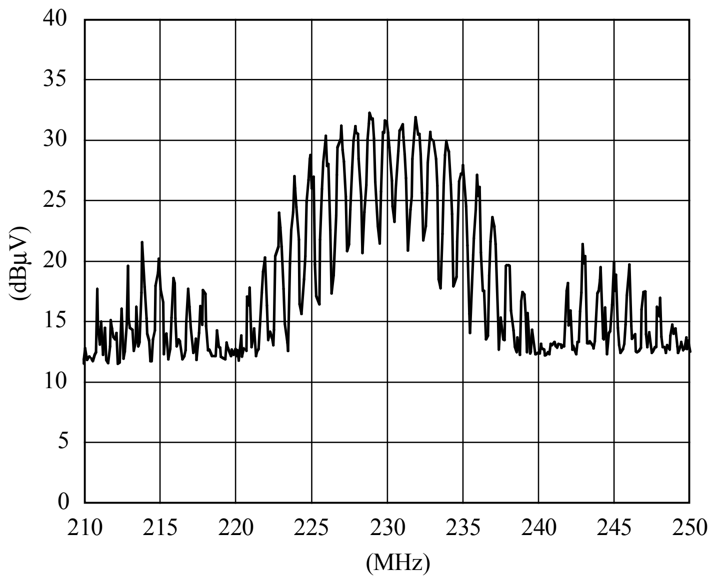

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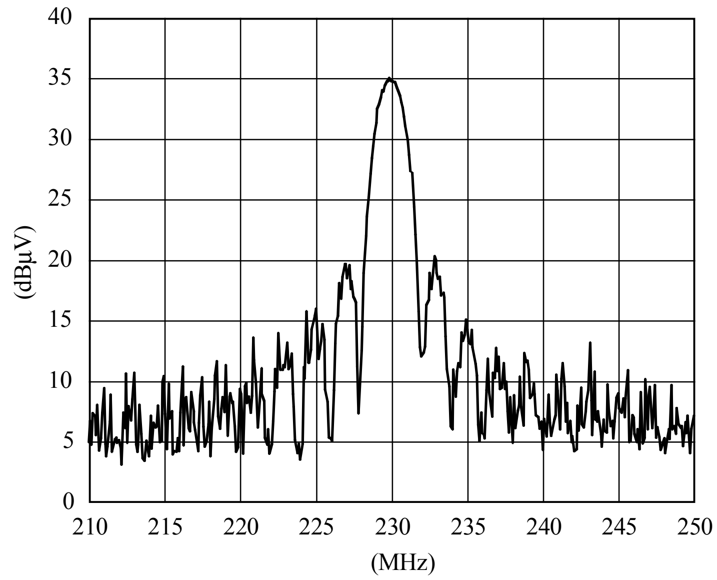
FIGURE 41
Interference signal consisting of a pulse width of 0.5 μs with a pulse repetition frequency of 0.5 MHz. The signal generator level is 37 dBμV. The spectrum above was measured with a pulse bandwidth of 1 MHz and the peak detector



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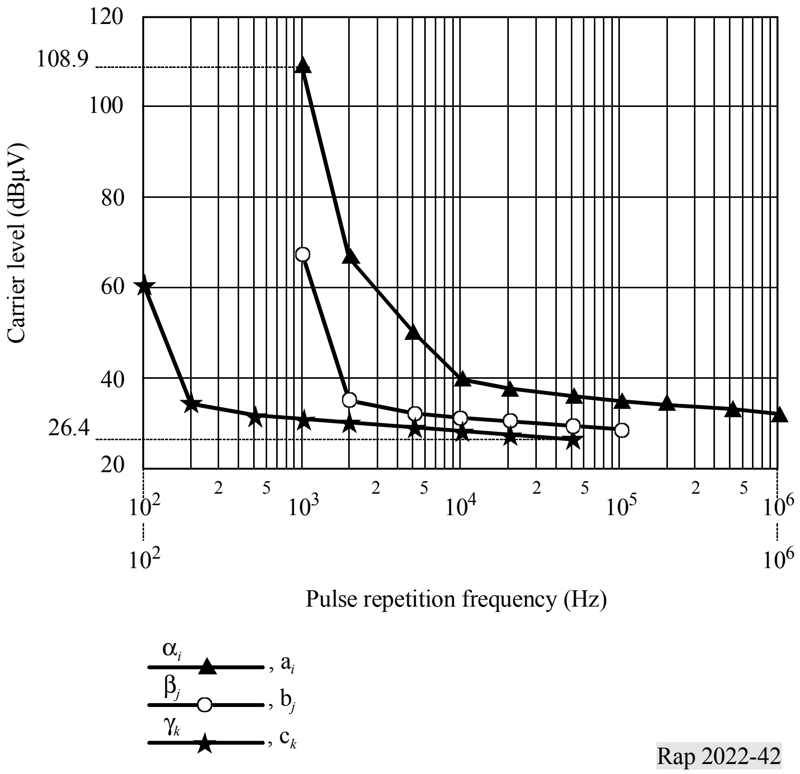
In addition to pulse-modulated signals, AM and unmodulated signals were used to determine the sensitivity of different systems to different types of electromagnetic interference (EMI).

4.3 Experimental example 1: digital video broadcasting (DVB-C)

As a first example, the sensitivity of digital video broadcasting DVB-C to EMI has been determined. The cable version of DVB consists of a 64-QAM signal with a symbol rate of 6.9 Msymbols/s. The signal spectrum comprises a bandwidth of 7 MHz. The transmit signal level is set so that the BER is below 1×10^{-8} (interference signal switched off). This requires a signal level of 6 dB above the signal level for the critical BER of 2×10^{-4}. After the transmit signal has been set, the interference signal is added and for each pulse modulation setting of the interference signal generator its level is adjusted so, that the critical BER is reached. The resulting weighting curves are shown in Fig. 42.

FIGURE 42

Weighting curves for pulse modulated interference to DVB-C. Traces are specific for certain pulse widths: ▲ for 0.1 μs (i.e. broadband), ○ for 1 μs and ★ for 10 μs pulse width. An unmodulated sine wave of 23.8 dBμV also causes the critical BER



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4.4 Experimental example 2: digital audio broadcasting (DAB)

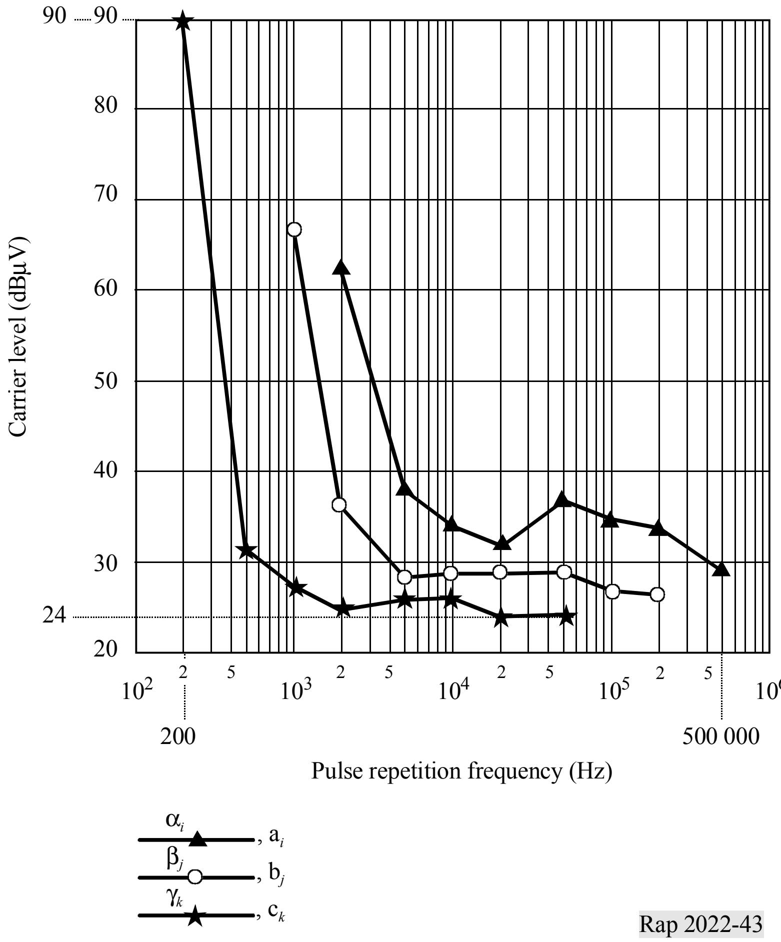
As a second example, the sensitivity of DAB to EMI has been determined. DAB consists of a coded orthogonal frequency division multiplex signal (COFDM). The signal spectrum comprises a bandwidth of 1.5 MHz. The transmit signal level is set so that the BER is very well below 1×10^{-6} (interference signal switched off). This requires a signal level of a few dB above the signal level for the critical BER of 1×10^{-4}. After the transmit signal has been set, the interference signal is added and for each pulse-modulation setting of the interference signal generator its level is adjusted so, that the critical BER is reached. The resulting weighting curves are shown in Fig. 43.

Figures 42 and 43 show different weighting functions. Whereas all curves in Fig. 42 are continuously rising for decreasing pulse repetition frequencies, Fig. 43 contains one curve where the sensitivity to EMI returns to a lower value for a relatively low frequency. The other curves are relatively flat. Below a certain pulse repetition frequency all curves are rising sharply. This is due to the error-correcting mechanism. Low repetition pulses cannot cause the critical BER.

Also the experiments show that DVB-C is relatively sensitive to unmodulated sine waves, whereas DAB has an intentional insensitivity to unmodulated sine waves.

FIGURE 43

Weighting curves for pulse modulated interference to DAB. Traces are specific for certain pulse widths: ▲ for 0.5 μs (i.e. broadband), ○ for 2 μs and ★ for 10 μs pulse width. An unmodulated sine wave of 29.2 dBμV also causes the critical BER



A similar result as for DAB can be expected for DVB-T, which also uses a COFDM modulation scheme. A DVB-T receiver was however not available for tests.

For a rough comparison with Part A, a cross-section in the figures showing the BER as a function of Part B *S*/*N* can be made. The cross-section would have to be applied at a given BER/*S*/*N* and would then show the weighting of different interference considerations. It should be noted in making the comparisons that Part A was derived from computer simulations and Part B from actual measurements. It is to be expected therefore that there will be residual differences in the two sets of results.

5 Conclusion

As a first step to the weighting of interference to digital modulation services, a concept for the definition of weighting curves has been defined and experimental results for two examples have been given. Further experimental and theoretical investigations on digital mobile radio, etc. will have to be performed in order to have sufficient material for the definition of weighting methods. The development of emission limits will need the concepts of radio planners and statistical considerations on the probability of interference.

References

CISPR [1993] IEC CISPR 16-1/1993-08. Specification of radio disturbance and immunity measuring apparatus and methods. Part 1: Radio disturbance and immunity measuring apparatus. International Special Committee on Radio Interference (CISPR).

UCHINO, M., HAYASHI, Y. SHINOZUKA, T. and SATO, R. [1997] Development of low-cost high-resolution APD measuring equipment. Proc. 1997 Int'l. Symp. EMC, p. 253-256, Beijing, China.

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STENUMGAARD, P. [September 1996] Impact of radiated emission standards on digital radio receiver performance. Proc. EMC'96, p. 445-449, Rome, Italy.

PART C

Simulation method for identification of interference source

1 Introduction

To understand and analyse interference within its unique environment, it can be defined in terms of its amplitude relationship to the amplitude of the carrier signal (carrier-to-interference ratio: C/I). In general, C/I is the minimum ratios of the desired signal levels to the interfering signal levels that are necessary to protect radio systems against interference from other radio systems.

The C/I characteristics of a receiver are typically related to the robustness of the modulation type being employed. The interference source with particular characteristics generates a specified BER by the interference signal added to the carrier signal. From the calculation of the BER performance at a certain C/I the probability density function as a function of E_b/N_0 can be obtained using the statistical calculation. The distribution of this probability density function depends on the interference modulation schemes and then the interference source at a wanted fixed-link receiver of a digital modulation format can be identified using these distribution characteristics.

In this study, the theoretical investigation was carried out using the advanced design system (ADS). In order to understand the effects of interferences with various modulation schemes on the digital communication systems we considered three types of digital fixed link modulation schemes of QPSK, π/4-dual quadrature phase shift keying (π/4-DQPSK) and 16-QAM affected by noise and interference from one source of dissimilar modulation scheme, QPSK, π/4-DQPSK and 16-QAM.

The QPSK modulation scheme is typically used for CDMA such as IMT-2000 and the π/4-DQPSK modulation technique is for TETRA (TErrestrial Trunk RAdio, a system used in Europe). The 16-QAM is usually applied to microwave digital radio, modems, DVB-C or DVB-T.

For the simulation, we assumed that the signal power of interference is higher than that of noise and the frequency of transmitting signal is same as that of receiving signal.

Finally, an identification method of the interference source to the digital communication systems is suggested.

2 Simulation method

Table 3 shows the simulation tasks, which are carried out in this study. Three types of wanted fixed link modulation schemes of QPSK, π/4-DQPSK and 16-QAM are considered.

TABLE 3

Simulation task lists

Task No.	Wanted fixed link modulation scheme of	Noise and unwanted fixed link modulation scheme of
1	QPSK	Noise + QPSK
2	QPSK	Noise + π/4-DQPSK
3	QPSK	Noise + 16-QAM
4	π/4-DQPSK	Noise + QPSK
5	π/4-DQPSK	Noise + π/4-DQPSK
6	π/4-DQPSK	Noise + 16-QAM
7	16-QAM	Noise + QPSK
8	16-QAM	Noise + π/4-DQPSK
9	16-QAM	Noise + 16-QAM

2.1 Simulation set-up

Figure 44 shows the simulation set-up to analyse BER according to the effect of an interference signal of required modulation formats on wanted signal. 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 fix Gaussian noise to give required $C/(N + I)$ at the input of a demodulator.

During each ADS simulation the simulation parameters were set as shown in Table 4.

FIGURE 44

Simulation set-up for wanted fixed links with noise and interference

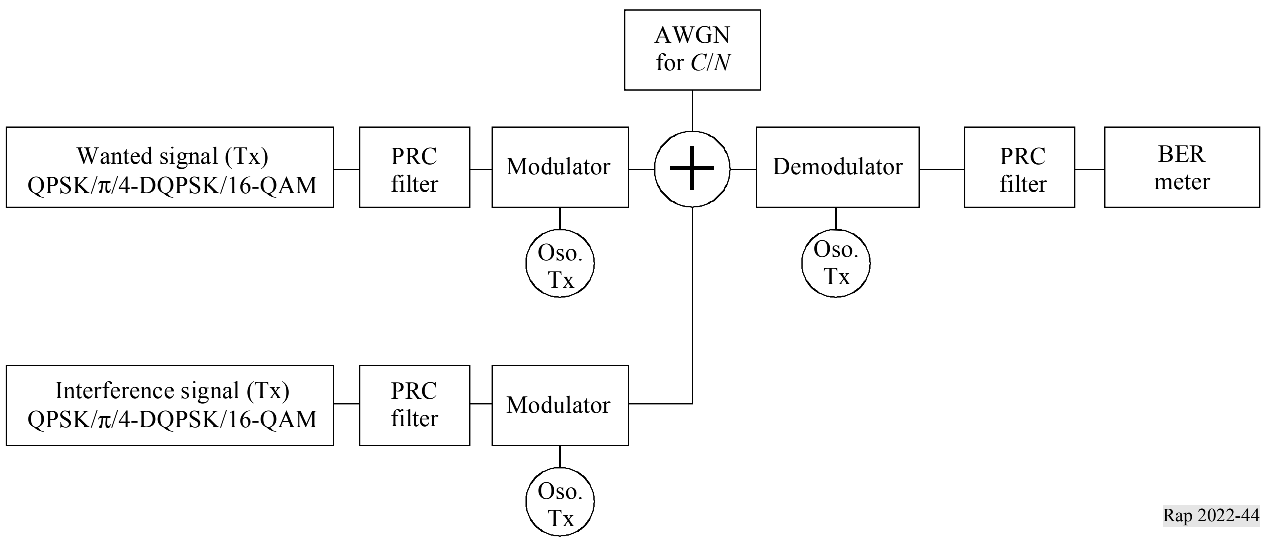


TABLE 4

Simulation parameter

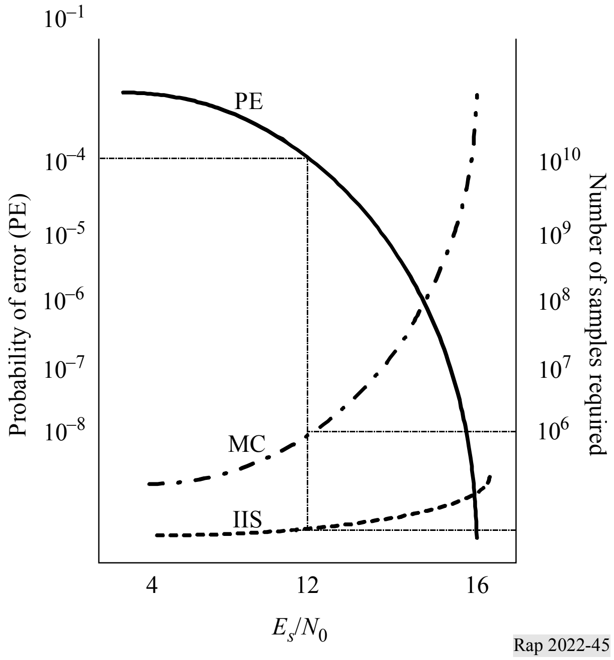
Source bit rate	48.6 kbit/s
RRC filter roll-off factor	0.5
Modulation frequency	2.5 MHz

2.2 BER calculation using improved importance sampling (IIS) method

The traditional method of extracting a numerical estimate of the BER from the simulation is the Monte Carlo (MC) method. The Monte Carlo method has an advantage of high accuracy. However, it needs many sampling numbers and then takes a long time for the simulations. In this study, we used the IIS method. This method can be applied to the amplitude modulation schemes such as QPSK, π/4-DQPSK and QAM. Even though the Monte Carlo method is excellent in accuracy, the IIS method is preferential to use for reducing sampling number and simulation time. For example, the MC method requires the 10^6 sample numbers to represent the probability error of 10^{-4} and the IIS method only the 10^{-3} sample numbers for that (see Fig. 45).

FIGURE 45

Comparison of sample numbers between MC and IIS method



3 Simulation results

3.1 BER performance

For the calculation of BER performance relating to test cases in Table 3, we considered the $C/(N + I)$ values with various power level of each interference modulation scheme and a fixed noise level as shown in Table 5. The BER of 1×10^{-3} was fixed as the required value for receiver. The power level of the wanted fixed link of each modulation format are varied from 10 to 30 dBm while that of interference signal with different modulation schemes are varied from 20 to –40 dBm. The Gaussian noise is set at –60 dBm.

TABLE 5

Power level of wanted signal, interference and noise for the simulations

<table>
<tr><th rowspan="2">C/(N + I) (dB)</th><th colspan="3">Wanted signal level (dBm)</th><th colspan="3">Interference level (dBm)</th><th rowspan="2">Noise level (dBm)</th></tr>
<tr><th>QPSK</th><th>π/4-DQPSK</th><th>16-QAM</th><th>QPSK</th><th>π/4-DQPSK</th><th>16-QAM</th></tr>
<tr><td rowspan="3">10</td><td colspan="3">10</td><td colspan="3">0</td><td rowspan="3">–60</td></tr>
<tr><td colspan="3">20</td><td colspan="3">10</td></tr>
<tr><td colspan="3">30</td><td colspan="3">20</td></tr>
<tr><td rowspan="3">20</td><td colspan="3">10</td><td colspan="3">–10</td><td rowspan="3">–60</td></tr>
<tr><td colspan="3">20</td><td colspan="3">0</td></tr>
<tr><td colspan="3">30</td><td colspan="3">10</td></tr>
<tr><td rowspan="3">30</td><td colspan="3">10</td><td colspan="3">–20</td><td rowspan="3">–60</td></tr>
<tr><td colspan="3">20</td><td colspan="3">–10</td></tr>
<tr><td colspan="3">30</td><td colspan="3">0</td></tr>
<tr><td rowspan="3">40</td><td colspan="3">10</td><td colspan="3">–30</td><td rowspan="3">–60</td></tr>
<tr><td colspan="3">20</td><td colspan="3">–20</td></tr>
<tr><td colspan="3">30</td><td colspan="3">–10</td></tr>
<tr><td rowspan="3">50</td><td colspan="3">10</td><td colspan="3">–40</td><td rowspan="3">–60</td></tr>
<tr><td colspan="3">20</td><td colspan="3">–30</td></tr>
<tr><td colspan="3">30</td><td colspan="3">–20</td></tr>
</table>

Each transmitter and receiver ADS simulations for wanted fixed links of QPSK, π/4-DQPSK and 16-QAM modulation formats are carried out and the BER performance of each wanted fixed link are plotted in Fig. 46, Fig. 47 and Fig. 48 to show the effect on BER of different interference modulation scheme in the wanted fixed-link receiver.

a) *QPSK wanted fixed-link receiver*

FIGURE 46

BER performance of a wanted fixed link receiver of QPSK modulation format interfered by an unwanted fixed link of other modulation format with Gaussian noise

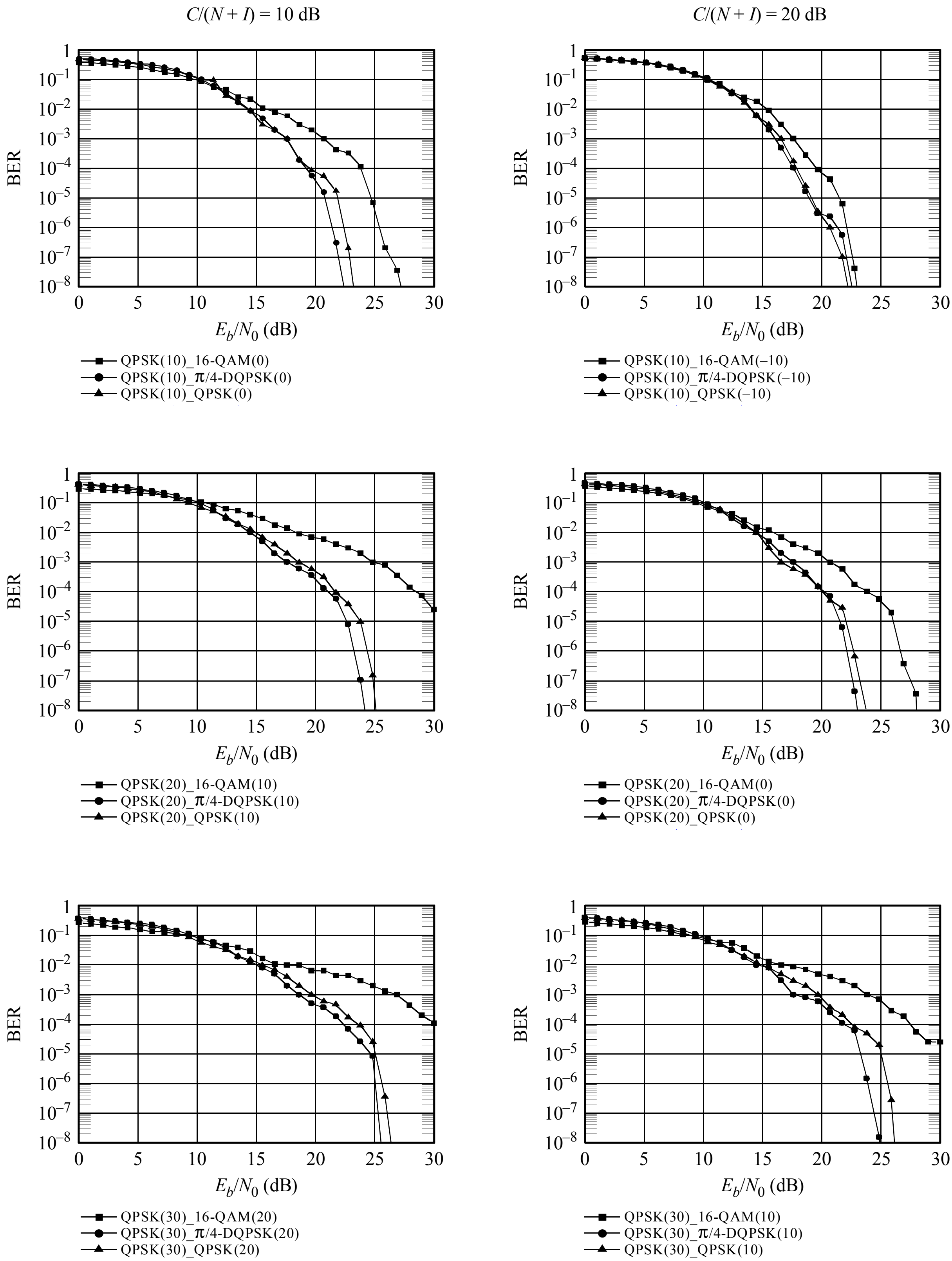


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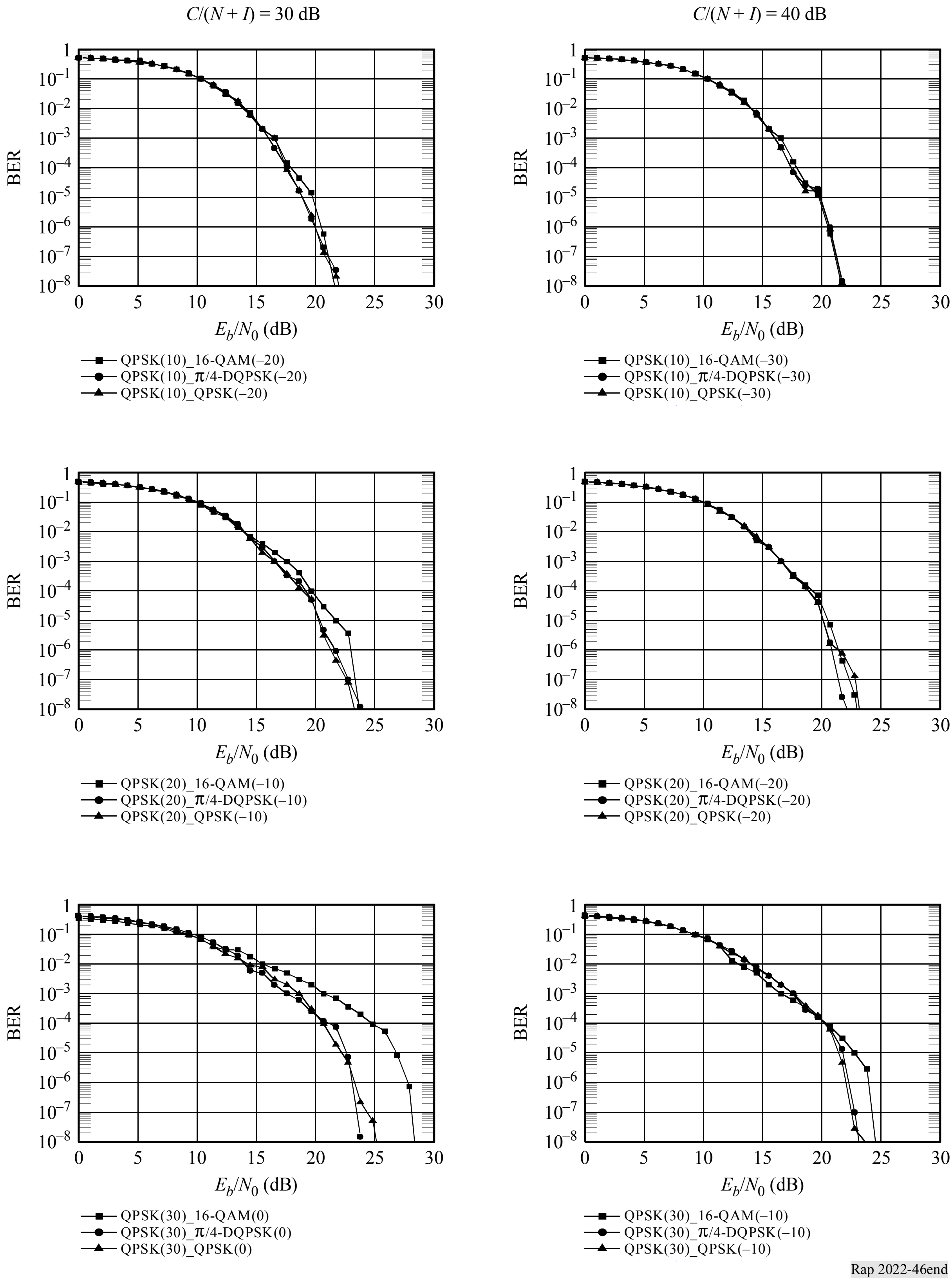
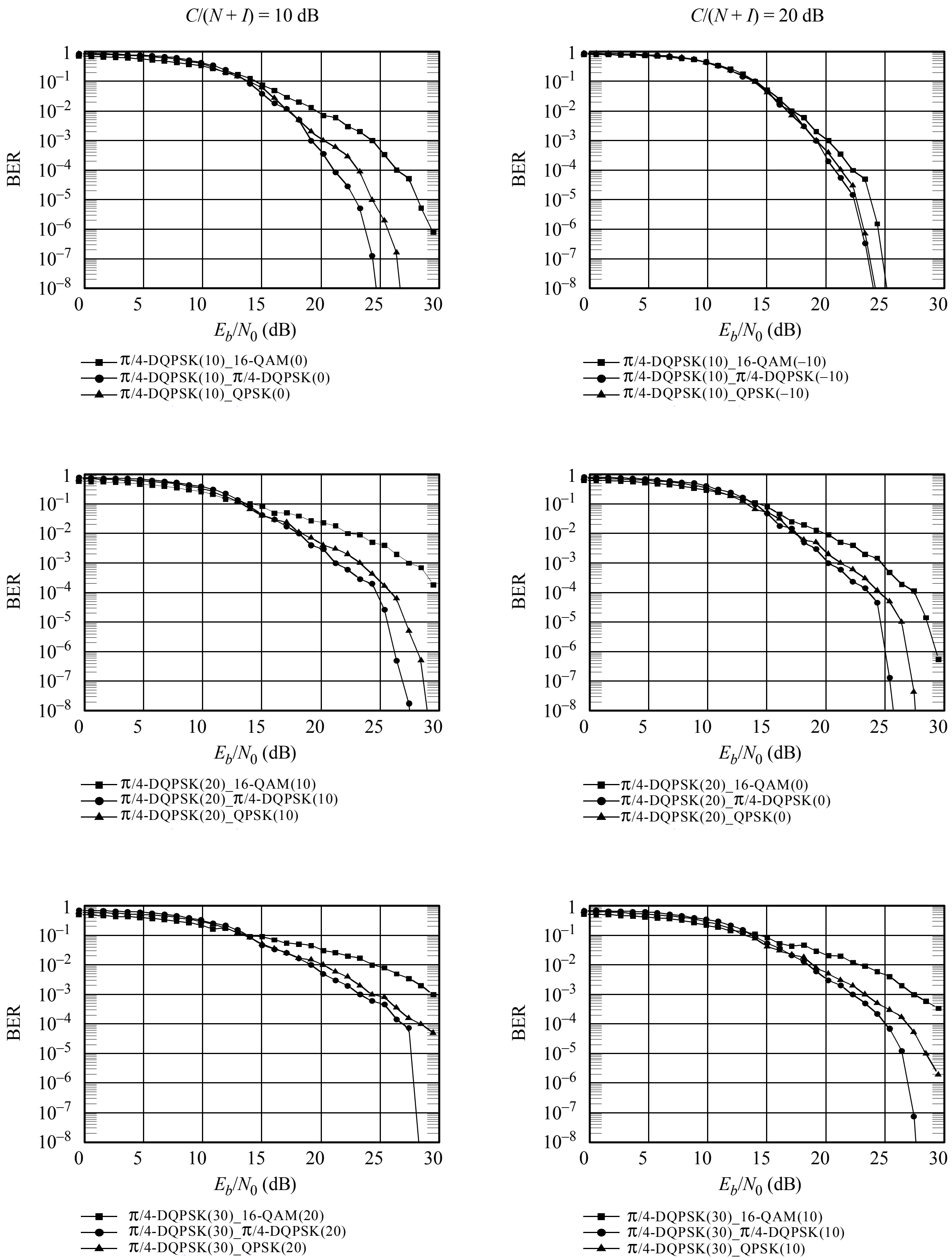
FIGURE 46 (*end*)



b) *π/4-DQPSK wanted fixed-link receiver*

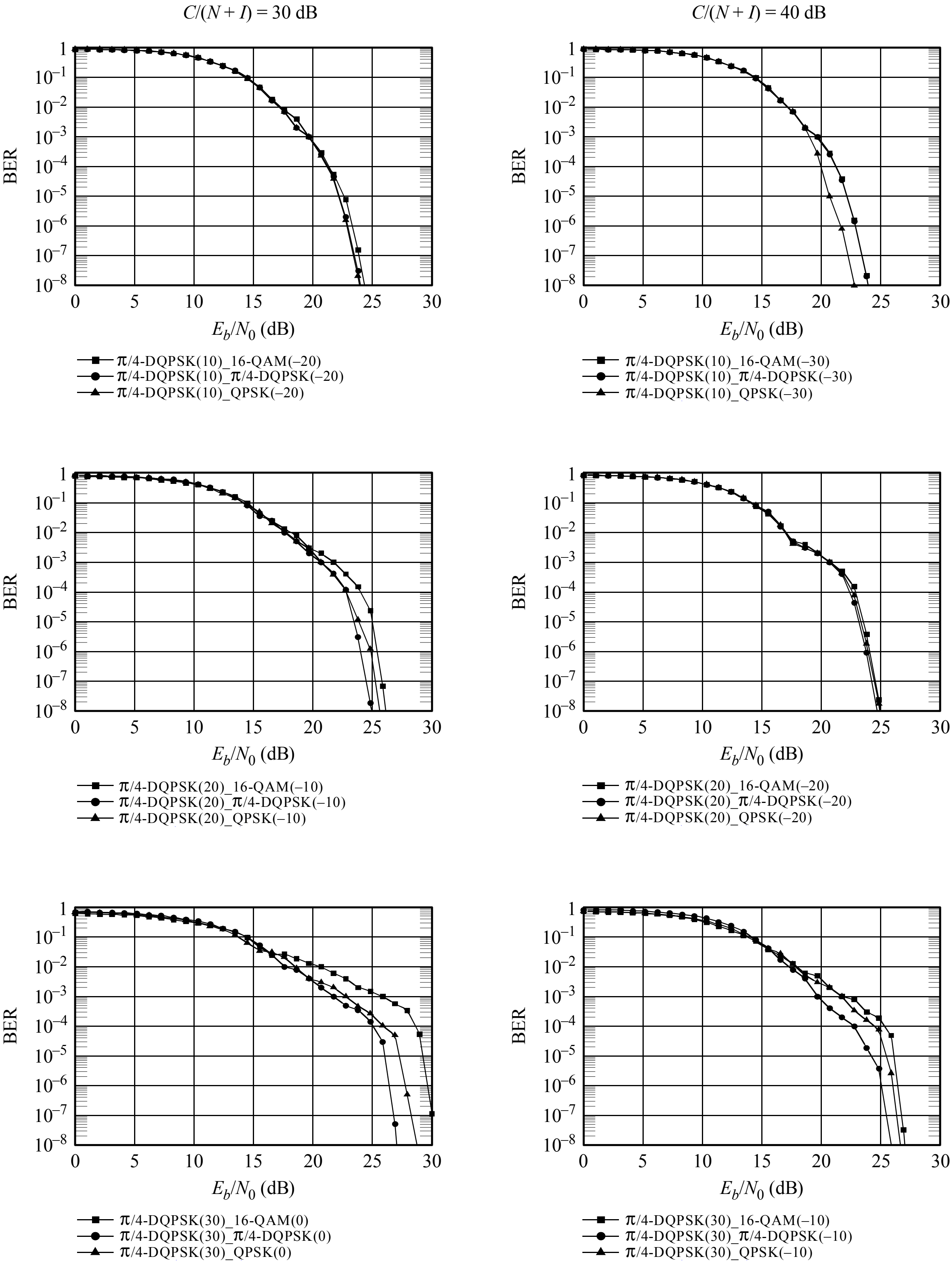
FIGURE 47

BER performance of a wanted fixed link receiver of π/4-DQPSK modulation format interfered by an unwanted fixed link of other modulation format with Gaussian noise



Rap 2022-47

FIGURE 47 (*end*)

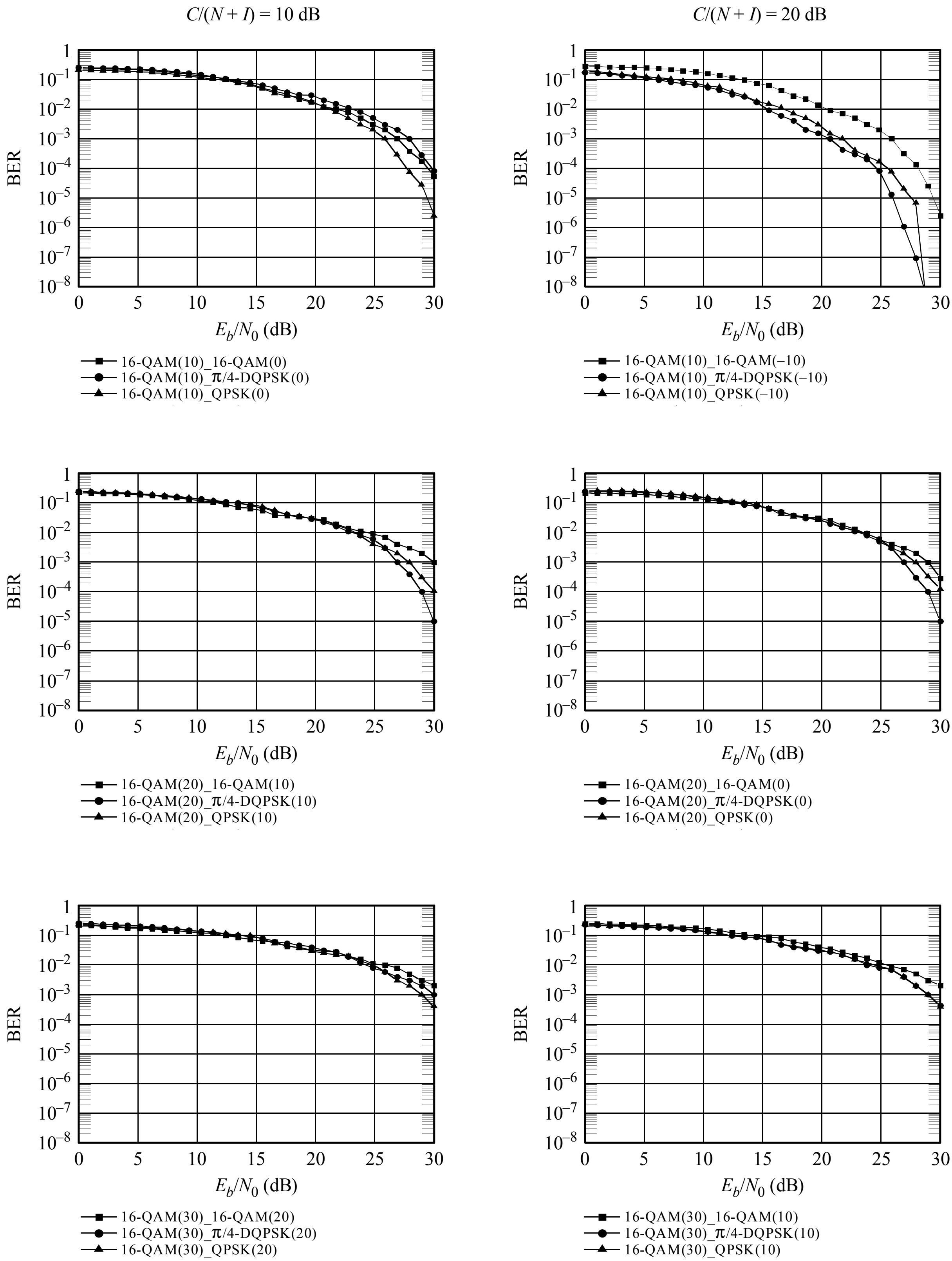


Rap 2022-47end

c) *QAM wanted fixed-link receiver*

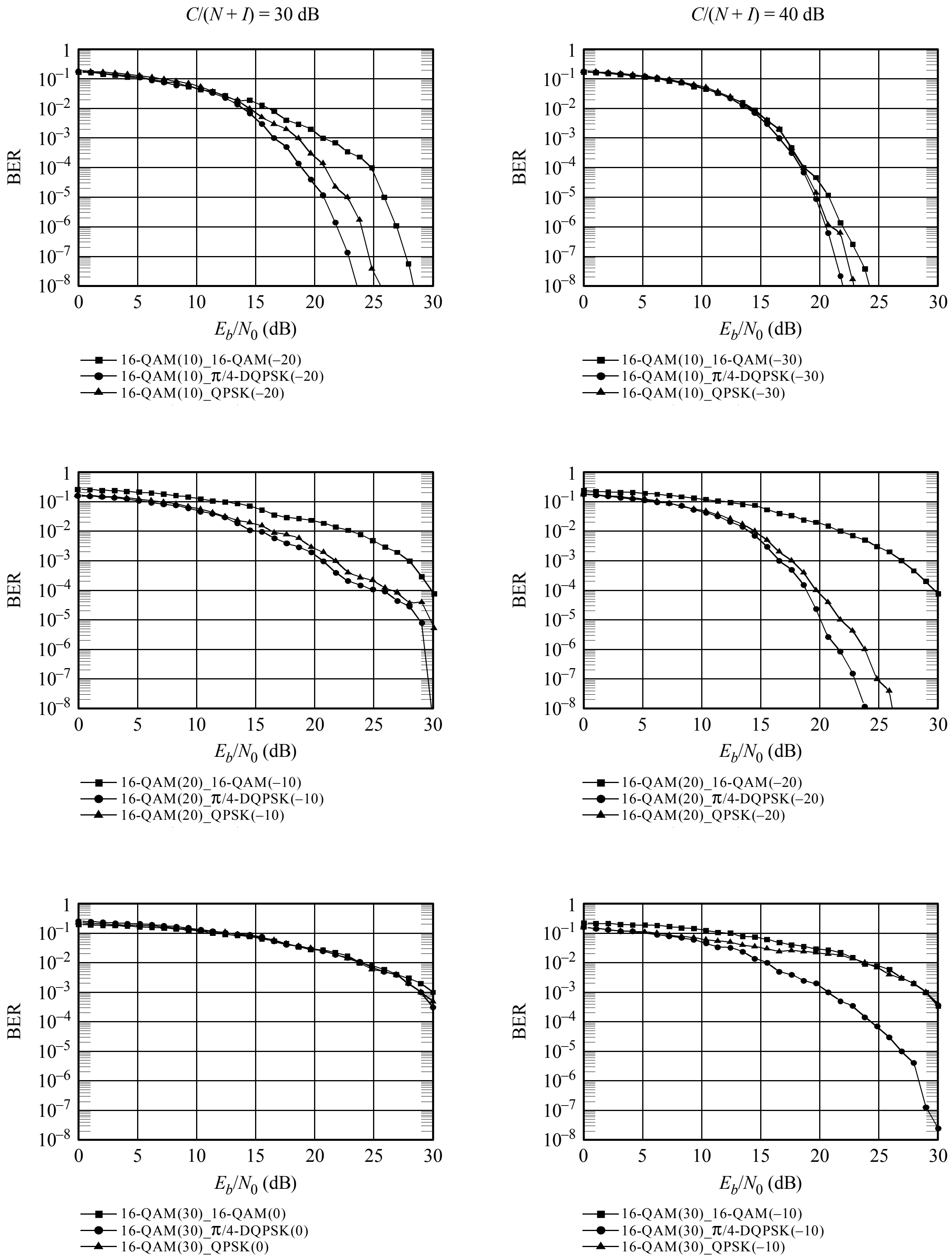
FIGURE 48

BER performance of a wanted fixed link receiver of 16-QAM modulation format interfered by an unwanted fixed link of other modulation format with Gaussian noise



Rap 2022-48

FIGURE 48 (*end*)



Rap 2022-48end

3.2 Probability density of E_b/N_0

From the BER performance results, it is clear that the wanted fixed link affected by an interference modulation scheme has different E_b/N_0 depending on the modulation scheme for a fixed $C/(N+I)$ level at the receiver. The E_b/N_0 is also changed due to the variation of the carrier and interference level at a fixed $C/(N+I)$ value.

From the various wanted signal levels and interference levels for a fixed $C/(N+I)$, the statistical parameters such as average, maximum and minimum values are calculated with deviation between maximum and minimum value for each interference modulation scheme.

Using statistical calculation, probability density function of each interference modulation scheme is plotted as a function of E_b/N_0 for a certain $C/(N+I)$.

Because the interference modulation scheme has own statistical distribution characteristics with a certain average E_b/N_0, the interference modulation scheme can be identified as the interference source if the probability density of E_b/N_0 for each modulation scheme can be clear separately arranged in the plots.

In this study, BER of 1×10^{-3} is set as a limited value for a receiver. If $C/(N+I)$ value is increasing, the wanted signal level is more dominant than the interference signal level and then the E_b/N_0 required at receiver is decreasing. Otherwise, if $C/(N+I)$ value is decreasing, the dominant effect of the wanted signal is reduced and there is a little difference between the E_b/N_0 levels of wanted signal with each modulation schemes.

If the probability density distribution of each interference modulation scheme is located closer to each other and they have overlapping areas, the identification of the interference source is not available.

On the other hand, the interference modulation scheme added into the wanted fixed link can be identified, if the probability density function of each interference modulation scheme is located independently and there are no overlapping areas.

As higher $C/(N+I)$, the wanted signal level is predominant than the interference signal level and the E_b/N_0 required by the receiver is reduced. Therefore, the probability density for each modulation scheme is close to each other and then it is not easy to distinguish the interference modulation scheme affected to the wanted signal.

a) *QPSK wanted fixed-link receiver*

Table 6 shows the statistical calculation of E_b/N_0 for QPSK wanted fixed-link receiver with each interference modulation. In the case of $C/(N+I)$ = 10 dB, the wanted fixed link of π/4-DQPSK format with 16-QAM interference has the highest probability density at E_b/N_0 of 23.1 dB, while that with π/4-DQPSK has the highest probability at E_b/N_0 of 17.93 dB.

Figure 49 shows the plots of probability density of E_b/N_0 for each modulation scheme from $C/(N+I)$ of 10 dB to 40 dB. In the case of $C/(N+I)$ = 10 dB, 16-QAM interference modulation scheme can be distinguished and π/4-DQPSK can distinguish from QPSK due to close to the probability density of E_b/N_0. That means, we can just distinguish the type of interference modulation scheme.

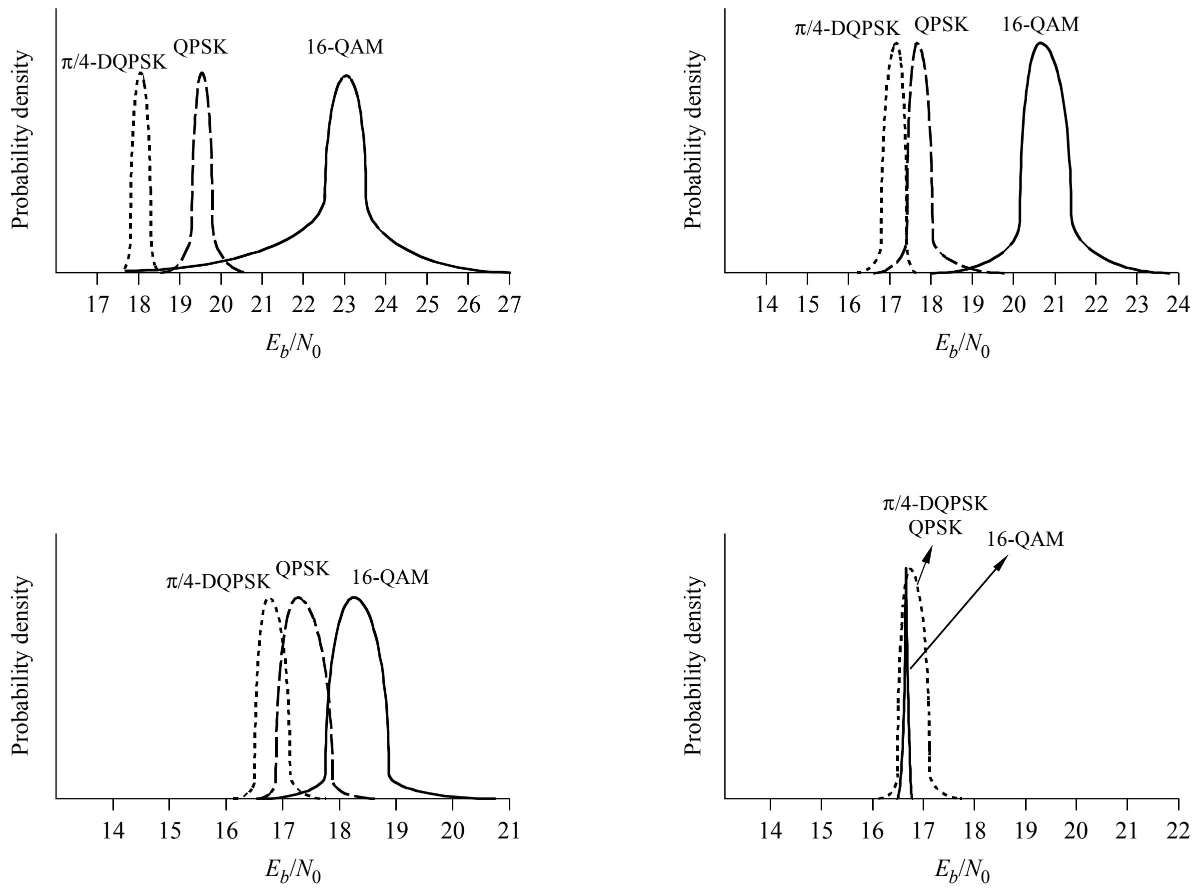
TABLE 6

Statistical calculation of E_b/N_0 for QPSK wanted fixed-link receiver with each interference modulation

$C/(N+I)$ (dB)	Statistical values (dB)	E_b/N_0 for interference modulation scheme		
		QPSK	**π/4-DQPSK**	**16-QAM**
10	Average	19.66	17.93	23.1
	Maximum	20.7	18.6	26.9
	Minimum	18.6	17.6	17.6
	Deviation	2.1	1	9.3
20	Average	17.63	17.13	20.83
	Maximum	19.7	17.6	23.8
	Minimum	16.6	16.2	18
	Deviation	3.1	1.4	5.8
30	Avgerage	17.26	16.8	18.3
	Maximum	18.6	17.6	20.7
	Minimum	16.6	16.2	16.6
	Deviation	2	1.4	4.1
40	Average	16.8	16.8	16.6
	Maximum	17.6	17.6	16.6
	Minimum	16.2	16.2	16.6
	Deviation	1.4	1.4	0
50	Avgerage	16.66	16.8	16.8
	Maximum	17.6	17.6	17.6
	Minimum	16.2	16.2	16.2
	Deviation	1.4	1.4	1.4

FIGURE 49

Probability density of E_b/N_0 for QPSK wanted fixed-link receiver with each interference modulation scheme from $C/(N+I)$ of 10 dB to 40 dB



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b) π/4-*DQPSK wanted fixed-link receiver*

Table 7 shows the statistical calculation of E_b/N_0 for π/4-DQPSK and Fig. 50 shows the plots of probability density of E_b/N_0 for each modulation scheme from $C/(N+I)$ of 10 dB to 40 dB.

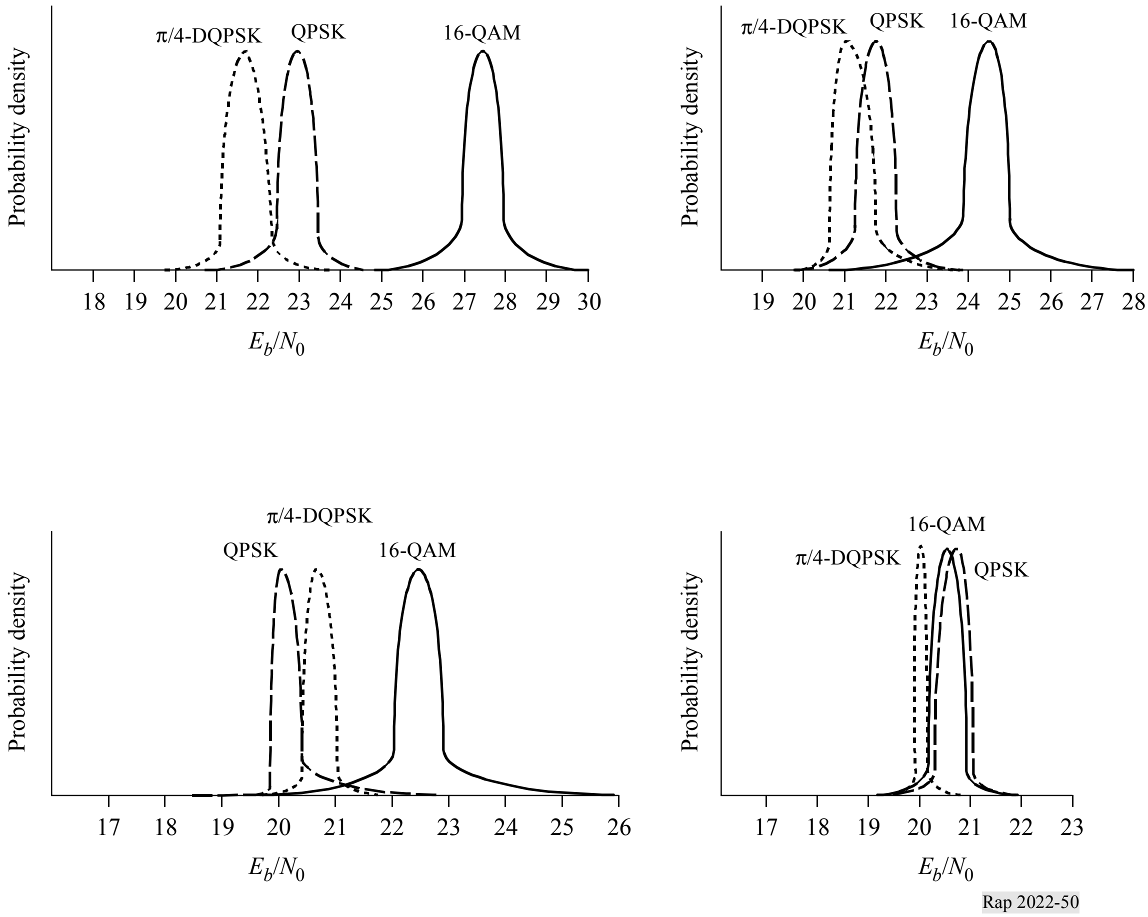
TABLE 7

Statistical calculation of E_b/N_0 for π/4-DQPSK wanted fixed-link receiver with each interference modulation

$C/(N+I)$ (dB)	Statistical values (dB)	E_b/N_0 for interference modulation scheme		
		QPSK	π/4-DQPSK	16-QAM
10	Average	23.1	21.73	27.56
	Maximum	24.8	23.8	30
	Minimum	20.7	19.7	24.8
	Deviation	4.1	4.1	5.2
20	Average	21.73	21.06	24.6
	Maximum	23.8	23.8	27.9
	Minimum	19.7	19.7	20.7
	Deviation	4.1	3.1	7.2
30	Average	20.06	20.7	22.43
	Maximum	22.8	21.7	25.9
	Minimum	19.7	19.7	19.7
	Deviation	3.1	2	6.2
40	Average	20.7	20.03	20.53
	Maximum	21.7	20.7	21.7
	Minimum	19.7	19.7	19.2
	Deviation	2	1	2.5
50	Average	20.53	19.86	20.53
	Maximum	21.7	20.2	21.7
	Minimum	19.2	19.7	19.2
	Deviation	2.5	0.5	2.5

FIGURE 50

Probability density of E_b/N_0 for π/4-DQPSK wanted fixed-link receiver with each interference modulation scheme from $C/(N+I)$ of 10 dB to 40 dB



c) *QAM wanted fixed-link receiver*

Table 8 shows the statistical calculation of E_b/N_0 for 16-QAM and Fig. 51 shows the plots of probability density of E_b/N_0 for each modulation scheme from $C/(N+I)$ of 10 dB to 40 dB.

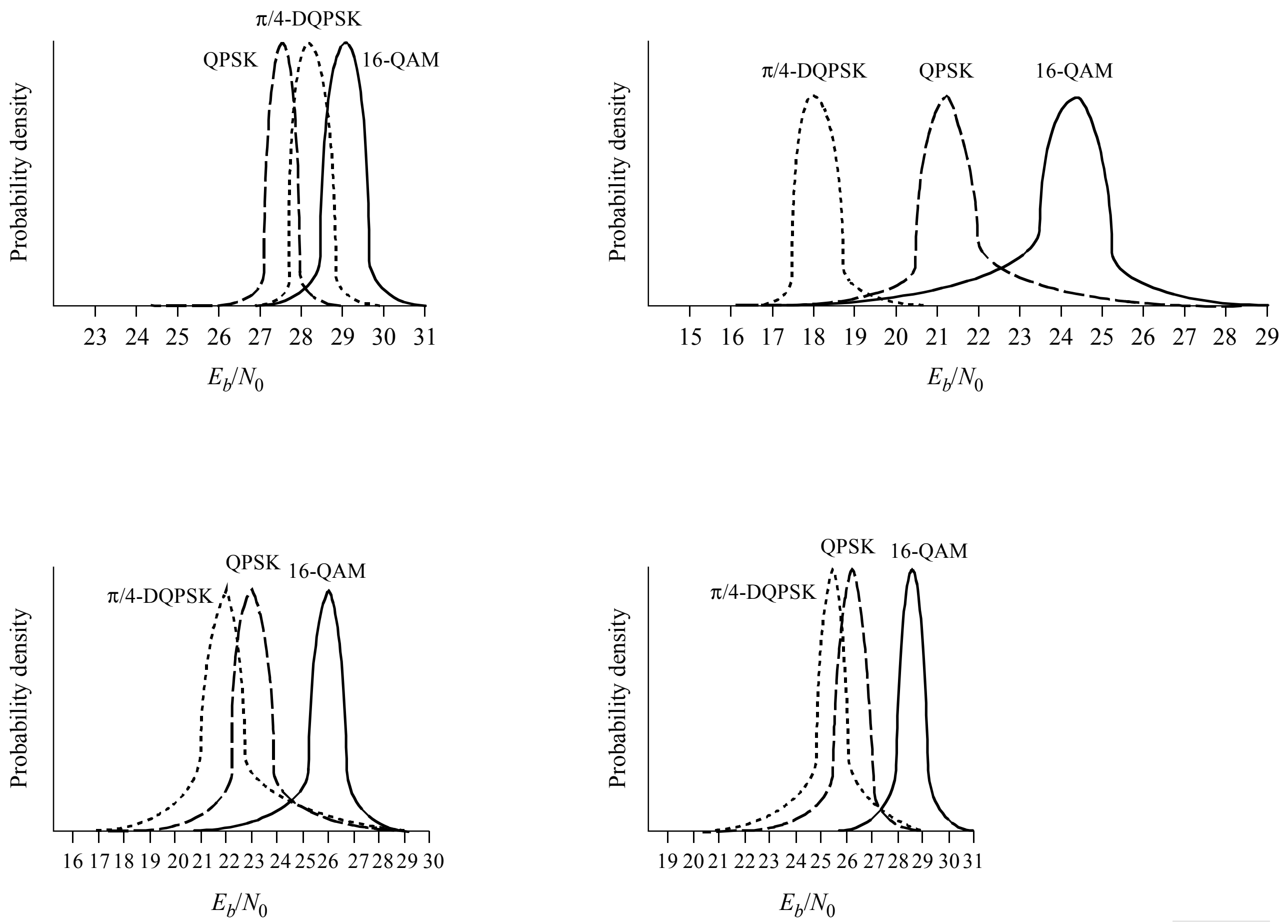
TABLE 8

Statistical calculation of E_b/N_0 for 16-QAM wanted fixed-link receiver with each interference modulation

$C/(N+I)$ (dB)	Statistical values (dB)	E_b/N_0 for interference modulation scheme		
		QPSK	π/4-DQPSK	16-QAM
10	Average	27.6	28.26	29.3
	Maximum	29	30	31
	Minimum	25.9	26.9	26.9
	Deviation	3.1	3.1	4.1
20	Average	26.3	25.53	28.63
	Maximum	29	29	31
	Minimum	22	20.07	25.9
	Deviation	7	8.3	5.1
30	Average	23.1	22.1	26.2
	Maximum	29	29	30
	Minimum	18.6	16.6	20.7
	Deviation	10.4	12.4	9.3
40	Average	21.26	17.96	24.36
	Maximum	29	20.7	29
	Minimum	17.2	16.6	17.2
	Deviation	11.8	4.1	11.8
50	Average	17.7	17	18.26
	Maximum	17.8	17.3	21.7
	Minimum	17.6	16.5	16.5
	Deviation	0.2	0.8	5.2

FIGURE 51

Probability density of E_b/N_0 for 16-QAM wanted fixed-link receiver with each interference modulation scheme from $C/(N+I)$ of 10 dB to 40 dB



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4 Conclusions

This modification describes for each transmitter and receiver, ADS simulation for wanted fixed links of QPSK, π/4-DQPSK and 16-QAM modulation formats interfered by unwanted fixed link of QPSK, π/4-DQPSK and 16-QAM modulation formats with noise.

Their BER performances were calculated using the IIS method and their probability density of E_b/N_0 were plotted. Because the probability density of E_b/N_0 for a wanted fixed link with each interference modulation scheme has individual statistical distribution characteristic, it is able to find out which interference modulation scheme affects on the wanted fixed link.

Finally, a procedure is proposed for identification of the interference modulation schemes in the wanted fixed links.

Initialization of interference modulation scheme as reference data:

Step 1: Establish $C/(N+I)$ at the receiver

(The modulation scheme and the signal level of the wanted fixed link should be known.)

Step 2: Calculate BER for the wanted fixed link with each interference modulation scheme

Step 3: Establish the required BER for the receiver and determine the E_b/N_0 for the BER

Step 4: Repeat Step 2 and 3 a couple of times and then calculate the probability density of the E_b/N_0

Step 5: Store the data for each interference modulation scheme as reference data

Prediction of interference modulation scheme:

Step 1: Measure $C/(N+I)$ at the receiver

(The modulation scheme and the signal level of the wanted fixed link should be known.)

Step 2: Calculate BER for the wanted fixed link with interference

Step 3: Obtain the E_b/N_0 for the required BER

Step 4: Repeat Step 2 and 3 a couple of times and then calculate the probability density of the E_b/N_0

Step 5: Compare the probability density with the reference data and estimate the interference modulation scheme as interference source.

Requirements

The carrier level must be reduced to properly identify the interference modulation scheme if the $C/(N+I)$ is high.