Design and Analysis of New Digital Modulation classification method

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Abstract: - In this paper, a new method of digital modulation classification is described. The method was applied to signals with FSK, BPSK, MSK, QAM-16 and QPSK modulations. The spectrogram analysis was used for the modulation type recognition. This classification method was examined on signals corrupted by Gaussian noise, phase noise and on signals after their transmission through multipath Rayleigh fading channel. The Matlab program is used for the analysis.

Key-Words: - Digital modulation, Classification, Spectrogram, Modulation recognition, noise, interference.

1 Introduction

In connection with the requirement for faster and more reliable communication, the digital processing methods and digital communications are mainly used. Together with the rapid growth of cellular technologies, PCS (Personal Communication Services) and WLAN (Wireless Local Area Network) services in the last decade, a number of different wireless communication standards were proposed and employed, and each of them has its own unique modulation type, access technique, etc. To realize a seamless inter-communication between these different systems, a multiband, multimode smart radio system, such as software radio, is becoming the focus of commercial and research interests. The automatic modulation classification technique, which is indispensable for the automatic choice of the appropriate demodulator, plays an important role in such a multimode communication system [1]. Automatic identification of the type of digital modulation has found application in many areas, including electronic warfare, surveillance, and threat analysis [2].

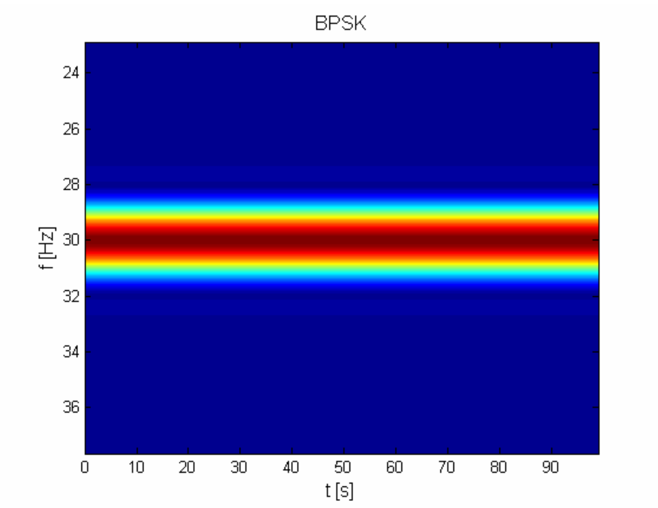
ASK (Amplitude Shift Keying), BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying), FSK (Frequency Shift Keying), QAM (Quadrature Amplitude Modulation), MSK (Minimum Shift Keying) belong to the best-known digital modulations. These modulation types are used in modern radio telecommunication systems (GSM, WiFi, WiMAX, etc.). Therefore these types of modulations were chosen for recognition.

In recent years, various methods of the modulation classification were developed. However, most of them are based on the knowledge of some parameters of the received signal and the other methods are computationally very intensive. This paper describes a new method of modulation classification, which is based on spectrogram analysis. The designed method is examined on signals corrupted by white Gaussian noise, phase noise and on signals after their transmission through multipath Rayleigh fading channel.

2 Obtaining Signal Spectrograms

Spectrograms for long signal intervals were analyzed. Simulations were performed in the Matlab simulation software, where the examined signal was obtained from modulator models. The signals with FSK, MSK, BPSK, QPSK and QAM16 modulation types were submitted to spectral analysis.

It is necessary to take into account some requirements while determining the segment size for spectrum calculation. The first one is the requirement that solely signal elements with the same value in the segment should appear. The simplest solution of this problem is to choose the segment size equal to the signal element size. The second requirement, which must be satisfied, is sufficient discrimination ability along the frequency axis. It is necessary for the discrimination of nearby frequencies that are present in MSK modulation. Then the obtained module and phase spectrograms (Figs. 1, 2) were analyzed by means of the recently proposed analysis.



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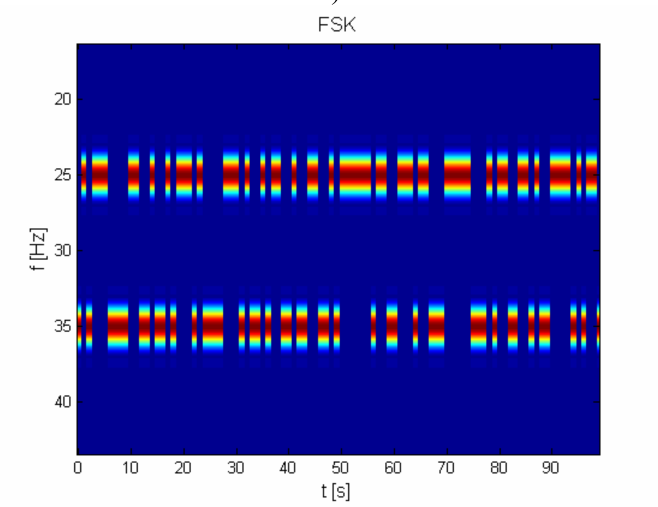

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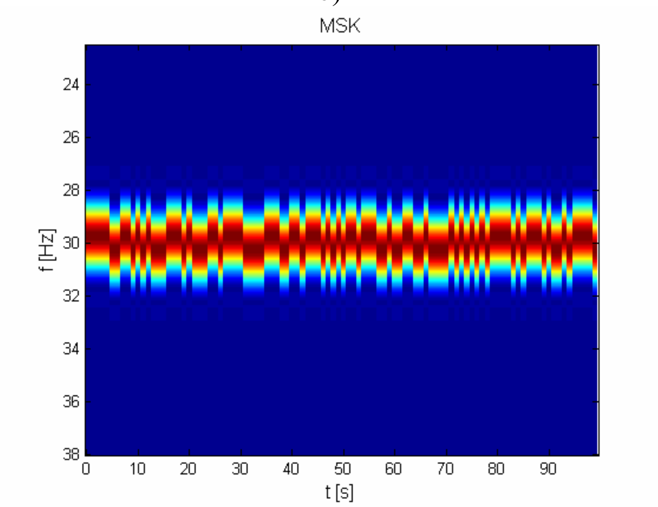

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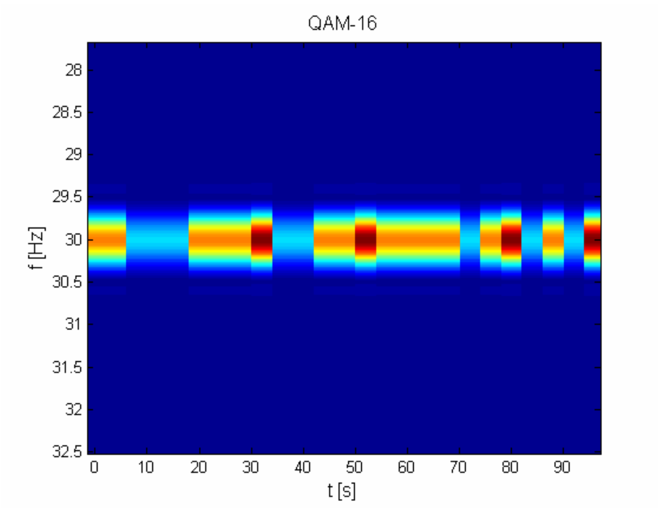

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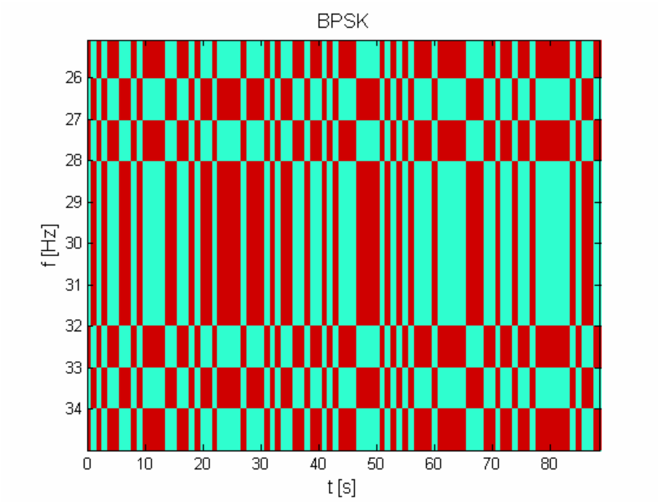
Fig. 1. Module spectrograms for each modulation type

Module spectrograms for BPSK and QPSK modulations are identical.



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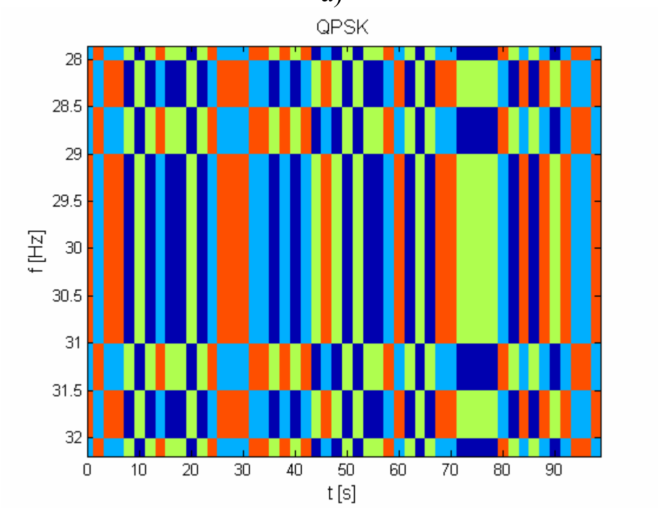

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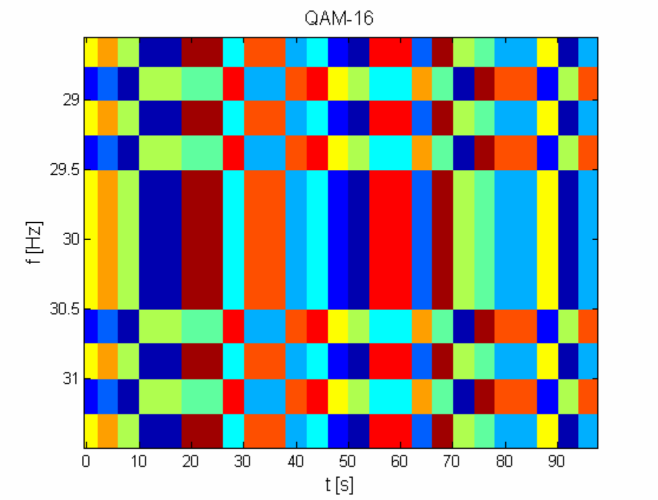

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Fig. 2. Phase spectrograms for each modulation type

3 Analysis of Signal Spectrograms

3.1 Analysis of Module Spectrograms

For the estimation of spectrogram features, it is advantageous to use their histograms. The spectrogram can be presented as a matrix of numbers $A(i, j)$, where i in the range [0, M-1] and j in the range [0, N-1] are indexes of rows or columns of the matrix. For the analysis of module spectrograms it is suitable to count the occurrences of column maximums in particular rows. The analysis results are shown in the following figures.

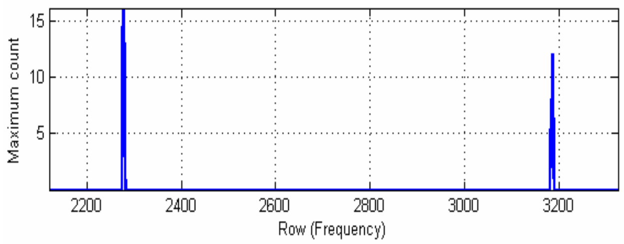


Fig. 3. Occurrence count of maxima in separate rows of FSK spectrogram

The FSK modulation type is easiest for recognition, because two distant carrier frequencies occur in the module spectrogram. Therefore the method of finding the column maximum occurrence in separate rows easily detects two characteristic maxima for this modulation (Fig. 3).

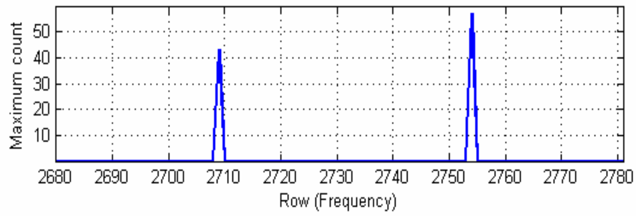


Fig. 4. Occurrence count of maxima in separate rows of MSK spectrogram

Similar to FSK modulation, two carrier frequencies can be found in the module spectrogram of the MSK modulation. It is possible to detect two maxima in the spectrogram by observing the occurrence of column maximum amplitudes on separate frequencies (Fig. 4). However, it is not easy to recognize them, because the distance between each other is just half of the bit rate R/2. Moreover, in the signal with noise, the next maxima often occur and cause wrong detection of MSK modulation.

3.2 Analysis of Phase Spectrograms

The analysis of module spectrograms described in chapter 3.1 can distinguish two different modulations with varying carrier frequency. For the remaining three modulation types (BPSK, QPSK and QAM-16) it is necessary to analyze the phase spectrograms. The graphs of maximum occurrence counts used for module spectrogram analysis do not provide any usable properties.

From the detailed view of phase spectrograms it is apparent that several different values of phases (brightness) occur in the area around the carrier frequency. The number of these values corresponds to the number of phase positions used in the modulation. Thus the analysis must evaluate how many phase values occur at the carrier frequency. If the carrier frequency is not known, it can be easily found from the module spectrogram.

However, there are different noises, inclusive Doppler shift, in a real transmission channel. Therefore, the method of phase analysis was slightly modified. Differences of phase values (not only phase value) were investigated between two successive symbols at carrier frequency. The counts of differences of phase values at the carrier frequency for BPSK, QPSK and QAM16 signals are shown in the following three figures.

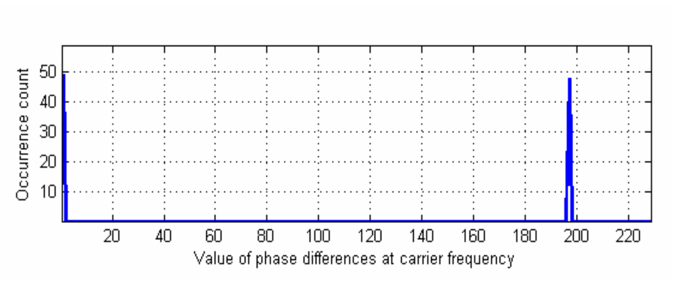


Fig. 5. Occurrence count of phase differences at the carrier frequency for BPSK spectrogram

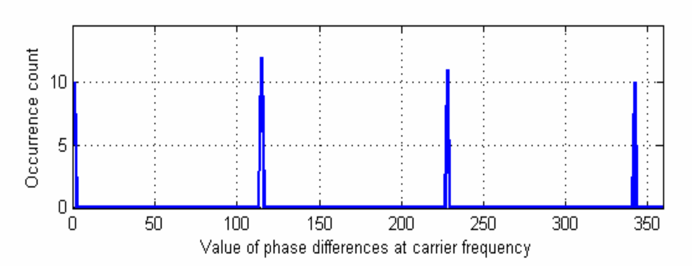


Fig. 6. Occurrence count of phase differences at the carrier frequency for QPSK spectrogram

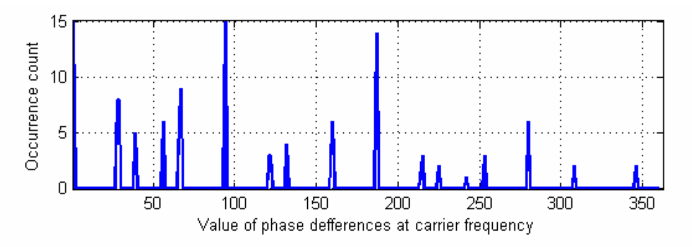


Fig. 7. Occurrence count of phase differences at the carrier frequency for QAM-16 spectrogram

The BPSK signal has two phase states and two differences of phase: changeover from one state to another or when the state does not change (zero difference). In Fig. 5, there are two expressive maxima that correspond with BPSK modulation. The QPSK signal has four phase states and also four changeovers between them that are shown in Fig. 6.

In the QAM-16 modulation, there are twelve phase values and twenty differences of phase values. In Fig. 7, there are only eleven phase differences, because some changeovers did not occur in analyzed signal. Therefore, it is necessary to analyze a longer segment of the signal so that more different symbols and changeovers between them occur. Thus, the classification algorithm determines the QAM-16 modulation, when minimally four and maximally twenty peaks are detected in the graph of occurrence count of phase differences.

The block-scheme of modulation classification algorithm is shown in Fig. 8.

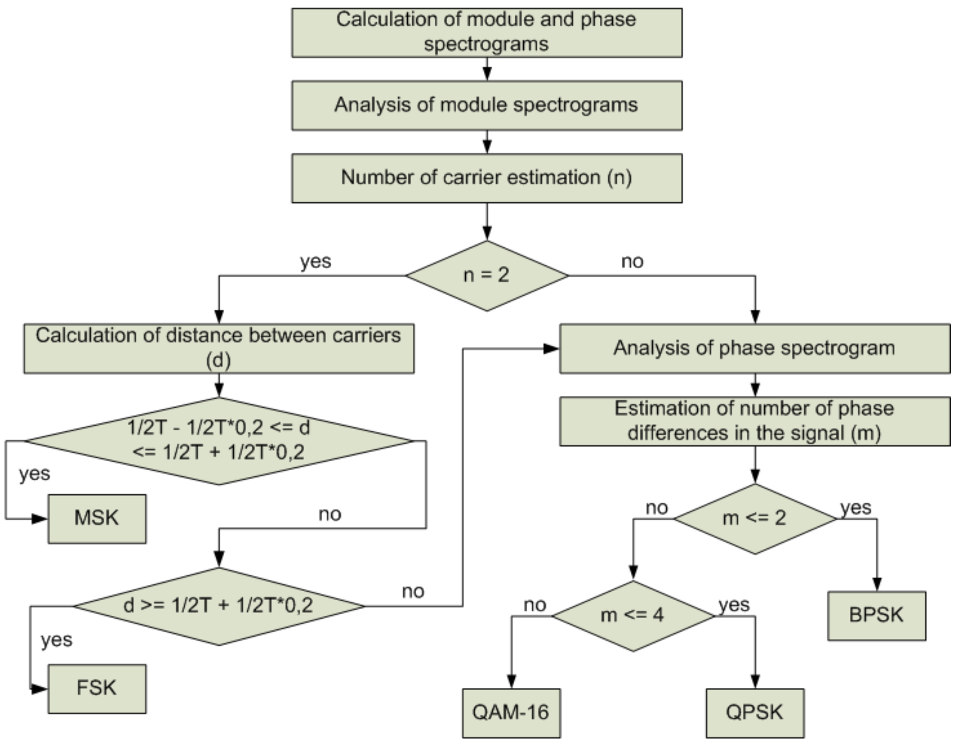
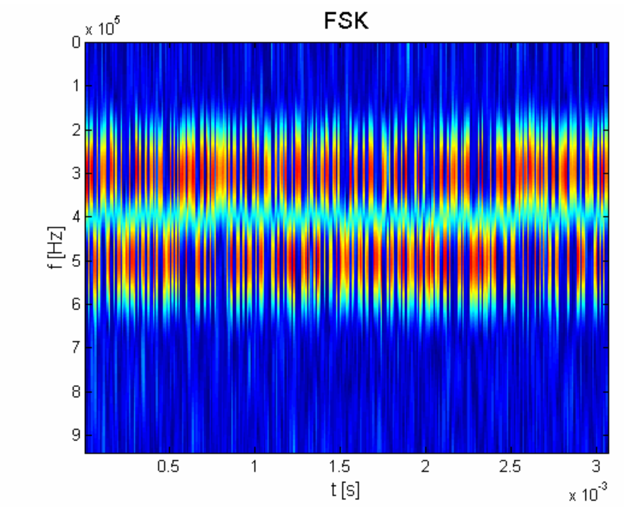


Fig. 8. Block-scheme of modulation classification algorithm

4 Analysis of signals with white Gaussian noise

The module and phase spectrograms of noisy signals were analyzed in the same way. The signal-to-noise ratio (SNR) of 0 dB for BPSK, QPSK, QAM-16, MSK and FSK modulations was used. The spectrograms of each modulation types are shown in following figures.



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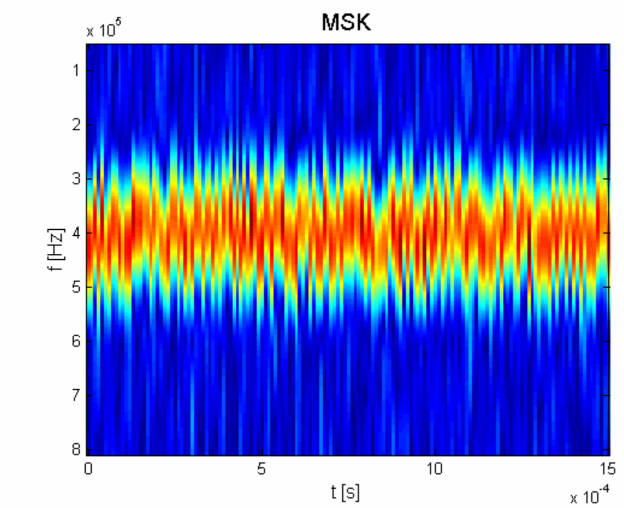

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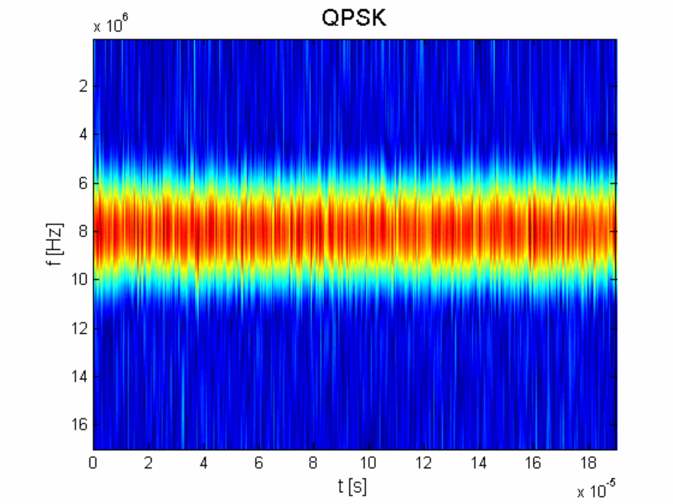

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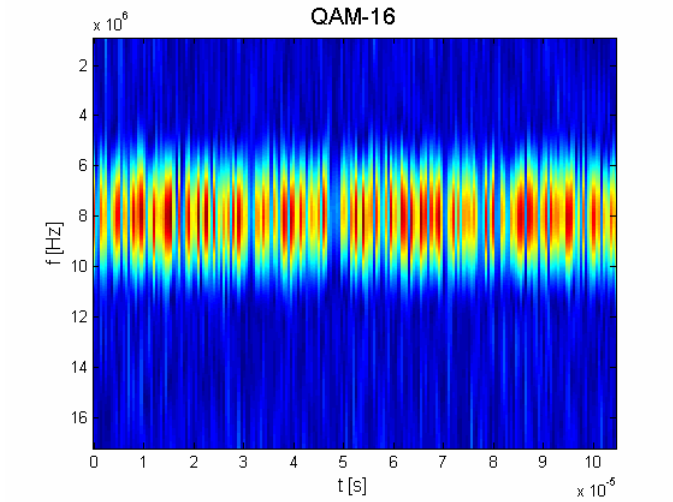

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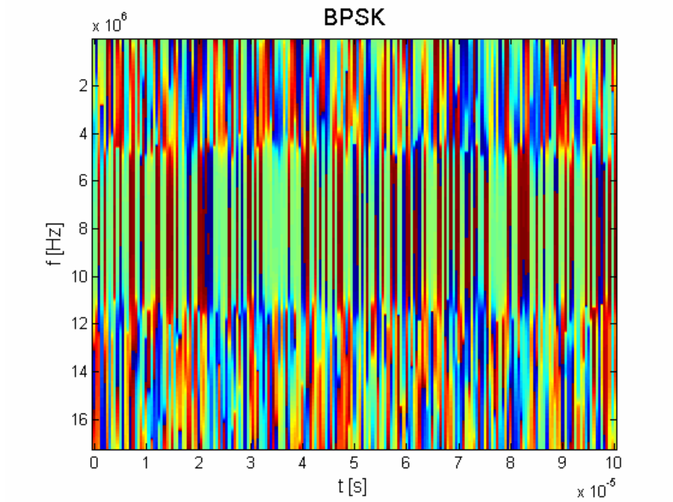
Fig. 9. Module spectrograms for each modulation type with white Gaussian noise



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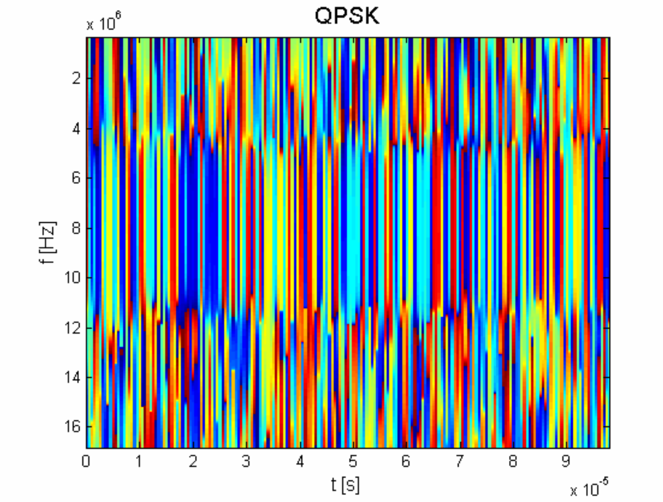

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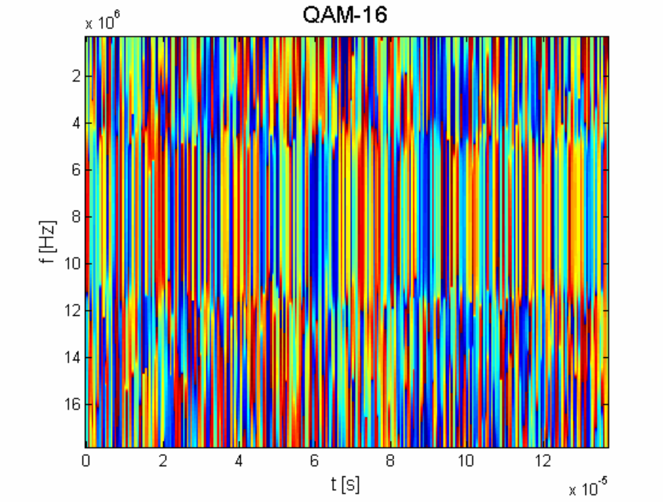

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Fig. 10. Phase spectrograms for each modulation type with white Gaussian noise

The added white noise in all the spectrogram analyses caused smoothing of acute transitions in the resulting graphs (Fig. 11-15), however the observed characteristic properties are still clearly visible in the graphs. The influence of the Gaussian noise is not significant in the analysis of phase spectrograms.

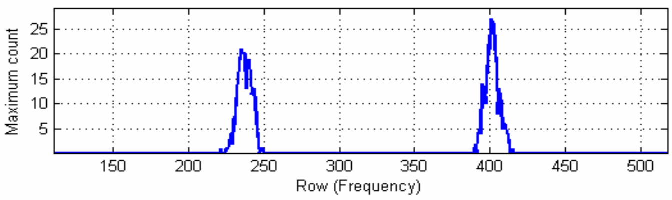


Fig. 11. Occurrence count of maxima in separate rows of FSK spectrogram with white Gaussian noise

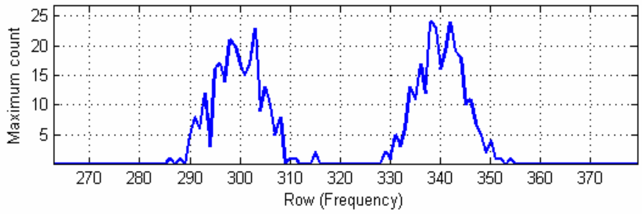


Fig. 12. Occurrence count of maxima in separate rows of MSK spectrogram with white Gaussian noise

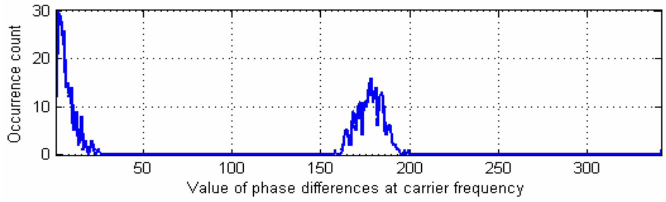


Fig. 13. Occurrence count of phase differences at the carrier frequency for BPSK spectrogram with white Gaussian noise

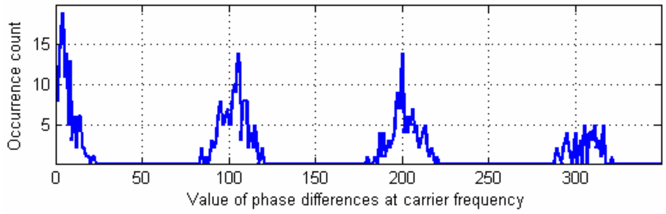


Fig. 14. Occurrence count of phase differences at the carrier frequency for QPSK spectrogram with white Gaussian noise

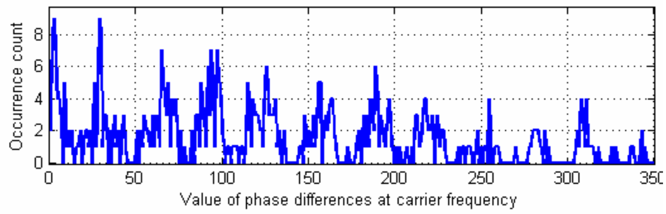


Fig. 15. Occurrence count of phase differences at the carrier frequency for QAM-16 spectrogram with white Gaussian noise

The designed method is able to recognize the modulation type in signals with SNR about 0 dB.

5 Analysis of signals after their transmission through multipath Rayleigh fading channel

A simulation model of transmission channel was created for the examination of the influence of real channel characteristics. The model of transmission channel consists of a phase noise block, a multipath Rayleigh fading channel and white Gaussian noise. Its scheme is shown in Fig. 16.

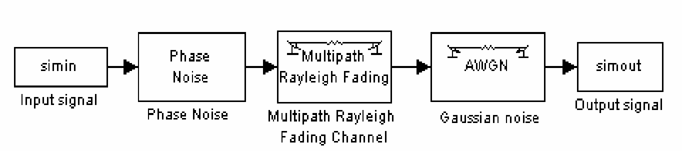
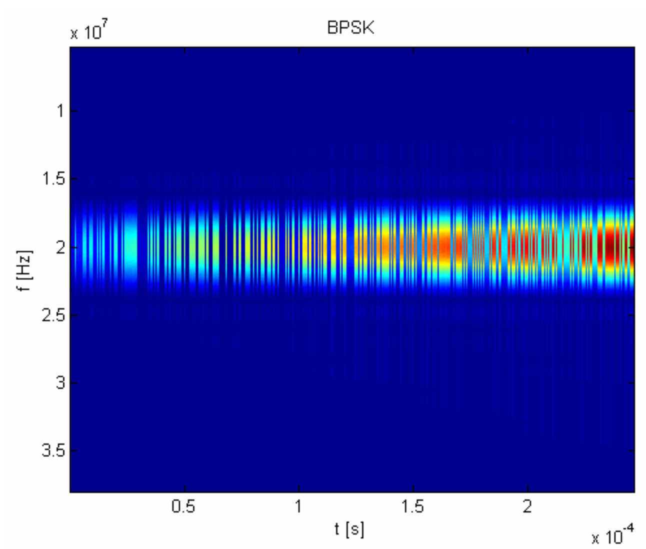


Fig. 16. Transmission channel

The parameters of transmission channel are described below. The value of white Gaussian noise is variable, the value of phase noise is equal to 100 dBc/Hz, the frequency offset is equal to 100 Hz, the maximum Doppler shift is equal to $1/(8T)$ Hz, where T is the simulation time, the delay vector is [0 0.1 0.01] μs and the gain vector is [0 -10 -30] dB.

The spectrograms of each modulation types after transmission through channel with SNR equal to 10 dB are shown in following figures.



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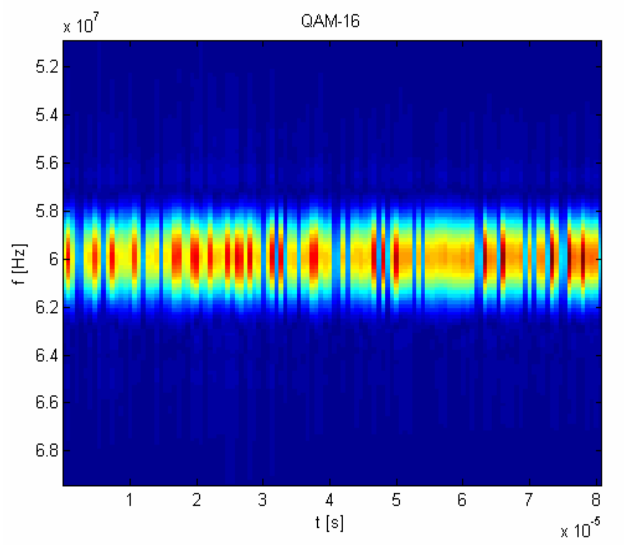

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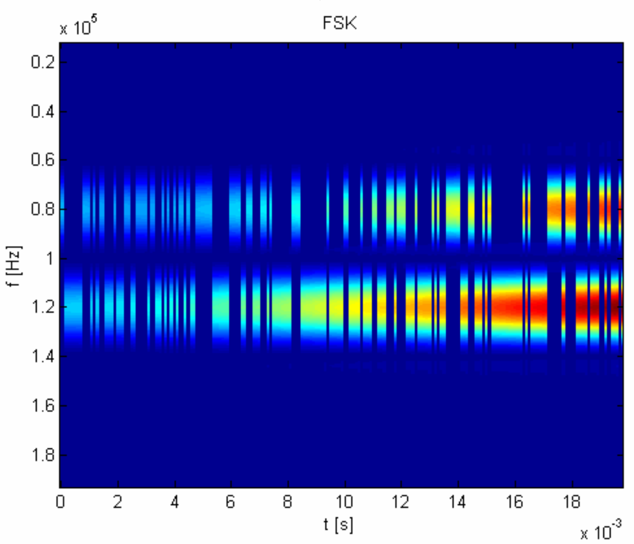

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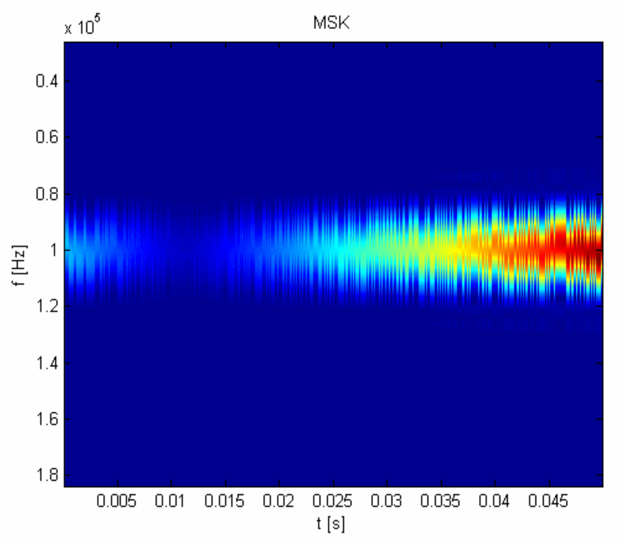

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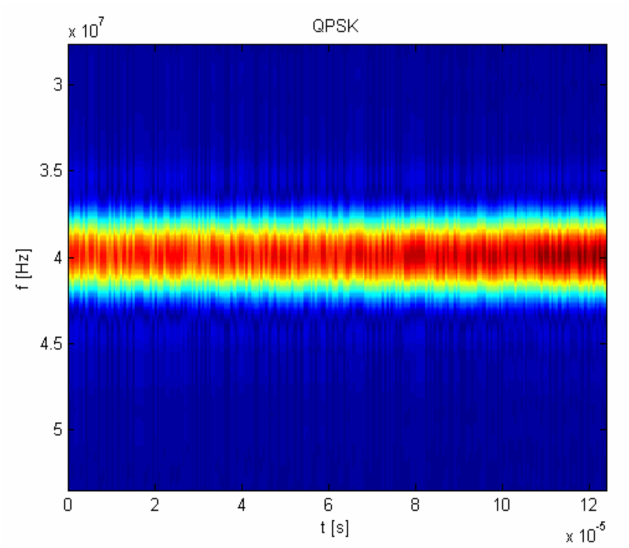

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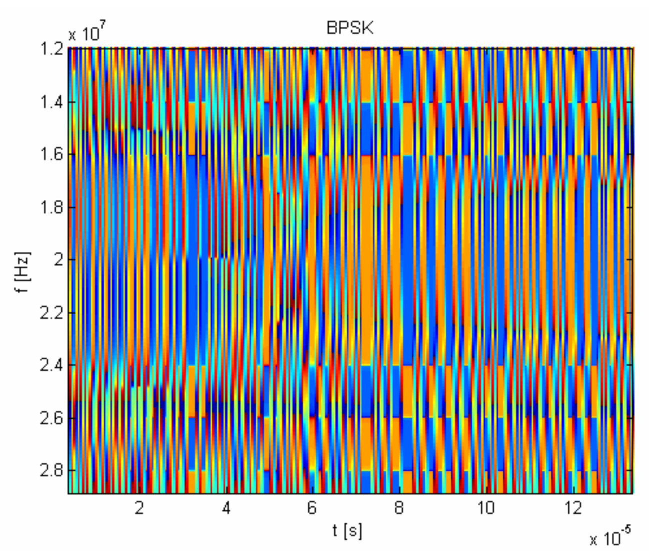
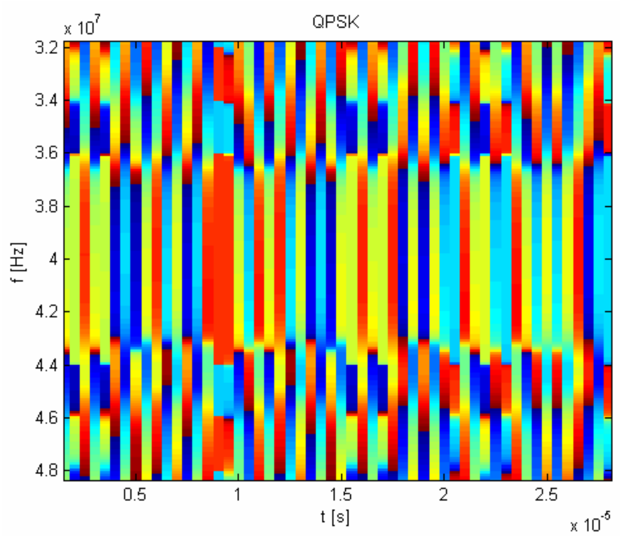
Fig. 17. Module spectrograms for each modulation type after transmission through multipath Rayleigh fading channel





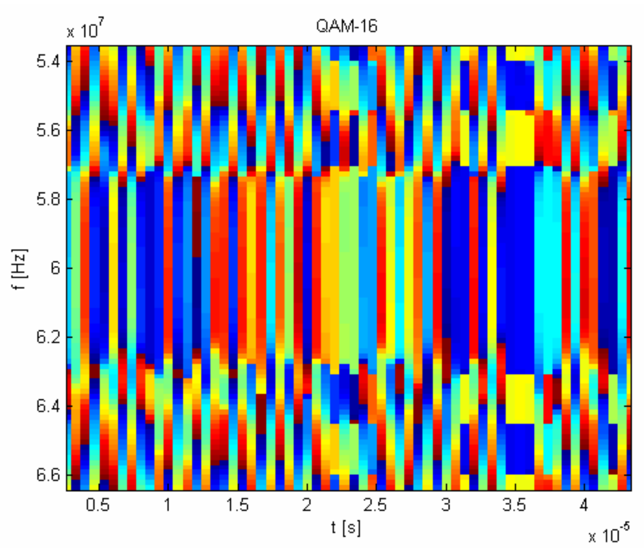


Fig. 18. Phase spectrograms for each modulation type after transmission through multipath Rayleigh fading channel

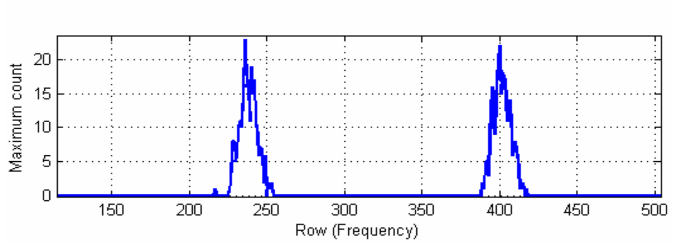


Fig. 19. Occurrence count of maxima in separate rows of FSK spectrogram after transmission through multipath Rayleigh fading channel

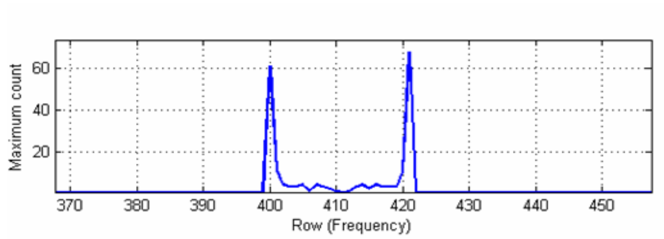


Fig. 20. Occurrence count of maxima in separate rows of MSK spectrogram after transmission through multipath Rayleigh fading channel

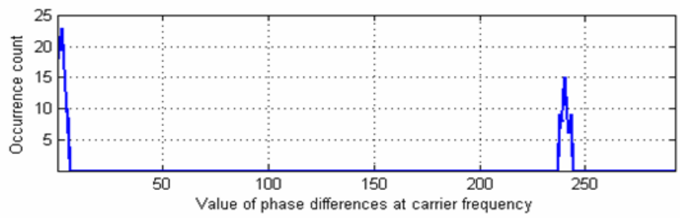


Fig. 21. Occurrence count of phase differences at the carrier frequency for BPSK spectrogram after transmission through multipath Rayleigh fading channel

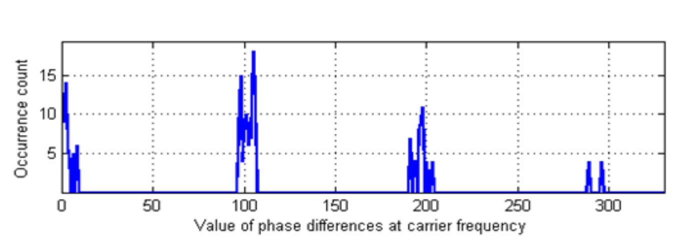


Fig. 22. Occurrence count of phase differences at the carrier frequency for QPSK spectrogram after transmission through multipath Rayleigh fading channel

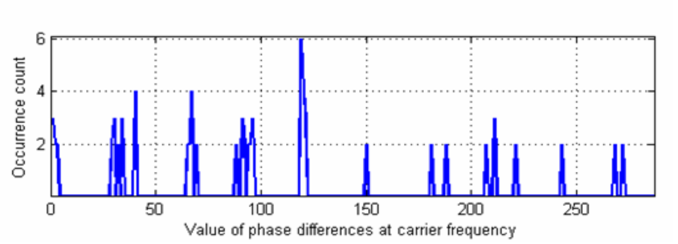
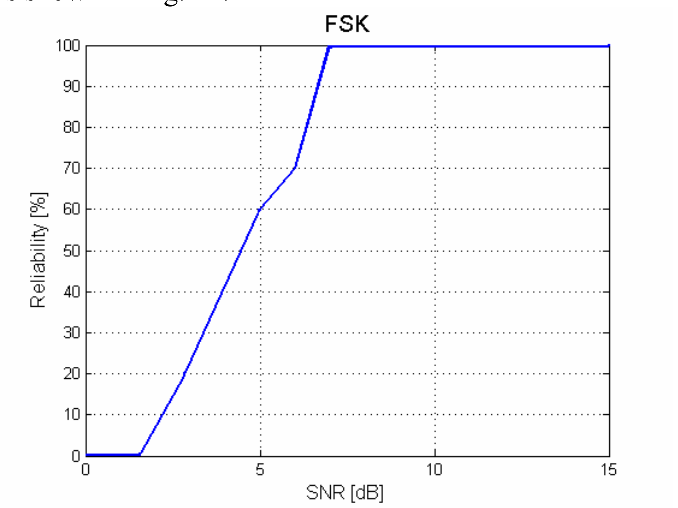


Fig. 23. Occurrence count of phase differences at the carrier frequency for QAM-16 spectrogram after transmission through multipath Rayleigh fading channel

The reliability of the correct detection of modulations is shown in Fig. 24.



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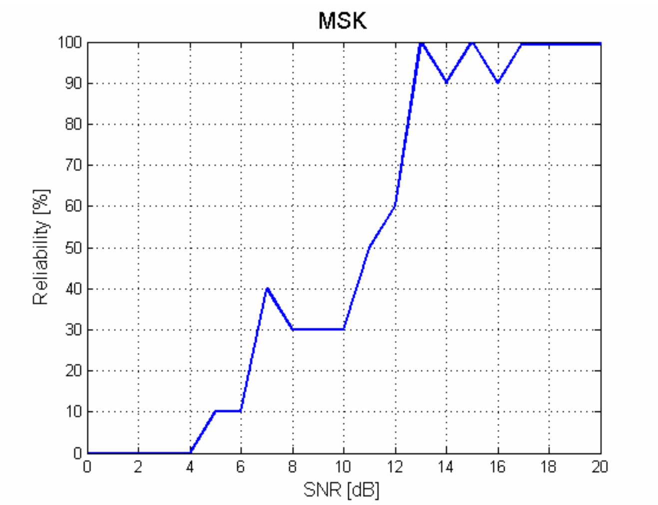

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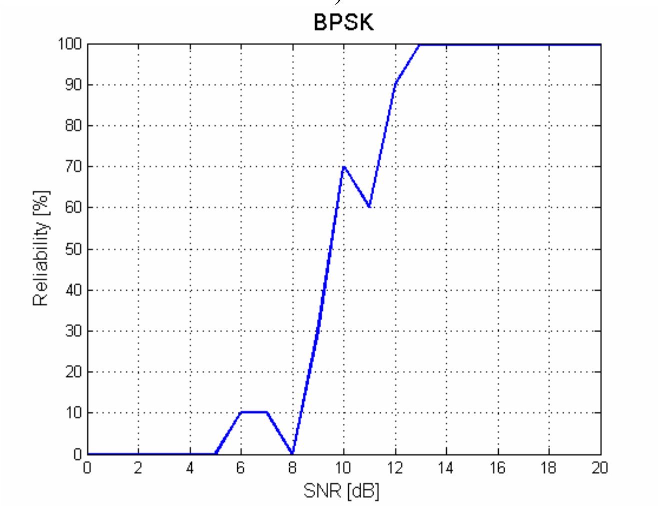

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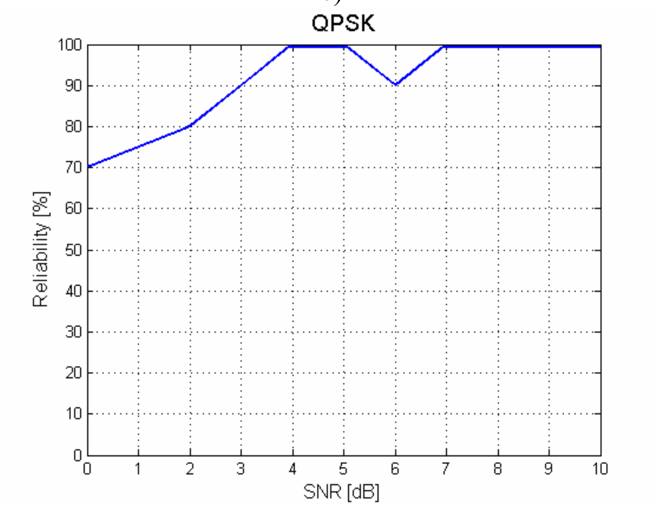

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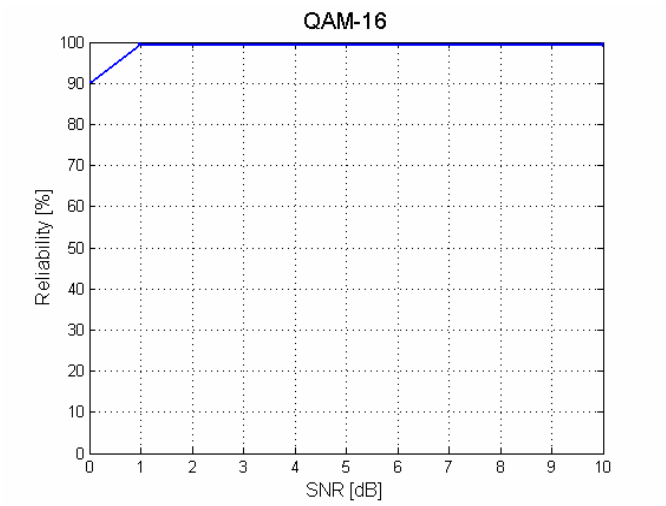

e)

Fig. 24. Reliability of the correct detection of modulation

5 Conclusion

In this paper, a new method of modulation classification based on spectrogram analysis is proposed. An analysis of histograms of spectrograms was used for the investigation of modulation properties. By means of this analysis, the typical parameters of each modulation were found (carrier frequency, number of amplitude levels, number of phase positions). Spectrograms of noisy signals were also obtained and analyzed. It has been proved that the designed method is also suitable for signals disturbed by different noises that are present in a real transmission channel.

Acknowledgments

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