Mathematical Problems of Computer Science 45, 27--34, 2016.

Determination of Received Unknown Signal Modulation Type Using Higher Order Statistics or Spectral Correlation Method

Eduard R. Sivolenko

Institute of Radiophysics and Electronics of NAS RA
e-mail: e_sivolenko@yahoo.com

Abstract

Nowadays modulated signals are being used everywhere. So, modulation type recognition becomes more important for communication systems. In this paper we suggest a new method to discriminate between two modulated signals: amplitude modulated (AM) and frequency modulated (FM). The simulation results are given below. The method is based on higher order statistics. In this paper we use bispectrum and triple autocorrelation function for signal modulation type recognition.

Keywords: HOS, Bispectral estimating, Cumulants, Phase coupling, Object detection, Automatic modulation type recognition, Carrier suppressed AM, FM.

1. Introduction

The technological world is moving forward rapidly. A lot of smart communication systems are developed. One of the main problems in communication is the received signal modulation type automatic recognition. Received signal modulation type automatic recognition plays an important role in various applications of signal analysis. The modulation type is considered as a signal signature. It is very important for receiver to be able to detect the received signal modulation type with less or without any knowledge about the transmitted signal. Modulation type automatic recognition is very important not only for civil but also for military applications such as useful information finding, interference identification and spectrum control, electronic warfare, control of communication quality, etc. Different methods have been developed for the received signal modulation type automatic recognition. A lot of algorithms have been evolved for analogue and digital modulations [1, 2]. There are a lot of different detection algorithms which are based on the first and second order statistics such as autocorrelation function and

Fourier transform [3]. Autocorrelation function and Fourier transform are more effective for linear signals. Besides, the first and second order statistics are providing information only about signal amplitude. Meanwhile, many of the signals are highly non-Gaussian, nonlinear processes. So there is a need of additional information frequencies and phases of components in power spectrum. That additional information can be provided by higher order statistics. Higher order statistics can suppress Gaussian noise and provide with useful information about the received signal. Bispectrum, which is also known as third-order statistics, is known as a powerful tool for coupled phase's information providing. As it is known the power spectrum can be found from the second ordered autocorrelation function using the Wiener-Khinchin theory [4]. By the same way the bispectrum can be found from the triple autocorrelation function using the Wiener-Khinchin theory. We use the bispectrum and third-order statistics for signal modulation type automatic recognition. In this paper deep analyses were done for two types of modulated signals, i.e., for amplitude and frequency modulation. These two modulations are the most interesting because in certain cases we have the same picks in specific frequencies in power spectrum. But power spectrum can provide information only about frequencies. It is very difficult to recognize which frequencies belong to the same modulation type. From this point of view it is very important to find additional information about the received signal for recognition modulation type automatically. This information can be provided by bispectrum. It can provide information about coupled phases which cannot do power spectrum because it is phase-blinded [5]. We use bispectrum to retain the phase information for the received signal modulation recognition.

2. Bispectrum Processing

As it is mentioned above bispectrum is a very powerful tool. Phase's relationship finding is the main motivation for using bispectrum estimation in modulation type recognition tasks. Besides, bispectrum is usually used for extraction of useful signal from noise. First we will consider the bispectrum properties for a real-valued stationary discrete process $\{x^{(m)}(i)\}$ with finite sample number $i = 1, \ldots, N-1$ and with finite set of $m = 1,2, \ldots, M$ independent realizations $x^{(m)}(i)$ [6]. Autocorrelation function can be written as

$$R_x(k) = \langle \sum_{i=0}^{N-1} [x^{(m)}(i) - E]\,[x^{(m)}(i+k) - E] \rangle_\infty, \tag{1}$$

where $k = -N+1, \ldots, N-1$ is the shift index, $\langle \ldots \rangle_\infty$ denotes the ensemble averaging for infinite realization number, i.e., for $M \to \infty$; $E = \langle \frac{1}{N} \sum_{i=0}^{N-1} x^{(m)}(i) \rangle_\infty$ is the mean value; $R_x(0) = \sigma_x^2 = \langle \sum_{i=0}^{N-1} [x^{(m)}(i) - E]^2 \rangle_\infty$ is the variance. Autocorrelation function is a function of one variable. Spectral density $P_x(p)$ is defined from Wiener-Khinchin theorem using direct Fourier transfer:

$$P_x(p) = \sum_{k=-\infty}^{k=+\infty} R_x(k) \exp(-j2\pi kp), \tag{2}$$

or by

$$P_x(p) = \langle X^{(m)}(p) X^{*(m)}(p) \rangle_\infty, \tag{3}$$

where $p = -N+1, \ldots, N-1$ is the frequency sample index;

$X^{(m)}(p) = \sum_{i=0}^{N-1} x^{(m)}(i)\exp(-j2\pi ip)$ is Fourier transform for m-th realization; * denotes complex conjugation. In equation (3) due to multiplication of the complex conjugated functions the phase information is lost.

In opposite to autocorrelation function and spectral density, $R_x(k,l)$ triple autocorrelation function and $\dot{B}_x(p,q)$ bispectrum are functions of two variables. $R_x(k,l)$ triple autocorrelation function is set as

$$R_x(k,l) = \langle \sum_{i=0}^{N-1} [x^{(m)}(i) - E]\,[x^{(m)}(i+k) - E][x^{(m)}(i+l) - E]\rangle_\infty, \tag{4}$$

where $k = -N+1, \dots, N-1$ and $l = -N+1, \dots, N-1$ are the independent shift indices. Unlike the spectral density, $\dot{B}_x(p,q)$ bispectrum is a complex-valued function of two independent frequencies p and q. It can be written as 2-D discrete Fourier transform of triple autocorrelation function

$$\dot{B}_x(p,q) = \sum_{k=-N+1}^{N-1} \sum_{l=-N+1}^{N-1} R_x(k,l)\exp[-j2\pi(kp+lq)]\,, \tag{5}$$

or as

$$\begin{aligned}\dot{B}_x(p,q) &= \langle \dot{X}^{(m)}(p)\dot{X}^{(m)}(q)\dot{X}^{*(m)}(p+q)\rangle_\infty \\ &= \langle \dot{X}^{(m)}(p)\dot{X}^{(m)}(q)\dot{X}^{(m)}(-p-q)\rangle_\infty\end{aligned} \tag{6}$$

where $\dot{B}_x(p,q) = |\dot{B}_x(p,q)|\exp[j\gamma_x(p,q)]$, $|\dot{B}_x(p,q)|$ and $\gamma_x(p,q)$ are the magnitude bispectrum (bimagnitude) and phase bispectrum (biphase), respectively $p = -N+1, \dots, N-1$ and $q = -N+1, \dots, N-1$ are the frequency indices. From (3) power spectrum is the ensemble averaging of the multiplication of two complex conjugated functions of one variable. Meanwhile, from (6) bispectrum is an ensemble averaging of three complex-valued functions corresponding to different frequency values. So, spectral density is providing information only about amplitude, meanwhile bispectrum can provide information about phase and amplitude.

We use bispectral estimating for one of the main properties: coupled phase information retention [7].

3. Modulation Type Recognition Method

This method relies on one of the main properties of bispectrum estimation: coupled phase information retention. As it was mentioned above this method is being used for recognition amplitude and frequency modulations.

As it is known the carrier suppressed amplitude modulated signal has two picks in power spectrum. Time domain and power spectrum of carrier suppressed amplitude modulated signal are shown in figure 1.

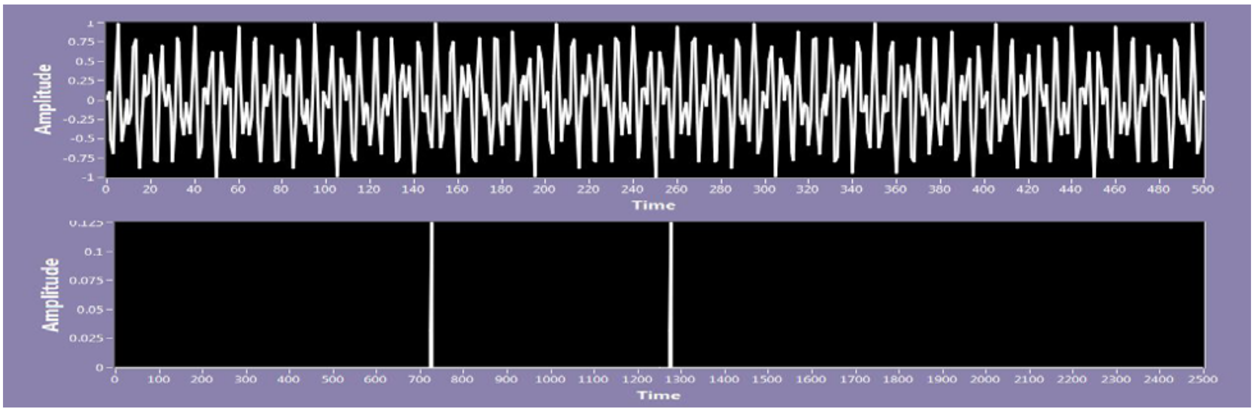


Fig.1. Time domain and power spectrum of carrier suppressed amplitude modulated signal.

Time domain and power spectrum of frequency modulated signal with clearly mentioned five picks are shown in figure 2.

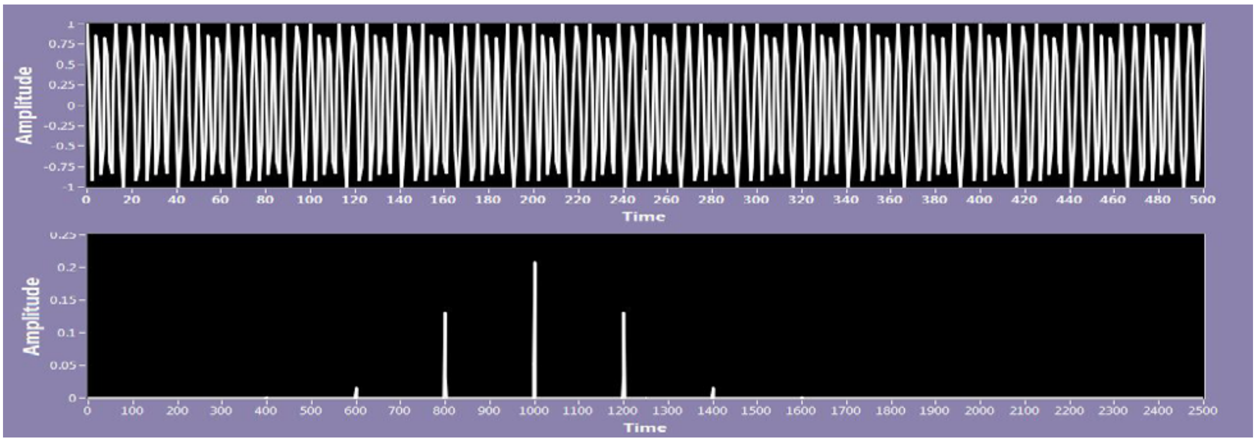


Fig.2. Time domain and power spectrum of frequency modulated signal.

Carrier suppressed amplitude modulated and frequency modulated signals in this simulation have the same carrier. Time domain and power spectrum of the signal, which is the amount of carrier suppressed amplitude modulated and frequency modulated signals, are shown in figure 3.

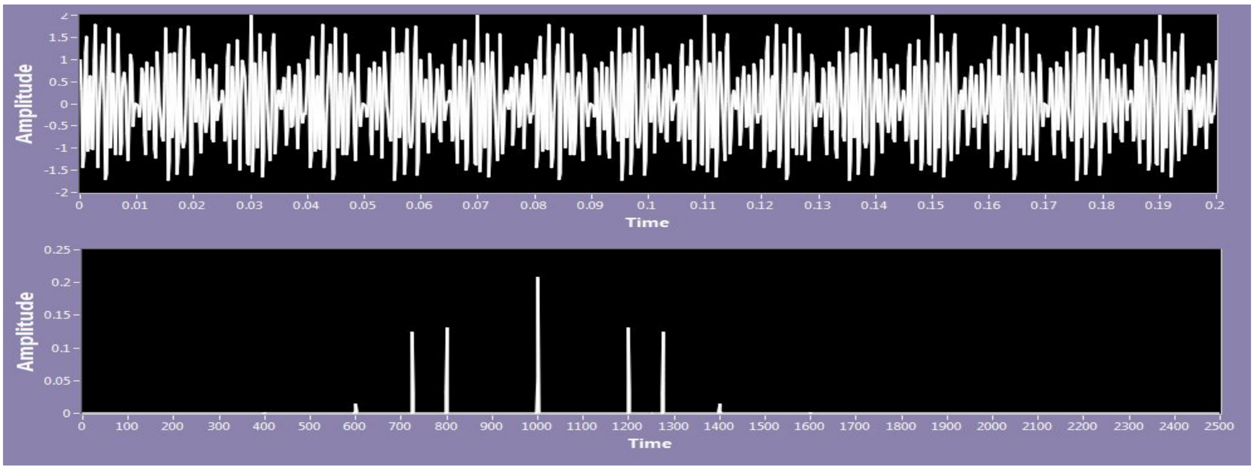
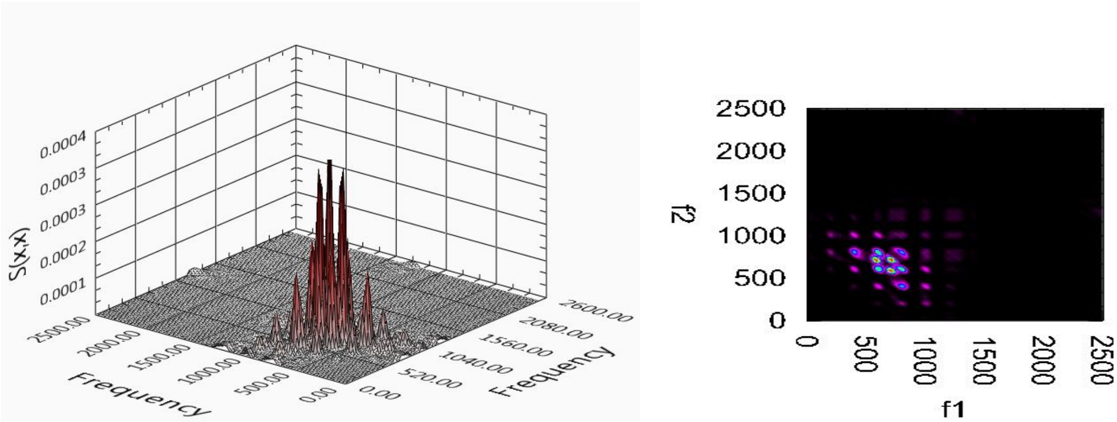


Fig.3. Time domain and power spectrum of the amount of carrier suppressed amplitude modulated and frequency modulated signals.

It is very difficult for the receiver to recognize the modulation type of the received signal using only power spectrum. Only amplitude information is very little to separate amplitude and frequency modulation. So, it is very important in such cases to have information about phases. This information can be provided by third-order statistics especially by bispectral estimating. Bispectrum estimating results are shown in figure 4.

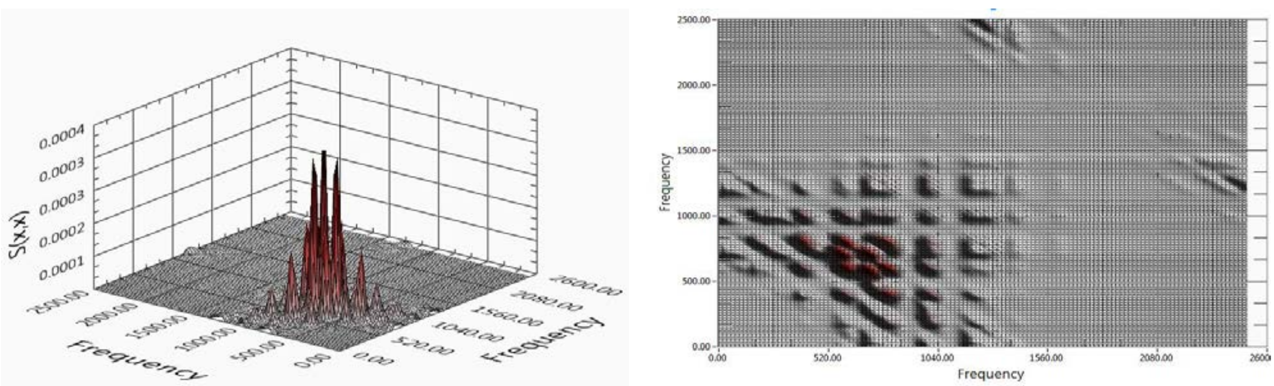


(a) (b)

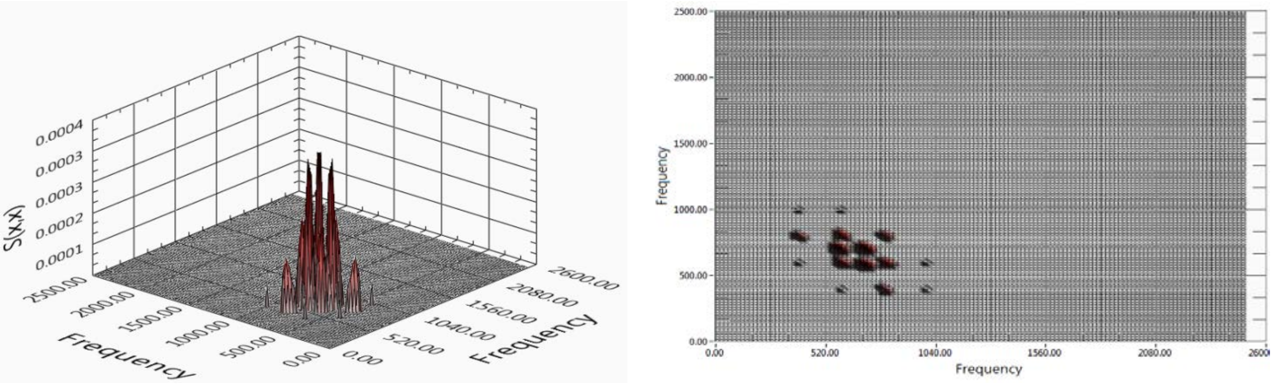
Fig. 4. Bispectrum estimation of the amount of carrier suppressed amplitude modulated and frequency modulated signals: default view (a) and top view (b).

As it is shown in figure 4 there are lots of picks on bispectrum graph. The picks of amplitude modulated signal are higher than the frequency modulated signal picks. Besides, the number of frequency modulated signal picks is more than the number of amplitude modulated signal picks. So, there is a possibility to separate those two signals using bispectrum estimation. The separation was done step by step.

Received signal filtering is the main part of modulation type recognition. The first step is disclosing the useful information from noise. Received signal with noises and disclosed useful signal are shown in figure 5.



(a)



(b)

Fig. 5. Carrier suppressed amplitude modulation and frequency modulation with the same carrier: top and default views with noise (a) and without noise (b).

As it is shown in figure 5 there are a lot of useful pics after deleting noise. Some of these picks belong to amplitude modulation and another part belongs to frequency modulation. So, it is very important to separate these modulation types. In this case we use phase coupled phenomena for separation.

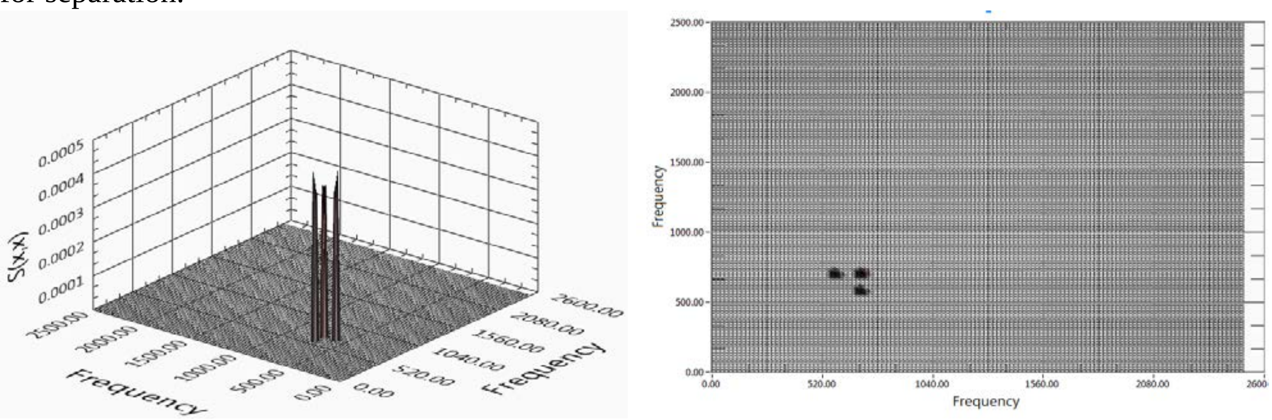


Fig. 6. Carrier suppressed amplitude modulated signal disclosing using bispectrum estimating.

Figure 6 illustrate the disclosed carrier suppressed amplitude modulated signal picks which were found using phase coupled phenomena. After finding amplitude modulated signal picks it is very easy to disclose frequency modulated signal picks. Those picks are shown in figure 7.

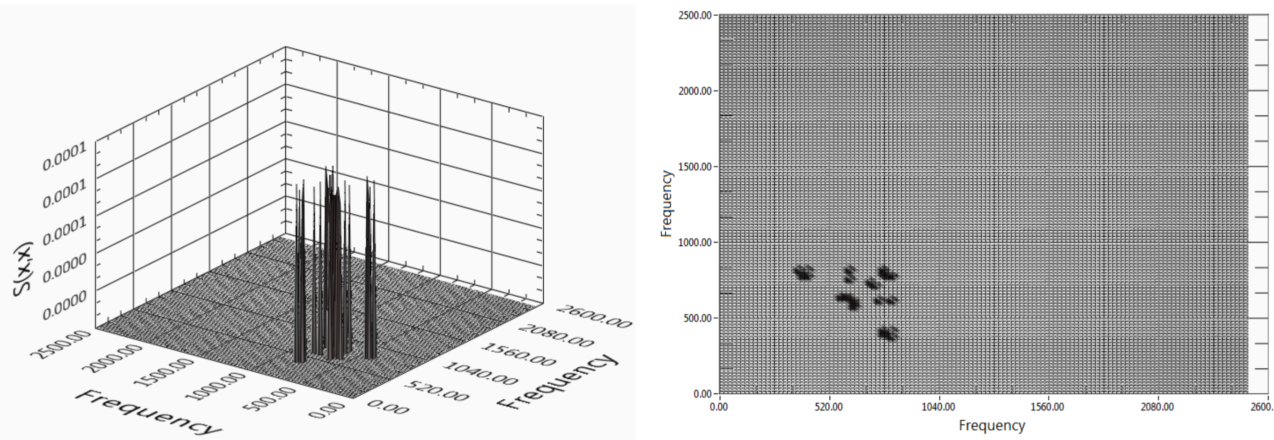


Fig. 7. Frequency modulated signal disclosing using bispectrum estimating.

4. Conclusion

Bispectrum estimation provides more information about signal than power spectrum. For automatic modulation type recognition it is more effective using bispectrum estimation than power spectrum. The main aim of the paper is to explain the modulation type recognition method based on higher order statistics: especially bispectrum and triple autocorrelation function. It has been found that different modulations have different bispectrum graphs. Finally, a received signal modulation type automatic recognition new method was presented. It has been shown how bispectrum based estimation techniques can be used in communication systems. The studies indicate the feasibility of bispectra application for solving the task of modulation recognition based on the results of measurements.

References

[1] M. Ali Khan, M. Muhammad Khan and M. Saad Khan, “Automatic modulation recognition of communication signals”, *Asian Journal of Natural & Applied Sciences*, vol. 2, no.1, pp. 17-22, Oyama, Japan 2013.

[2] D. Le Guen and A. Mansour, “Automatic recognition algorithm for digitally modulated signals”, *IASTED International Conference “Signal Processing, Pattern Recognition & Applications”*, Crete, Greece, June 25-28, pp. 32- 37, 2002.

[3] S. V. Vaseghi, *Advanced Digital Signal Processing and Noise Reduction*, second edition, UK by John Wiley & Sons, Ltd 2000.

[4] И. В. Шиховцев и В. П. Якубов, “Статистическая Радиофизика”, с. 26-28, Новосибирск, 2011.

[5] W. Kicinski and A. Szczepanski “Quadratic phase coupling phenomenon and its properties”, Akademia Marynarki Wojennej, pp. 81-103 ,Gdynia, Poland.

[6] А. В. Тоцкий, Я. Астола, К. О. Егиазарян, А. А. Зеленский, И. В. Курбатов и В. В. Лукин, <<Восстановление сигналов по оценкам биспектров в присутствии гауссовых и негауссовых помех>>, Успехи современной радиоэлектроники, 2002, N 11, C. 44-58

[7] A. A. Hakhoumian and E.R. Sivolenko “Pedestrian detection using higher order statistics (HOS) or polyspectral analyses”, *Proceedings of the International Conference on “Microwave and THz Technologies and Applications”*, Aghveran, Armenia, pp. 68-71, 2014.

Submitted 07.09.2015, accepted 20.01.2016

Գրանցված անհայտ ազդանշանի մոդուլյացիայի տեսակի որոշումը բարձր կարգի վիճակագրությամբ կամ սպեկտրալ կոռելյացիայի միջոցով

Է. Սիվոլենկո

Ամփոփում

Այսօր մոդուլացված ազդանշաններ օգտագործվում են գրեթե ամենուր: Այդ իսկ պատճառով գրանցված անհայտ ազդանշանի մոդուլյացիա տեսակի որոշելը շատ կարևոր դեր է խաղում հեռահաղորդակցական համակարգերի համար: Այս աշխատանքում առաջարկվում է ալգորիթմ, որը հնարավորություն է տալիս իրարից տարանջատել երկու տեսակի ՝ ամպլիտուդային (AM) և հաճախամոդուլված (FM) ազդանշանները: Ալգորիթմի աշխատանքի արդյունքները ներկայացված են աշխատանքում: Մեթոդը հիմնված է բարձր կարգի վիճակագրության վրա: Այս աշխատանքում մոդուլյացիայի տեսակները տարանջատելու համար մենք օգտվում ենք բիսպեկտրումից և եռակի ավտոկոռելյացիոն ֆունկցիայից:

Определение типа модуляции неизвестного сигнала методом статистики высших порядков или корреляции спектра

Э. Сиволенко

Аннотация

На сегодня модулированные сигналы используются везде. А это значит, что распознавание типа модуляции самая главная задача телекоммуникационных систем. В работе представлен алгоритм определения типа модуляции для двух типов модулированных сигналов: амплитудной (AM) и частотной (FM) модуляции. Метод основан на статистике высших порядков. Для распознавания типа модуляции сигналов мы используем биспектрум и тройную автокорреляционную функцию. Результаты алгоритма представлены в работе.