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REPRESENTATION OF NARROW-BAND RADIO SIGNALS WITH ANGULAR MODULATION IN TRUNKED RADIO SYSTEMS USING THE PRINCIPAL COMPONENT ANALYSIS

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Summary. *The analysis of the narrow-band radio signals in the spectral representation features in the systems of trunked radio-systems has been carried out in the paper. Basing on it the application of the principal component analysis has been proposed for building the spectrum with the concentrated features of the useful signal. Transformation of the signal constellation with four-phase guadrature modulation has been analysed as the example.*

Key words: *principal components analysis, trunking, signal constellation, basis, spectrum.*

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Statement of the problem. Analysis of the wide range of available standards of the trunked radio-communication (APCO 25, TETRAPOL, TETRA, DMR) [1 – 3] signifies the existence of trend for application of the angle manipulation (FSK, PSK, QAM variations) in the narrow-band radio channels of the decimeter range. Narrow-band characteristic of the communication channels in these systems causes poor identification of useful signals in the frequency region [4]. Thus, the need of spectral production of narrow-band radio signals with the angle manipulation, the basis of which makes possible to identify the signal reception with high accuracy, arises nowadays.

The Objective of the work is to provide the identification of useful signal reception in the spectrum transformation due to the building of basis highly correlated with the possible signals constellation.

Statement of the task. The essence of the principal component analysis deals with the possibility to present the features of useful signal, the characteristic of which is in average uniform energy distribution between the possible values of the modulated waves in the form of sharp non-uniform energy distribution between the coefficients. This property makes possible to use smaller number of the spectrum coefficients to constellation. For the discrete case it is determined as the matrix $X_{ij} = [x_1, x_2 ... x_n]^T$, where X_{ij} -is the *j* signal of the constellation of general dimension *n*. The image class ω_i is called the feature vectors cluster:

$$\left\{ x_{i1} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}, x_{i2} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}, ... x_{ik} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \right\} \quad (1)$$

Basis development. In the case of QPSK modulation [2] the signal constellation consists of 4-states-symbols, which are transmitted (Fig. 1 a-b). Besides, the influence of inter-symbol transmissions on the symbol as well as the influence of the smoothing filter should be taken into account (Fig. 1 d, e), which in general makes $i=4 \bullet 4^2=64$ of possible realization.

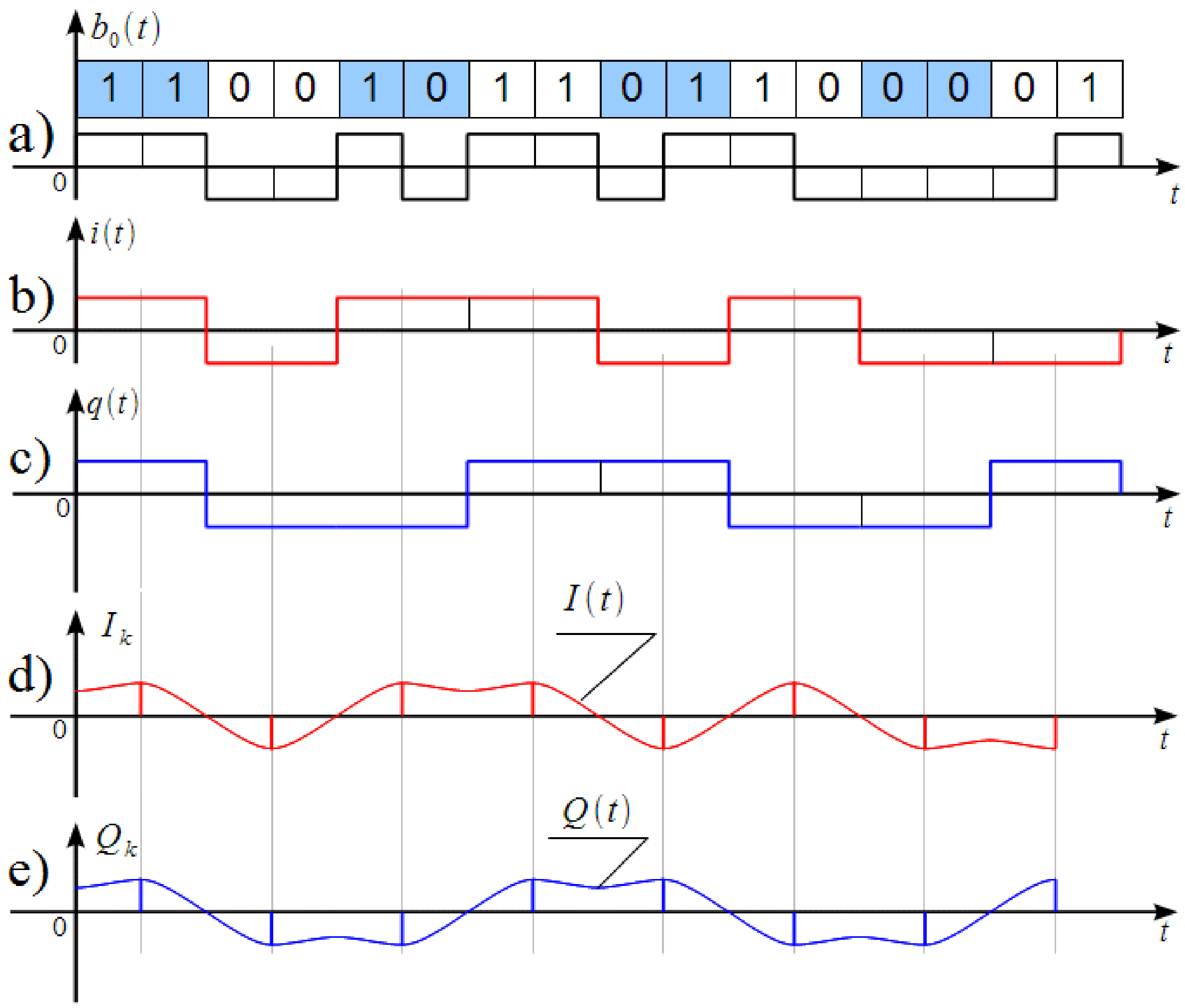

Figure 1. QPSK signal graphs

The reception of the minimum number of the weight coefficients of the useful signal is realized by two operations. The first deals with the linear transformation of the signal constellation as the vector of characteristics, obtaining of the covariance matrix. The optimal estimation of the covariance matrix *cov(X)* for this process is found as follows:

$$\operatorname{cov}(X) = C_x = \frac{1}{K}\sum_{k=1}^{K}(X_k - m_x)(X_k - m_x)^T = \begin{bmatrix} \sigma_{11}^2 & \sigma_{11}^2 & \cdots & \sigma_{1n}^2 \\ \sigma_{21}^2 & \sigma_{22}^2 & \cdots & \sigma_{1n}^2 \\ \vdots & \vdots & \vdots & \vdots \\ \sigma_{n1}^2 & \sigma_{n2}^2 & \cdots & \sigma_{n2}^2 \end{bmatrix}, \qquad (2)$$

where the mean value of the class image vectors being

$$m_x = \frac{1}{K}\sum_{k=1}^{K} X_k \, .$$

For the real and symmetric covariance matrix (1) there always exist orthonormal basis $\{\Phi_i\}$, which consists of n eigenvectors. Let us sign the matrix $\Phi = [\phi_1, \phi_2, ...\phi_n]$ of the eigenvectors of the covariance matrix C_x. Then there is such a diagonal matrix $D_x=\lambda$, for which the equality is fulfilled:

$$\Phi^T C_x \Phi = D = \mathrm{diag}[\lambda_1, \lambda_2, ...\lambda_n] = \lambda,$$

where $\lambda_1, \lambda_2, ..., \lambda_j, ...\lambda_n$ – eigenvalues of the matrix C_x.

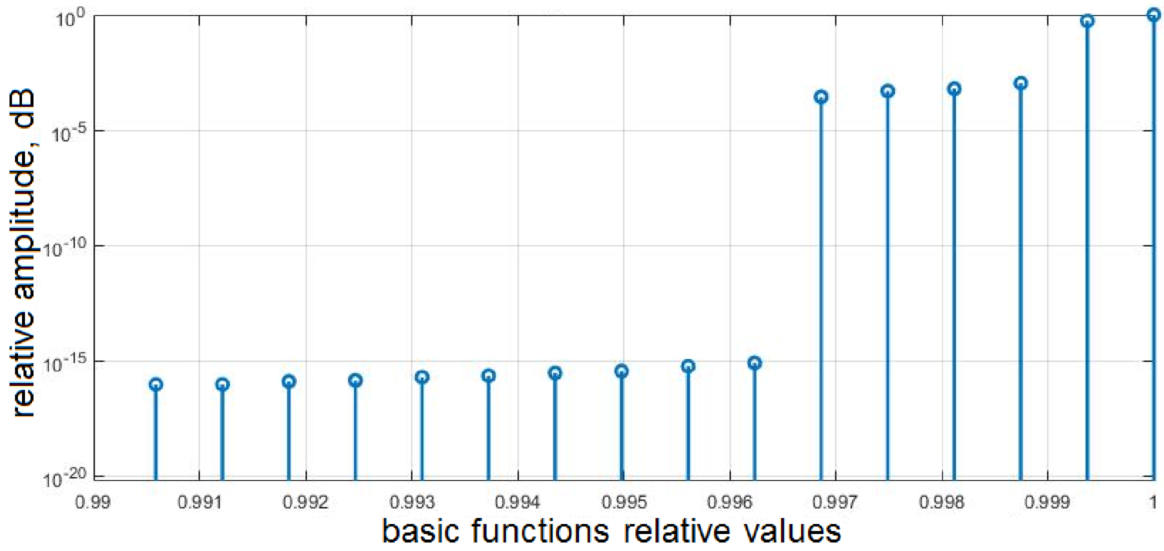

Figure 2. The eigenvalues of covariance matrix λ of QPSK signal constellation

By means of the second operation the choise of the transformation coefficients is performed. For this purpose the eigenvalues must be put in order with dropping values as fallows:

$$\lambda_j \le \lambda_{j+1}, \text{ for } j = 1, 2, ..., n-1. \quad (3)$$

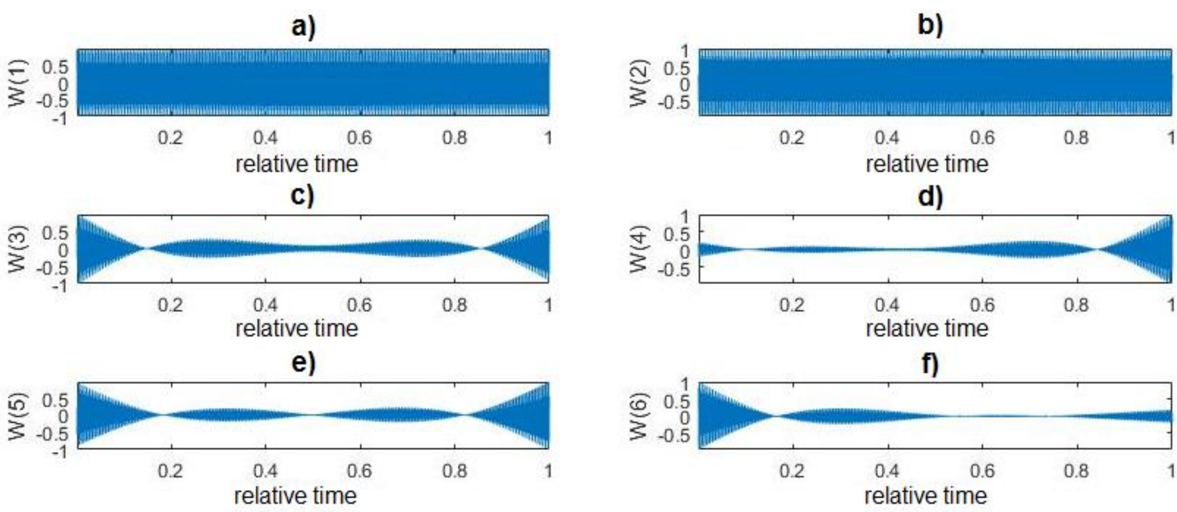

Figure 3. The first 6 basic functions ordered by the expression (3) for QPSK signal constellation example

Let $W = \Phi^T$ be the matrix composed of the transposed eigen vectors of the covariance matrix C_x in such a way, as they correspond to the ordered eigenvalues (3). The matrix $W = [W_1, W_2, \ldots W_n]$ is used as the nucleus of the direct and reversed Khottelling's transformation correspondingly.

$$\hat{X} = W\left(X - m_x\right), \qquad (4)$$

$$X = W^T \hat{X} + m_x. \qquad (5)$$

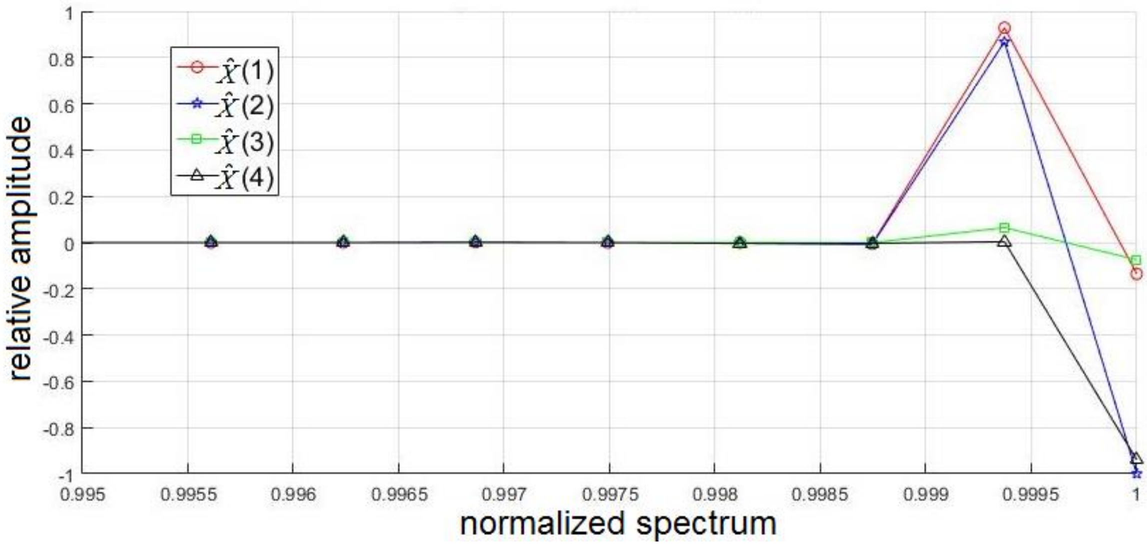

Figure 4. QPSK signals constellation in its own basis

In its turn, to regenerate the signal let us assume, that instead of using eigen vectors of the covariance matrix C_x the transformation nucleus W_l is built, which consists of only l eigen vectors, to which most dispersion eigenvalues, l correspond. Then the regeneration of the output vector is found by the relation

$$X' = W_t^T \hat{X}_t + m_x. \qquad (6)$$

The root-mean-square error (RMS), which appears under rejection of n-l coordinates while regenerating of X according to the found coordinates is found by the expression

$$\varepsilon = \sum_{j=1}^{n} \lambda_j - \sum_{j=1}^{l} \lambda_j = \sum_{j=l+1}^{n} \lambda_j. \qquad (7)$$

As the eigenvalues drop while predering, the error can be minimal choosing l eigen vectors to which the largest values correspond.

Conclusion. To sum up, the application of the basis built taking advantage of the principal component analysis, as compared with the harmonic functions for the identification of the input signals of the narrow-band radio signals with the angle modulation, is very promising because of the high correlation of the basis with the signals constellation.

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ПРЕДСТАВЛЕННЯ ВУЗЬКОСМУГОВИХ РАДІОСИГНАЛІВ ІЗ КУТОВОЮ МОДУЛЯЦІЄЮ В СИСТЕМАХ ТРАНКІНГОВОГО РАДІОЗВ’ЯЗКУ МЕТОДОМ ГОЛОВНИХ КОМПОНЕНТ

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Резюме. *Проведено огляд особливостей спектрального представлення вузькосмугових радіосигналів у системах транкінгового радіозв’язку. Запропоновано та наведено використання методу головних компонент для побудови спектра із зосередженими ознаками корисного сигналу. У якості прикладу розглянуто розклад ансамблю сигналів із чотирипозиційною квадратурною модуляцією.*

Ключові слова: *метод головних компонент, транкінг, ансамбль сигналів, базис, спектр.*

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