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OTEH 2011

ON DEFENSIVE TECHNOLOGIES

Belgrade, 6 – 7 October 2011

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A TWO-STAGE DIGITAL PROCESSING OF NOFDM SIGNALS RECEIVED FROM MULTIPLE UAV IN PLANAR DIGITAL ANTENNA ARRAY

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Abstract: *A new two-stage digital processing of Non Orthogonal Frequency Division Multiplexing (NOFDM) signals received from multiple UAV in planar digital antenna array (DAA) is described in this report with the purpose of effective elimination of jammers influence. This technology can be use for Secure Wideband Networking Waveform (WNW).*

Key words*: UAV, digital antenna array (DAA), digital beamforming, directivity characteristics (DC), NOFDM.*

1. INTRODUCTION

In this report is described a two-stages NOFDM signals processing in planar digital antenna array (DAA) of base station with the purpose of effective elimination of jammers influence in UAV communications (Picture 1) [1]. The essence of it is an intermediate estimation of amplitudes of NOFDM signals on an exit of digital beamforming procedure. It allows separating the signals of jammers in each readout time for use in the further processing only a part of a amplitudes vector, which corresponds to UAV's data signals.

2. MAIN PART

We will suppose, that angular coordinates of sources of jammers are determined before the beginning of measurements, and also, that directions of data signals arrival from multiple UAV are precisely known. If this information is full and given, we can present a vector of voltage U for NOFDM signals on exit of planar digital antenna array (DAA) in separate moments of readout time as

$$U = KW + n\,, \tag{1}$$

where $U=\begin{bmatrix}\dot{U}_{11} & \dot{U}_{12} & \cdots & \dot{U}_{rs} & \cdots & \dot{U}_{RZ}\end{bmatrix}^{T}$ - a vector of complex voltage of signals responses on exit of R×Z secondary spatial channel of flat DAA, $K = \left[Q \; [\blacksquare] \; V\right]$ - a signals matrix,

$[\blacksquare]$ - the symbol of blocked matrix product of Khatry-Rao,

$Q = \left[Q_S \mid Q_P\right]$ – block matrix of values directivity characteristics of antenna (DC) of secondary spatial channels in azimuth planes in directions on UAV sources (a block Q_S) and on jammers signals (block Q_P); for general case of M UAV sources and J of jammers a matrix's blocks of a directivity characteristics of secondary spatial channels in azimuth planes can be written as

$$Q_S = \begin{bmatrix} Q_1(x_1) & Q_1(x_2) & \cdots & Q_1(x_M) \\ Q_2(x_1) & Q_2(x_2) & \cdots & Q_2(x_M) \\ \vdots & \vdots & \vdots & \vdots \\ Q_R(x_1) & Q_R(x_2) & \cdots & Q_R(x_M) \end{bmatrix},$$

$$Q_P = \begin{bmatrix} Q_1(x_1) & Q_1(x_2) & \cdots & Q_1(x_J) \\ Q_2(x_1) & Q_2(x_2) & \cdots & Q_2(x_J) \\ \vdots & \vdots & \vdots & \vdots \\ Q_R(x_1) & Q_R(x_2) & \cdots & Q_R(x_J) \end{bmatrix},$$

$V = \left[V_S \mid V_P\right]$ - block matrix of values directivity characteristics of antenna (DC) of secondary spatial channels in elevation planes in directions on UAV sources (a block V_S) and on jammers signals (block V_P); for general case of M UAV sources and J of jammers a matrix's blocks of a directivity characteristics of secondary spatial channels in elevation planes can be written as

$$V_S = \begin{bmatrix} V_1(y_1) & V_1(y_2) & \cdots & V_1(y_M) \\ V_2(y_1) & V_2(y_2) & \cdots & V_2(y_M) \\ \vdots & \vdots & \vdots & \vdots \\ V_R(y_1) & V_R(y_2) & \cdots & V_R(y_M) \end{bmatrix},$$

$$V_P = \begin{bmatrix} V_1(y_1) & V_1(y_2) & \cdots & V_1(y_J) \\ V_2(y_1) & V_2(y_2) & \cdots & V_2(y_J) \\ \vdots & \vdots & \vdots & \vdots \\ V_R(y_1) & V_R(y_2) & \cdots & V_R(y_J) \end{bmatrix},$$

$$x_m = \frac{2\pi}{\lambda} d_x \left(r - \frac{R-1}{2} \right) \sin\theta_m \cos\varepsilon_m ,$$

$$y_m = \frac{2\pi}{\lambda} d_y \left(r - \frac{R-1}{2} \right) \sin\theta_m \sin\varepsilon_m ,$$

$$Q_r\left(x_m\right) = \left[\sin\left(\frac{R}{2}\left[r - x_m \right] \right) \right] \left[\sin\frac{1}{2}\left(r - x_m \right) \right]^{-1} ,$$

$$V_r\left(y_m\right) = \left[\sin\left(\frac{Z}{2}\left[r - y_m \right] \right) \right] \left[\sin\frac{1}{2}\left(r - y_m \right) \right]^{-1} ,$$

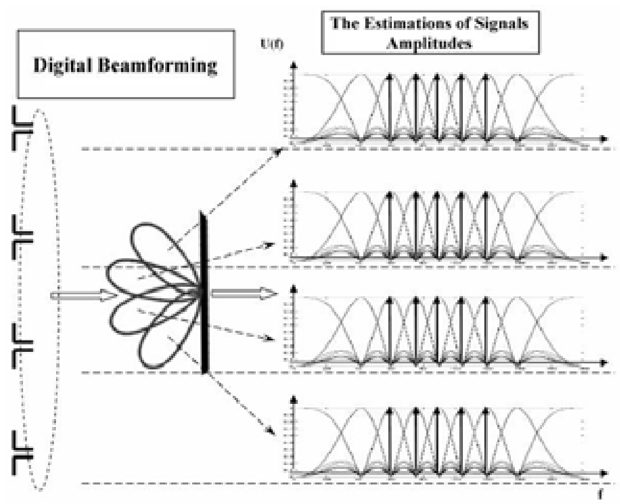
d_x, d_y - the distance between array's elements of planar DAA in two coordinate planes, ε_m - the angle between directions on a UAV sources and DAA normal in a second coordinate planes, R – a number of array's elements in azimuth planes, Z – a number of array's elements in a second coordinate planes.

λ – wavelength of UAV signals or jammers carrier,

$W^T = \left[W_S \mid W_P \right]$ – a block vector of the generalized amplitudes of NOFDM signals (a block W_S, which contains the information about of directivity characteristics (DC) of antenna elements), and of jammers signals (a block W_P); "T" – a symbol of operation of transposing; *n* – a vector of noise's voltage.

For the NOFDM signals and jammers signals separation during the forming of optimum estimation of amplitudes vector $W = \left(K^T K\right)^{-1} K^T U$ are calculated only the segments of a vector $\hat{W}$, corresponding data of signals NOFDM, that is the block W_S. Thus a segment of a vector of estimations of amplitudes jammers signals (block W_P) is not formed at all.

A correction of the reception channels characteristics can be used for errors minimization of digital beamforming system with non-identical channels of antenna arrays [2].



Picture 1. Two-stage digital processing of NOFDM signals.

At the second stage of processing of estimations of amplitudes of the signals, which are taken by means of moments sequence of readout time, should be executed a procedure of fast Furrier transformation (FFT), that allows to synthesize the frequency filters, which are necessary for spectral selection of NOFDM signals carriers, and also they are necessary for final estimation their amplitudes. It is also should be mentioned, it is essential, that 2-stage strategy of processing does not demand formation of frequency filters for all planar DAA reception channels. It cardinally simplifies processors' speed requirements and reduces operative memory volumes requirements and data transmission lines throughput requirements.

If a vector of voltage *U* for NOFDM signals on exit of digital beamforming in separate moments of readout time is presented as (1), that expression for Cramer-Rao low bound (CRB) for dispersions estimations of a vector of the generalized amplitudes can be written in the form of

$$\sigma_W^2 \geq \sigma_n^2 diag\left[K^T K\right]^{-1} , \qquad (2)$$

where σ_n^2 – a dispersion of noise in separate moments of readout time on exit of the secondary spatial channel, $diag[L]$ – a vector made of diagonal elements of a matrix *L*.

Or in recalculation to a dispersion of noise on an exit of the analog-to-digital converter:

$$\sigma_W^2 \geq \sigma_{ADC}^2 \cdot R \cdot Z \cdot diag\left[K^T K\right]^{-1} , \qquad (3)$$

where R×Z – a dimension of spatial FFT (a number of DAA elements), σ_{ADC}^2 – a dispersion of noise on an exit of the analog-to-digital converter.

On conditions that responses of frequency filters after FFT can be given in the form of

$$\hat{W}_{FFT} = FA + n_W , \qquad (4)$$

where $\hat{W}_{FFT}$ – a vector of voltage of responses of frequency filters,

$F = \begin{bmatrix} \dot{F}_1(\omega_{11}) & \cdots & \dot{F}_1(\omega_{T1}) \\ \vdots & \cdots & \vdots \\ \dot{F}_G(\omega_{11}) & \cdots & \dot{F}_G(\omega_{T1}) \end{bmatrix}$ – a matrix of amplitude-frequency response (AFR) $\dot{F}_g\left(\omega_{tm}\right)$ of *G* frequency filters synthesized as a result of operation FFT for *R*×*Z* identical reception channels; *A* – a vector of amplitudes of signals, which contains the information about of directivity characteristics of antenna elements for frequency ω_{tm}, n_W – a vector of noise voltages, as dispersions of estimations for a vector of the amplitudes, which correspond to CRB, it is necessary to consider expression

$$\sigma_A^2 \geq \sigma_W^2 \cdot N \cdot diag\left[F^T F\right]^{-1} , \qquad (5)$$

where *N* – dimension of FFT, used for synthesis of frequency filters.

Substitution of expression (2) into (5), allows us to present a final ratio for CRB estimations of signals parameters within the limits of two-stage procedures.

When signals coming from different directions, have an identical grid of frequencies, the borders for dispersions can be written in the form of:

$$\sigma_A^2 \geq \sigma_n^2 \cdot diag\left[K^T K\right]^{-1} \otimes \left(N \cdot diag\left[F^T F\right]^{-1}\right), \quad (6)$$

where $\otimes$ – a symbol of Kronecker products of matrices.

If the grid of frequencies is unique on each angular direction, estimations of dispersions (6) should be copied in the form of:

$$\sigma_A^2 \geq \sigma_n^2 \cdot \left(diag\left[K^T K\right]^{-1}\right)_r [\otimes] \left(N \cdot diag\left[F_r^T F_r\right]^{-1}\right), (7)$$

or recalculation to a dispersion of noise on an exit of the analog-to-digital converter we can receive:

$$\sigma_A^2 \geq \sigma_{ADC}^2 R \cdot Z\left(diag\left[K^T K\right]^{-1}\right)_r [\otimes]\left(N \cdot diag\left[F_r^T F_r\right]^{-1}\right), (8)$$

where $[\otimes]$ – a symbol of block Kronecker product of matrices, F_r – a matrix of AFR for the frequency grid, which corresponds to *r*-th a direction of arrival of signals, $(diag[M])_r$ – *r*-th element of a vector $diag[M]$.

For comparison it is necessary to provide the CRB estimation, which corresponds to one-stage estimation, using the following expression:

$$\sigma_A^2 \geq \sigma_{nW}^2 \cdot diag\left[P^T P\right]^{-1}, \quad (9)$$

where σ_{nW}^2 – a dispersion of noise on exits of frequency filters, $P = K[\otimes]F$ – the signal's matrix, which elements are formed by products of values AFR of frequency filters and DC of secondary spatial channels.

In recalculation to dispersions of noise on an exit of the analog-to-digital converter expression (9) can be copied in the form of:

$$\sigma_A^2 \geq \sigma_{ADC}^2 \cdot R \cdot N \cdot diag\left[P^T P\right]^{-1}. \quad (10)$$

$$\sigma_A^2 \geq \sigma_{ADC}^2 \cdot R \cdot Z \cdot N \cdot diag\left[\left(K[\otimes]F\right)^T \left(K[\otimes]F\right)\right]^{-1}. (11)$$

The taken result allows us to conduct the comparative analysis of accuracy one- and two-stage procedures of demodulation that is the purpose of the further researches.

Using the result of modeling it was possible to confirm validity of identity:

$$diag\left[K^T K\right]^{-1} \otimes \left(diag\left[F^T F\right]^{-1}\right) = diag\left[\left(K \otimes F\right)^T \left(K \otimes F\right)\right]^{-1},$$

that exists on the assumption of full orthogonally of signals on frequency and a direction of arrival.

If non-orthogonally frequency of signals (the case of NOFDM signals [3]) and non-orthogonally angular coordinates are used, 2-stage estimation with different matrixes AFR gives more exact estimations, than with use of common matrix AFR hence, and generally it is possible to write:

$$diag\left[K^T K\right]^{-1} \otimes \left(diag\left[F^T F\right]^{-1}\right) \geq diag\left[\left(K \otimes F\right)^T \left(K \otimes F\right)\right]^{-1}.$$

3. CONCLUSION

The majority of known approaches to the improvement of transmission capacity of communication channels consist in expanding their spectral band. In turn it leads to a number of problems such as the electromagnetic compatibility of equipment and the deficiency of frequency resources in the most intensively used ranges of the electromagnetic spectrum. This situation can be improved if the processing of UAV communication signals is performed based on their nonorthogonal frequency-division multiplexing (N-OFDM).

The proposed new two-stage digital processing of NOFDM-signals received from multiple UAV in planar digital antenna array (DAA) is a perspective technology for future UAV-systems.

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