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A METHOD OF MEASUREMENT OF DIRECTIVITY CHARACTERISTICS OF ANTENNA'S ELEMENTS FOR DIGITAL ANTENNA ARRAY IN CONDITIONS OF JAMMERS

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Abstract

A new two-stage digital processing of OFDM signals for measurement of directivity characteristics (DC) of antenna elements in digital antenna array (DAA) with test sources is described in this report.

Keywords: digital antenna array (DAA), digital beamforming, directivity characteristics (DC), OFDM.

A measurement of directivity characteristics (DC) of antenna elements in digital antenna array (DAA) with test sources, as is known, is based on estimation of signals amplitudes on exits of reception channels DAA. For simultaneous controlling of directional characteristic over a wide frequency band an injection of multifrequency OFDM signals with equal amplitudes can be applied on input DAA.

In this case with the purpose of reduction of computing costs on OFDM signals amplitudes estimation, (signals are received by DAA), and also with the purpose of effective elimination of jammers influence the use of two-stages signals processing is expedient (fig. 1) [1]. The essence of it is an intermediate estimation of amplitudes of 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 test signals. It is also supposed, that angular coordinates of sources of jammers are determined before the beginning of measurements, and also, that directions of test signals arrival are precisely known.

If this information is full and given, we can present a vector of voltage U for OFDM signals on exit of digital beamforming in separate moments of readout time as

$$U = QW + n, \quad (1)$$

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

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

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

where $x_{m(j)}$ – a generalized angles coordinates of test sources or jammers with respect to DAA normal,

$$x_{m(j)} = \frac{2\pi}{\lambda} d \left(r - \frac{R-1}{2} \right) \sin\theta_{m(j)},$$

λ – wavelength of test sources or jammers carrier,

d – the distance between array's elements of DAA, R – number of array's elements, $\theta_{m(j)}$ – the angles coordinates of test sources or jammers with respect to DAA normal,

$W^T = [W_S \;\vdots\; W_P]$ – a block vector of the generalized amplitudes of OFDM 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 OFDM signals and jammers signals separation during the forming of optimum estimation of amplitudes vector $\hat{W} = \left(Q^T Q\right)^{-1} Q^T U$ are calculated only the segments of a vector $\hat{W}$, corresponding data of signals OFDM, 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.

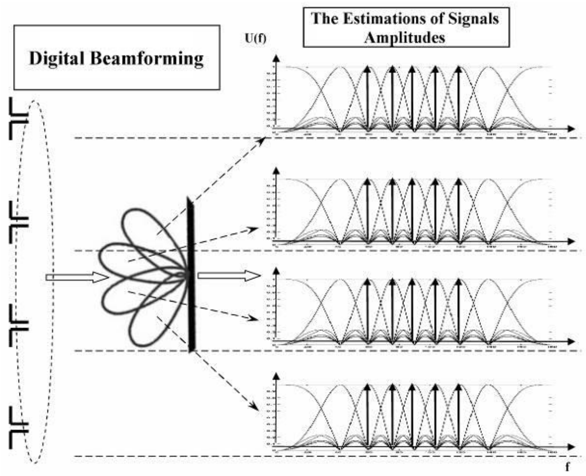

Fig. 1. Two-stage digital processing of OFDM signals.

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].

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 OFDM 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 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 OFDM 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

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

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

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

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

where R – 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) $\dot{F}_g(\omega_{tm})$ of G frequency filters synthesized as a result of operation FFT for R 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:

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

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

or at recalculation to a dispersion of noise on an output of the analog-to-digital converter:

$$\sigma_A^2 \geq \sigma_{ADC}^2 \cdot R \cdot diag\left[Q^T Q\right]^{-1} \otimes \left(N \cdot diag\left[F^T F\right]^{-1}\right). \qquad (7)$$

If the grid of frequencies is unique on each angular direction, estimations of dispersions (6) and (7) should be copied in the form of:

$$\sigma_A^2 \geq \sigma_n^2 \cdot \left(diag\left[Q^T Q\right]^{-1}\right)_r [\otimes] \left(N \cdot diag\left[F_r^T F_r\right]^{-1}\right), \qquad (8)$$

$$\sigma_A^2 \geq \sigma_{ADC}^2 R \cdot \left(diag\left[Q^T Q\right]^{-1}\right)_r [\otimes] \left(N \cdot diag\left[F_r^T F_r\right]^{-1}\right), \qquad (9)$$

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:

$$\sigma_A^2 \geq \sigma_{nW}^2 \cdot diag\left[P^T P\right]^{-1}, \qquad (10)$$

where σ_{nW}^2 – a dispersion of noise on exits of frequency filters, $P = Q[\otimes]F$ – 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 (10) can be copied in the form of:

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

$$\sigma_A^2 \geq \sigma_{ADC}^2 \cdot R \cdot N \cdot diag\left[(Q[\otimes]F)^T (Q[\otimes]F)\right]^{-1}. \qquad (12)$$

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.

In this time the authors have a result only for one-frequency and two-frequency OFDM signals (fig. 2, 3, where σ_A is a mean-square error (MSE) of amplitudes estimations, Δf – a frequency's interval).

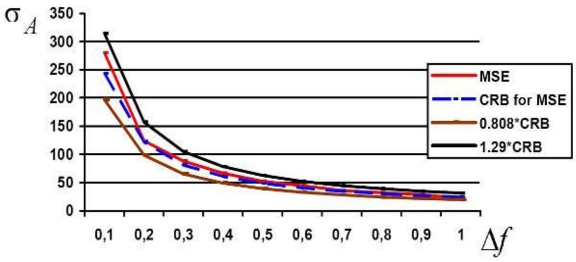

Fig. 2. A mean-square error (MSE) of amplitudes estimations at one-stage measurement for 16-elements DAA, two-frequency OFDM's signals and full orthogonally of 2 signals at a direction of arrival (one direction of arrival is a jammer).

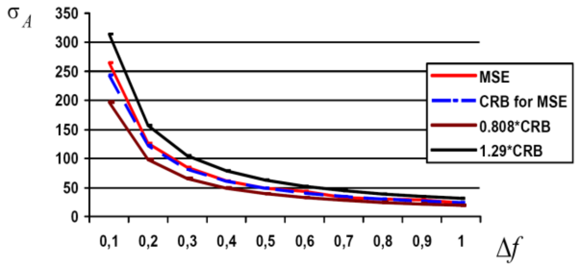

Fig. 3. A MSE of amplitudes estimations at two-stage measurement for 16-elements DAA, two-frequency OFDM's signals and full orthogonally of signals at a direction of arrival (one direction of arrival is a jammer).

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

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

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 N-OFDM 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:

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

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