VIII International Conference on

Antenna Theory and Techniques

To the memory of antenna science Atlantes
Pistolkors A.A., Zelkin Y.G., Bakhrakh L.D.

Kyiv, Ukraine
September 20-23, 2011

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AN ESTIMATION OF DIRECTIVITY CHARACTERISTICS OF ANTENNA ELEMENTS IN ANTENNA ARRAY WITH COUNTING OF SIGNAL CONJUGATE COMPONENTS

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Abstract

In this paper a two-stage digital processing of N-OFDM signals test sources for measurement of directivity characteristics (DC) of antenna elements in digital antenna array (DAA) with counting of complex conjugate components are presented.

Keywords: digital antenna array (DAA), digital beamforming, complex conjugate components (CCC), N-OFDM.

A measurement of directivity characteristics (DC) of antenna elements in receiver digital antenna array (DAA) according to [1] can be simultaneously carried out on several test sources, being based on estimation amplitudes of signals on outputs of reception channels DAA.

At use of quadrature-free circuits of an analog reception path, and also in a case of the non-identical quadratures channels providing formation of complex voltages of signals in an analog kind, the problem of DC measurement becomes complicated due to occurrence of complex conjugate components (CCC) of signals. Presence CCC at the signals response on outputs of procedure digital beamforming processing (fig. 1) results in mistakes in estimation amplitudes of test signals, that limits accuracy of measurement DC antennas elements.

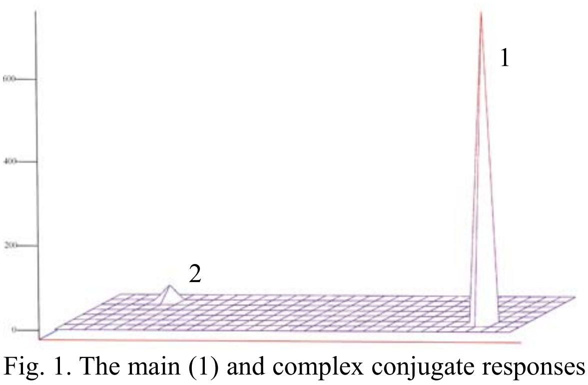

Fig. 1. The main (1) and complex conjugate responses of signals (2) on an output of digital beamforming procedure in planar DAA.

Treating complex-conjugate components of signals as jammers, we use for measurement of directivity characteristics an approach, which advanced in [1].

Let's believe that amplitudes of signals of all test sources are identical or normalized with known weight factors to amplitude of benchmark signal. It will allow to refuse necessity of the control for time of a constancy of amplitudes of test signals at statistically significant series of measurements and to use for DC estimation a broadband or even noise signals influences.

It is supposed, that directions of test signals arrival are precisely known. This condition automatically predetermines, that an angular coordinates of responses of a complex conjugate components of signals are also known (fig. 1).

Within the framework of an offered method at the first stage of processing of signals it is necessary to execute digital beamforming with the help of procedure of fast Fourier transformation, having generated so-called secondary spatial channels. It will allow to improve the attitude signal - noise that is important for carrying out an estimation of directivity characteristics.

In the case of linear DAA the estimation of amplitudes of signals on an exit of digital beamforming procedure can be shown similarly [1] to the decision of the matrix equation

$$U = QA + n\,, \qquad (1)$$

where $Q = \left[Q_S \,\vdots\, Q_P \right]$ – block matrix of values DC of secondary spatial channels in directions on test sources (a block Q_S) and on complex conjugate components (block Q_P);

for general case of M test sources a matrix's blocks of a directivity characteristics of secondary spatial channels can be written as

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

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

where $x_{m(j)}$ – a generalized angles coordinates of main responses of test sources or responses of CCC 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 carrier, d – the distance between array's elements of DAA, R – a number of array's elements, $\theta_{m(j)}$ – the angles coordinates of main responses of test sources or responses of CCC with respect to DAA normal,

$Q_r(x_m)$, $Q_r(-x_m)$ - a directivity characteristics of rth secondary spatial channels of DAA in azimuth planes in directions on a main response of mth test sources with angle coordinate x_m relative to DAA normal and its complex conjugate response with angle coordinate $-x_m$;

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

$A^T = [A_S \mid A_P]$ – a block vector of the amplitudes of signals (a block A_S, which contains the information about of the amplitudes of test signals, and a block A_P, which contains the information about of the complex conjugate components of response of test signals); "T" – a symbol of operation of transposing; n – a vector of noise's voltage.

For separation of test signals responses and CCC–response separation during the forming of optimum estimation of amplitudes vector $A = (Q^T Q)^{-1} Q^T U$ are calculated only the segments of a vector A, corresponding data of main response of test signals, that is the block A_S. Thus a segment of a vector of estimations of amplitudes CCC (block A_P) is not formed at all.

In case of planar DAA the formula (1) need transform in the form of

$$\mathrm{U} = \mathrm{K} \cdot \mathrm{A} + \mathrm{n}, \qquad (2)$$

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

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

$$Q = [Q_S \mid Q_P],$$
$$V = [V_S \mid V_P],$$

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

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

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

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

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

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 test sources and DAA normal in a second coordinate plane, Z – a number of array's elements in a second coordinate plane.

The estimation of a vector of amplitudes $A = (K^T K)^{-1} K^T U$ without taking into account structure of matrix K remains to the same.

The expression for Cramer-Rao low bound (CRB) for dispersions estimations of amplitudes vector can be written in the form of [1]:

a) linear DAA: $\sigma_A^2 \ge \sigma_n^2 diag[Q^T Q]^{-1}$,

б) planar DAA: $\sigma_A^2 \ge \sigma_n^2 diag[K^T K]^{-1}$,

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

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

$$\sigma_A^2 \ge \sigma_{ADC}^2 \cdot R \cdot diag[Q^T Q]^{-1}$$

or

$$\sigma_A^2 \ge \sigma_{ADC}^2 \cdot R \cdot Z \cdot diag[K^T K]^{-1},$$

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

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