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LIMITING DEPTH OF JAMMER'S SUPPRESSION IN A DIGITAL ANTENNA ARRAY IN CONDITIONS OF ADC JITTER

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Abstract: *In this report are presented results of research of limiting depth of jammer's suppression in a linear digital antenna array (DAA) in conditions of ADC jitter.*

Key words: *digital antenna array (DAA), nulling’s algorithm, jammer, ADC jitter.*

1. INTRODUCTION

One of the advantages of digital antenna arrays is the possibility of the formation of multibeam adaptive pattern. This one allows to perform a deep adaptive compensation of broadband noise, which is realized through the formation of "zeros" radiation pattern in the direction of the source of interference. The limit of jammer's suppression is determined by the accuracy of direction-finding of jammer's source. The ADC jitter is one of the factors determining the direction-finding accuracy.

2. MAIN TEXT

For research of influence of ADC jitter on depth of suppression of jammers we will consider a case linear DAA. We will consider that the jammer represents the unique monochromatic signal operating from an angular direction β, and voltage of the n-th DAA receiver's complex output are described by expression (1)

$$\dot{u}_n(t) = A\exp\left(j\left(\omega t + d\left(\frac{N-1}{2} - n\right)\Omega c^{-1}\sin\beta + \varphi\right)\right), \quad (1)$$

where :

A - amplitude;

ω - IF radian frequency;

Ω - received radian frequency;

c - velocity of light;

d - the distance interval between antenna elements in DAA;

φ - initial phase of received signal.

As nulling’s algorithm for linear DAA we use the known algorithm described in [1, 2]:

$$U = \left(\mathbf{1} - P\left(P^{*}P\right)^{-1} \cdot P^{*}\right)U_0, \quad (2)$$

where U_0 - the initial vector of signal samples at output of receiving DAA;

U - the signal vector after jammer's suppression;

$$P = \left(1 \;\; \exp(-j\Psi\sin(\beta)) \;\; \cdots \;\; \exp(-j(R-1)\Psi\sin(\beta))\right)^{T};$$

P^{*} - the complex-conjugate and transposed vector or matrix P;

$$\Psi = 2\pi\lambda^{-1}d;$$

λ - the wavelength;

R –- a number of elements in DAA;

β - the angle coordinate of jammer;

1 - identity matrix.

Efficiency of jammer suppression we will estimate by means of the relation of the jammer's power in a signal vector after supression to an initial jammer's power

$$\varsigma = \frac{|U|^2}{|U_0|^2}. \quad (3)$$

Further we consider that the direction on a jammer source is estimated by a method considered in [3] for linear DAA on one time sample:

$$\beta = \arcsin\left(\frac{1}{\Psi}\operatorname{arctg}\left(\frac{\sum_{k=0}^{K-1}\sum_{r=0}^{R-2} U_{r,k}^{S}U_{r+1,k}^{C} - \sum_{k=0}^{K-1}\sum_{r=0}^{R-2} U_{r,k}^{C}U_{r+1,k}^{S}}{\sum_{k=0}^{K-1}\sum_{r=0}^{R-2} U_{r,k}^{S}U_{r+1,k}^{S} + \sum_{k=0}^{K-1}\sum_{r=0}^{R-2} U_{r,k}^{C}U_{r+1,k}^{C}}\right)\right), \quad (4)$$

where r is the receiving channel number,

$U_{r,k}^{c}$, $U_{r,k}^{s}$ - voltages of *k*th sample of co-phase and quadrature components at ADC outputs of r-th channel.

It is possible to show that in case of direction finding with an error the quantity ς for four-element linear DAA is described by expression

$$\varsigma = \frac{1}{2}\{5 + 4\cos\left(\Psi\left(\sin\beta - \sin\left(\beta+\alpha\right)\right)\right) +$$

$$+\cos\left(2\Psi\left(\sin\beta - \sin\left(\beta+\alpha\right)\right)\right)\}\times$$

$$\times\sin\left(2^{-1}\Psi\left(\sin\beta - \sin\left(\beta+\alpha\right)\right)\right), \quad (5)$$

where α - a direction finding estimation error. The quantity ς, i.e. the part which has remained after suppression of a jammer, aspires to zero for lack of errors of direction finding of a jammer source.

Assuming that an angle estimation error is small, we can apply a linear Taylor expansion of expression (5) around α, keeping members of the second order accurate

$$\varsigma \approx \frac{5}{4}\Psi^2\alpha^2\cos^2\beta\ . \quad (6)$$

The error of direction finding is defined by noise in reception channel DAA (in particular, jitter). So α is a random variable.

To define average level of suppression of a jammer we write down a direction finding error α in a kind

$$\alpha = E\{\beta\} - \beta + \beta'\ , \quad (7)$$

where $\left(E\{\beta\} - \beta\right)$ - estimation displacement direction finding as a result of noise action;

β' - a casual component of an direction finding error with the average value equal to zero.

Then it is possible to present average value ς for four-elements DAA by following expression

$$E\{\varsigma_4\} \approx \frac{5}{4}\Psi^2\cos^2\beta\left(\left(E\{\beta\} - \beta\right)^2 + D\{\beta\}\right), \quad (8)$$

where $E\{\beta\}$ - a mathematical expectation of estimation of angle coordinate β; $D\{\beta\}$ - a dispersion of angle coordinate β.

Similarly the expressions for average value ς we can write for eight- and 16-elements DAA, accordingly:

$$E\{\varsigma_8\} \approx \frac{21}{4}\Psi^2\cos^2\beta\left(\left(E\{\beta\} - \beta\right)^2 + D\{\beta\}\right),$$

$$E\{\varsigma_{16}\} \approx \frac{85}{4}\Psi^2\cos^2\beta\left(\left(E\{\beta\} - \beta\right)^2 + D\{\beta\}\right). \quad (9)$$

In case of R antenna's elements in DAA a mathematical expectation of estimation ς have the form

$$E\{\varsigma_R\} \approx \frac{R^2-1}{12}\Psi^2\cos^2\beta\left(\left(E\{\beta\} - \beta\right)^2 + D\{\beta\}\right). \quad (10)$$

Let's substitute statistical characteristics of angles estimations (3) into expression (10). Performing the limit by directing quantity of DAA elements to infinity we will obtain the next expression

$$\begin{aligned}\lim_{R\to\infty} E\{\varsigma_R\} = \frac{\sigma_\eta^2}{6A^2} + \frac{1}{2}f^2\sigma_\tau^2\pi^2 + \frac{2}{3}f^4\sigma_\tau^4\pi^4 + \\ +\left(\frac{1}{6}f^2\sigma_\tau^2\pi^2 - \frac{2}{3}f^4\sigma_\tau^4\pi^4\right)\lim_{R\to\infty}\cos\left(4(R-1)\Psi\sin\beta\right)\end{aligned}, \quad (11)$$

where σ_η^2 - a dispersion of additive noise, σ_τ^2 - a dispersion of ADC jitter, A – an amplitude of jammer's signal, f - a frequency of jammer's signal.

The limit $\lim_{R\to\infty}\cos\left(4(R-1)\Psi\sin\beta\right)$, generally speaking, does not exist. However, owing to cos-function definition, it is possible to tell that for any number of elements R the inequality is fair

$$-1 \le \cos\left(4(R-1)\Psi\sin\beta\right) \le 1\,. \quad (12)$$

Considering (12) and limiting a change range jitter to inequality $f\sigma_\tau \le 0{,}01$, it is possible to show that the minimum value of expression (12) is reached at $\cos\left(4(R-1)\Psi\sin\beta\right) = -1$.

Accordingly, as much as possible achievable average depth of suppression of a jammer is described by expression

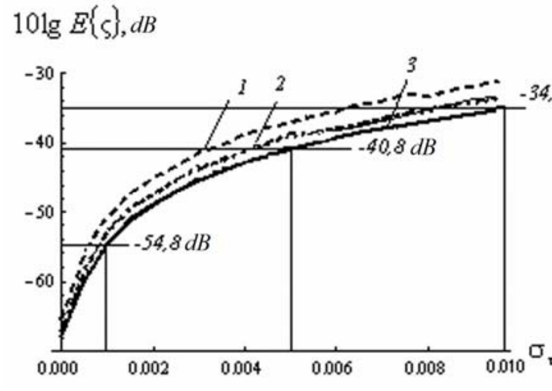
$$\min\lim_{R\to\infty} E\{\varsigma_R\} = \frac{\sigma_\eta^2}{6A^2} + \frac{1}{3}f^2\sigma_\tau^2\pi^2 + \frac{4}{3}f^4\sigma_\tau^4\pi^4\,, \quad (13)$$

Thus, it is possible to draw a conclusion that for in common analyzed method of direction finding and a method of suppression of jammers in DAA there is as much as possible achievable average depth of suppression of the jammer, limited jitter and additive noise which cannot be increased by escalating of quantity of antenna elements.

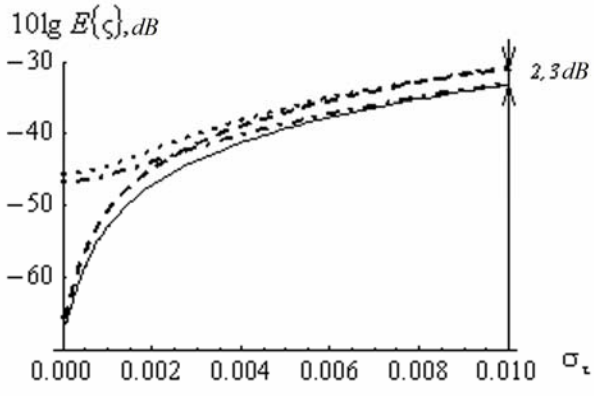
For check of the obtained expressions statistical modeling of suppression procedure according to expression (1) has been carried out. At modeling the true direction on a jammer source was equaled 5 grad, and the relation a „jammers signal/additive noise“ was equaled 60 dB. In picture 1.a curves for 3 variants of quantity of antenna elements are presented: a line 1 – *R*=4, a line 2 – *R*=8, a line 3 - *R*= ∞ (from expression (12)). Each point of diagrams is obtained by averaging on 1000 realisations.

On the schedule limiting values of depth the suppression calculated according to expression (13) are noted.

The Picture 1.b illustrates theoretical expressions (7) and (8) for reduction of a jammer suppression efficiency with growth a jitter. The abscissa is standard deviation of jitter given as fraction of the period of an entrance IF signal.



a)



b)

Picture 1. The average level of suppression of a jammer at presence of ADC jitter

Shaped and dotted lines correspond to a case of a four-elements DAA, continuous and a line stroke-dotted - to a case of an eight-elements DAA. Shaped and continuous lines correspond to the relation a „jammers signal/the additive noise“, equal 60 dB, dotted and stroke-dotted to a line - to the relation a „jammers signal/the additive noise“, equal 40 dB at direction finding of a source of a jammer. From the diagram it is visible that growth of quantity of elements of a DAA from four to eight leads to increase in depth of suppression of a jammer on 2,3 dB. At the further increase in quantity of elements of an antenna array depth of suppression grows non-linear, aspiring to a limit defined by expression (13).

Coincidence of results of modeling to settlement dependences (7) - (9), (13) proves the received results.

The analysis allows to draw a conclusion that jitter reduces depth of "zero" of the diagramme of an orientation in a jammer source direction as a result of deterioration of direction estimation accuracy. The given fact testifies to an urgency of the methods of jitters estimation that allowing to form requirements to ADC jitter in DAA proceeding from the set parametres of noise immunity of radio engineering system.

3. CONCLUSION

Expressions for an expectation of depth of jammer suppression in conditions ADC jitter reception channel DAA are obtained. It is shown that increase standard deviation of jitter about 0,001 periods of an entrance signal to 0,01 leads to reduction of depth of jammer suppression on 20 dB. The impossibility to increase depth of jammer suppression by increase in quantity of antenna array elements is shown for a considered method of direction finding and a method of jammers suppression.

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