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The Influence of Nonlinearity of N-channel Receiver on Interference Cancellation in Communication Networks

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Abstract: In modern communication networks of different purpose, spatial interference suppression by providing nulls in the antenna array pattern, oriented towards the interference sources, is widely used. There are a number of algorithms based mainly on two approaches: correlation matrix inversion or gradient descent. Linearity is an important prerequisite for their effectiveness. In practice, automatic gain control is widely used to compress a huge dynamic range of input signals to an acceptable range for processing circuits. This leads to nonlinearity of the receiving paths. The article analyzes the influence of nonlinearity of the receiving path on the efficiency of interference suppression. It has been found that interference cancellation based on the gradient descent algorithm is significantly less susceptible to the influence of nonlinear effects than that implementing the inversion of the correlation matrix. By simulating a large number of random interference situations for both algorithms, statistical characteristics were obtained depending on the number of interference sources.

Keywords: Adaptive antenna array, Nonlinearity, Interference cancellation, Effectiveness

1. Introduction

As for wireless communication, any (both natural and malicious) sources of electromagnetic radiation in the operating frequency range cause interference to the reception of useful signals. The most promising and effective methods for solving this problem are time-spatial signal processing, which combines frequency-time coding with adaptive regulation of the array's Antenna Pattern (AP). In scientific publications, such arrays are called Adaptive Antenna Arrays (AAA) and in less academic terminology - smart antennas.

Given the severity and complexity of this problem for communication systems of any purpose, not to mention military systems, it is not surprising that the development of methods and means for increasing interference resistance of the systems began a long time ago [1][2][3][4][5][6][7][8] and their improvement continues to this day [9][10][11][12]. Among the huge number of publications devoted to adaptive interference cancellation, there are a significant number of reviews and dozens of fundamental books, for example, [3][5][7] and [13][14][15][16][17][18][19], respectively, which reflect the chronology, content and results of theoretical and experimental research on the topic. The interested reader may refer to these reviews.

Below we briefly, without going into details, describe a typical antenna array configuration and the two adaptation algorithms widely used in radio communication networks. Unlike the main stream of relevant publications, we will take into account the nonlinearity of the receiving path, caused, for example, the widely used automatic gain control. The objective of this paper is to evaluate the impact of path nonlinearity on interference cancellation.

2. Antenna Array with Main Element and N Compensating Ones

In the absence of interference, the AAA must have the initial pattern[1] $F_0(\theta,\varphi)$, and when interference sources appear, it should provide nulls in the corresponding directions with the smallest possible deviation from the initial AP. Therefore, the AAA often contains a main element that provides the $F_0(\theta,\varphi)$ pattern and N additional elements being designed to suppress interference signals. To form zeros in the directions of the interference sources, they are excited by adjustable weights generated by an adaptive processor, the structure of which will be discussed below.

Keeping in mind the assessment of the effectiveness of interference cancellation with nonlinear amplitude characteristics of the receivers used in comparison with the case of ideal receivers, for the sake of certainty, we will consider a communication system with an axisymmetric working area in a hemisphere (isotropic in the horizontal plane) and proportional to sin(θ) in the meridional plane. Under these conditions, a Hertzian dipole (in practice, a quarter-wave monopole over a plane) is excellent as the main element. It is natural to assume that interference can come from any direction with equal probability. Under these conditions, it is practically advantageous to arrange N compensating elements uniformly on a circle of radius a. Moreover, to weaken interference effects and mutual influence of antenna array elements, it is useful to use not isotropic, but weakly directional elements, say, having radially oriented cardioid radiation patterns in the horizontal plane and sin(θ) in the vertical. Figure 1 illustrates the configuration of the antenna array under consideration. The blue lines depict the elements' radiation patterns in the plane of antenna array: isotropic for the central one and cardioidal for compensators.

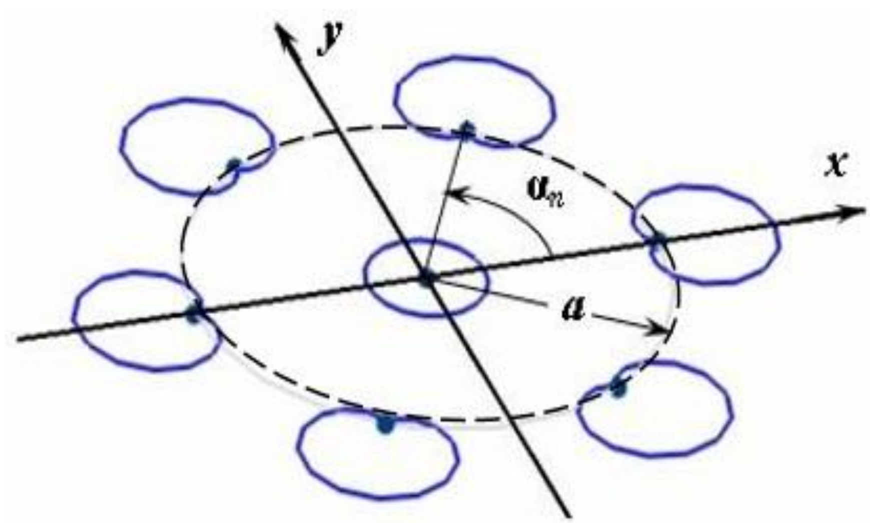

Figure 1: Configuration of antenna array with a main element and six compensators

[1] For example, for a radar, a narrow beam focused on a target, or a sectoral AP covering the working area in navigation or asynchronous communication system.

Thus, in the global spherical coordinate system, the AP of *n-th* compensating element is as follows[2]:

$$f_n(\theta,\varphi) = \sin\theta\,(1+\cos(\varphi-\alpha_n))\,e^{\,j\beta\, a\cos(\varphi-\alpha_n)\sin\theta}\,. \quad (1)$$

Here and after, the notations used are j for the imaginary unit, $\beta = 2\pi/\lambda$ for the wave number, $n = (1\ldots N)$ for the index of the compensating element, $\alpha_n = 2\pi\,(n-1)/N$ for the angular coordinate of the element.

If the intensity of the *m-th* signal source is such that the power of the signal receiving by the main element is equal to P_m, then the complex envelope of the signal receiving by the *n-th* element is

$$S_{n,m}(t) = \sqrt{P_m}\; f_n(\theta_m,\varphi_m)\,, \quad (2)$$

where the angular coordinates θ_m and φ_m correspond to the direction of the signal source. Needless to say that there must be an a priori distinction between useful and interference signals, and the adaptation circuits that adjust the antenna array pattern must respond only to interference. In reality, it is not possible to exclude the influence of useful signals on the course and results of adaptation, but this influence is negligible, and we will ignore it.

Physically, the essence of the process of nulling the antenna array pattern in the required directions is that signals from compensators with adjustable amplitudes and phases (complex weighting factors $\{W_n\}$) are added to the signal of the main element. Thus, at the current moment, the radiation pattern of antenna array is a sum of the main element's radiation pattern sinθ and the weighted AP of compensators:

$$F(\theta,\varphi) = \sin(\theta) + \textstyle\sum_{n=1}^{N} W_n\, f_n(\theta,\varphi)\,. \quad (3)$$

Expression (3) does not reflect this explicitly, but it should be borne in mind that the weighting coefficients $\{W_n\}$ are changing at the rate of their adjustment associated with the dynamics of the interference situation caused by the emergence and movement of interference sources. Therefore, expression (3) should include functions $F_0(\theta,\varphi,T)$ and $f_n(\theta,\varphi,T)$, where the designation T denotes the time for functions that change slowly compared to the rate of changing signal envelopes $S(t)$. The value of the latter is inversely proportional to the receiver bandwidth relating to the width of the useful signals' spectrum.

3. Two Compared Algorithms

At first, the method for suppressing interfering signals using an adjustable antenna array grew out of intuitive considerations Soon the problem of adaptation to a jamming situation received an elegant formulation as the minimization of an goal function reflecting the requirements for a radio communication system. On the one hand, it is necessary to suppress interference at the output of the receiving device, and on the other hand, to the extent possible, to maintain the necessary working area of communication with useful correspondents. The objective function G(W)

[2] We have omitted epy factor $1/\sqrt{2}$, which is not significant for comparative analysis.

$$G(\mathbf{W}) = \begin{cases} P_{\text{out}}(\mathbf{W}) + \mu \parallel F(\theta,\varphi,\mathbf{W}) - F_0(\theta,\varphi) \parallel^2 \\ P_{\text{out}}(\mathbf{W}) + \mu \parallel \mathbf{W} - \mathbf{W}_0 \parallel^2 \\ P_{\text{out}}(\mathbf{W}) + \mu \parallel \mathbf{W} \parallel^2 \end{cases} \quad (4)$$

plays the role of a penalty function, combining the feasibility of physical characteristics with the attractiveness/robustness in mathematical terms. Here W = {Wn} is the vector of weight coefficients n = (1…N), Pout(W) is the power of interference signals at the output of the antenna array, $F_0(\theta,\varphi)$ is the initial radiation pattern, W_0 is the initial weight vector in the case of the Appelbaum scheme. The coefficient μ specifies the cost of the penalty for deviation from the initial state: as its value increases, the requirement for its preservation becomes more stringent.

The objective function represented by the top line in (3) adequately controls the preservation of the required communication area through the deviation of the radiation patterns. The middle line carries out this control indirectly, through the deviation of the weighting coefficients $\{W_n\}$ for the sake of a noticeable simplification of the calculations in the minimization process. With mutual orthogonality of the diagrams of the antenna array elements, both mentioned options are equivalent to each other. In practice, the elements of the antenna array are not located close to each other, but rather far apart, so that their radiation patterns are practically mutually orthogonal. Therefore, the adaptive antenna array optimization criterion presented in the middle line is widely used. Finally, the bottom line is the objective function into which the midline function degenerates for an adaptive antenna array with a main unregulated element (vector W_0 is the zero vector) that we will consider.

Of greatest interest in theoretical and practical terms are adaptation algorithms that arise from two approaches [8, 16, and 18]. *Firstly*, correlation matrix inversion algorithm. For AAA with the main element, it consists of calculating the square matrix <R> of complex correlation coefficients $\rho_{n,k}$ of signals received by the compensating elements ($n = 1…N$, $k = 1…N$), and computing the optimal complex weight vector (CWV) W that minimizes the penalty function (4)

$$\mathbf{W} = (<\mathbf{R}> + \mu <\mathbf{E}>)^{-1} \mathbf{R}_0. \quad (5)$$

Here **<E>** is the identity matrix, $(…)^{-1}$ means the inverse matrix, $\mathbf{R}_0$ is the vector of correlation coefficients $\rho_{n,0}$ of the compensator signals and the signal of the main element of the antenna array. Figure 2 shows the block diagram of the corresponding AAA.

Inversion of a matrix of relatively small order (N<10) using modern computers requires practically no time. However, this does not mean that CWV (5) appears immediately. The point is that the elements ρ_{nk} of matrix <R>, corresponding to the moment of time τ, are the average value of the product of complex envelopes S(t) of signals over time ΔT, significantly exceeding their correlation interval

$$\rho_{n,k}(\tau) = \int_{\tau}^{\tau+\Delta T} S_k(t)\, S_n^*(t) dt \quad (6)$$

Naturally, the rate τ of the adaptation process is quite slow, being predetermined by the dynamics of the interference situation: the emergence of interference sources and the change in their location relative to the AAA.

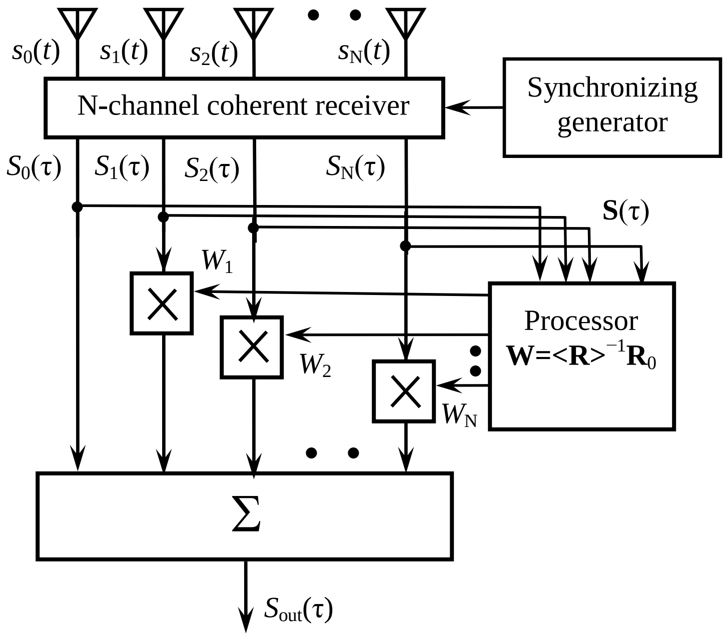

Figure 2: Block diagram of AAA implementing correlation matrix inversion algorithm

Secondly, the gradient descent algorithm, which can be defined either by the equation

$$\mathbf{W}(\tau) = \mathbf{W}\big|_{t=0} - h\int_0^{\tau}\mathbf{Gr}(t)\,dt \qquad (7)$$

or by recursions

$$\mathbf{W}(\tau_{k+1}) = \mathbf{W}(\tau_k) - h\,\mathbf{Gr}(\tau_k), \qquad (8)$$

where $\mathbf{Gr}(t)$ is the gradient vector of the objective function (4) at the current moment. The meaning of both equalities is that the CWV **W** changes in the direction opposite to the gradient $\mathbf{Gr}(t)$, at a rate proportional to the value of h. Thus, the value of the objective function (4) decreases rapidly in real time.

It is easy to show [8] that the *n-th* component of the vector $\mathbf{Gr}(t)$ equal to the correlation coefficient $\rho_{n,0}$ of the signal S_n of the *n-th* antenna element and the output signal S_{out} at the current moment of time τ:

$$\mathrm{Gr}_n = \partial \mathrm{G}(\mathbf{W}) / \partial W_n = \int_{\tau-\Delta T}^{\tau} S_{out}(t)\, S_n^*(t)dt\,. \qquad (9)$$

It is obvious that the process of gradient descent in any of the options pd(7) or (8) converges to the optimal solution (5). Figure 3 shows the block diagram of the AAA implementation, corresponding to the integral equation (7). By the way, it is more practical to use a low-pass filter with a very large time constant $T_{lpf} >> 1/\Delta f$ instead of an integrator. Such a replacement allows to avoid keeping zero in the direction of the disappeared interference source.

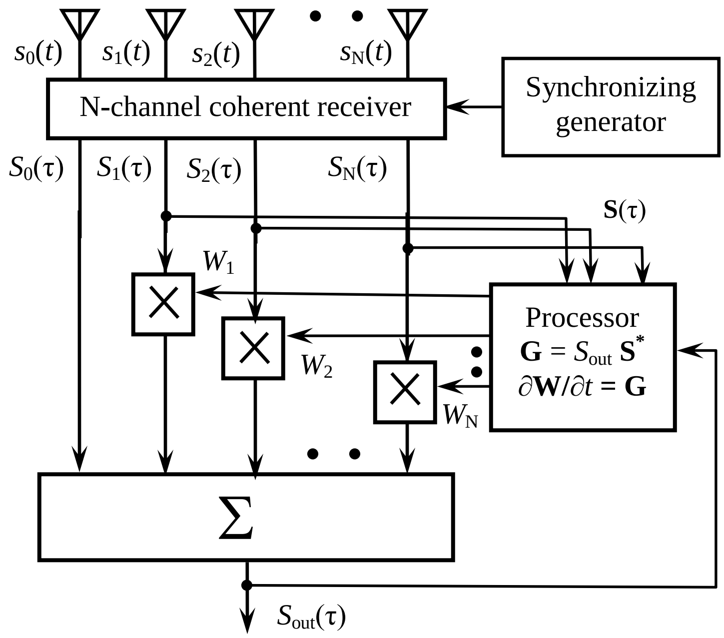

Figure 3: Block diagram of AAA implementing the gradient descending algorithm

Despite the fact that achieving the optimal state (5) takes a certain amount of time, an attractive quality of the gradient algorithm is a significantly lower computational load on the processor. In addition, the high initial speed ensures, if not the ultimate, then effective suppression of interference already at the initial stage of gradient descent.

4. Effect of Receivers' Nonlinearity on Effectiveness of Interference Cancellation

Analytical analysis and numerical studies aimed at assessing the potential capabilities and technical implementation of certain configurations of antenna arrays and principles of adaptive regulation in a variety of interference situations, is carried out in the assumption of the linearity of the characteristics of all AAA elements. The value of such studies is undeniable. However, in practice, the dynamic range of signals processed by the adaptation circuits is limited by the ADC resolution (in the digital version) or sensitivity/accuracy of the attenuators of analog weight multipliers. The dynamic range of both useful and interference signals at the inputs of the receiver is much higher, since the location of their sources changes within the large working area.

4.1. Nonlinearity of Receiver

Each of the receivers, which is part of the N-channel coherent receiver, has to compress the high range of input signals in the range, acceptable for the output circuits, or due to nonlinearity of its multi-stage schema, or by automatic gain control. That is why receivers with a logarithmic characteristic are widespread. In the calculations below, logarithmic characteristics corresponding to the dependences between the amplitudes of the input A_{in} and the A_{out} of the output signals, defended by the following formula:

$$A_{out}(A_{in}) = \log(1 + A_{in}), \quad * \quad (10)$$

depicted in Figure 4 by blue line, will be used below in the calculations. The black line here shows a linear dependence $A_{out} = A_{in}$.

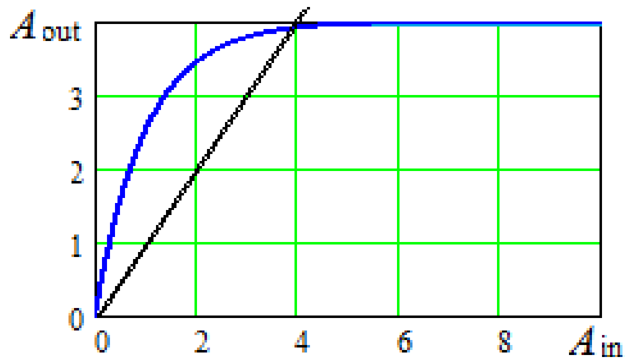

Figure 4: Receiver amplitude characteristic

Naturally, if the amplitude pattern of all the antenna elements is identical, then the non - linearity of the transmission coefficient of the receivers equally changes the proportion between the intensity of the interference signals of various sources and, importantly, in all channels $n = 1...N$ the same. Thus, the situation is equivalent to how if the receivers were linear, and the intensity of the interference sources themselves would have changed: more intense ones would become weaker. Therefore, the orientation of the nulls formed by the AAA towards the interference sources would not change. Some increase in their level is compensated by weakening of the interference intensity due to the logarithmic characteristic. Most often, AAA contains identical elements, and this is probably why there is no interest in taking into account the influence of receiver nonlinearity.

However, circular AAAs, which provide a uniform working area in the plane of the element arrangement, consist of elements with radially oriented weakly directed patterns. Therefore, the ratio of the intensities of interference signals received by different elements is not the same. In each of them, the source located at the maximum of the pattern will prevail over the sources in the opposite region, and for each element, these are different sources. Therefore, the nonlinearity of the amplitude characteristic of receivers in different elements changes the ratio of interference intensities differently, which cannot but introduce distortions both into the correlation matrix <R> and into the "direction" of the gradient vector Gr. This refers to the orientation of the vector Gr in the space of weight coefficients.

Under these circumstances, nonlinearity is the factor that influences the process and efficiency of interference cancellation, and the corresponding estimates are of practical interest.

4.2. Correlation Matrix Inversion Algorithm

Naturally, the effect of non-linearity of receivers on the effectiveness of interference cancelation manifests itself in different ways depending on interference situations i.e. the number of sources, their location and intensity. Nevertheless, before moving on to statistical estimates of the numerical measures of effectiveness, it is curious to see what changes occur at the level of AP and weakening of interferences. Figures 5 to Figure 8 show antenna patterns after adaptation for different numbers $M = 1 \ldots 4$ of interference sources and several situations with their location. Blue curves correspond to linear receivers, and red ones to nonlinear receivers. All interference had the same power exceeding internal noise by 10 times.

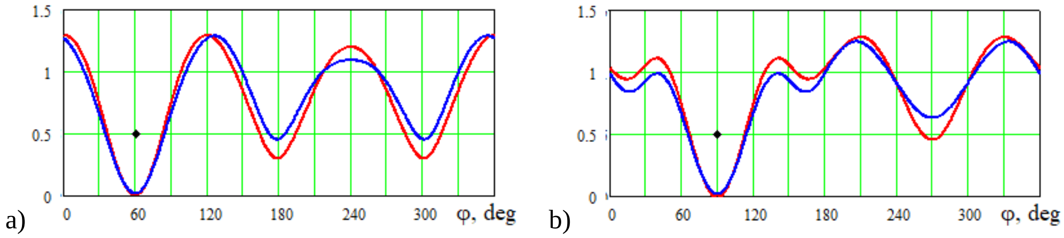

Figure 5: Antenna patterns after nulling the only interference source

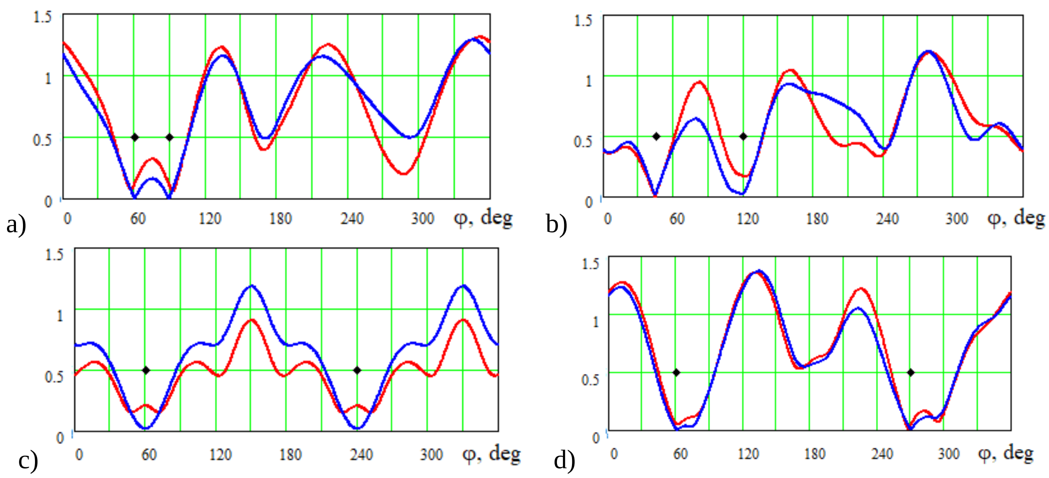

Figure 6: Antenna patterns after nulling two interference sources

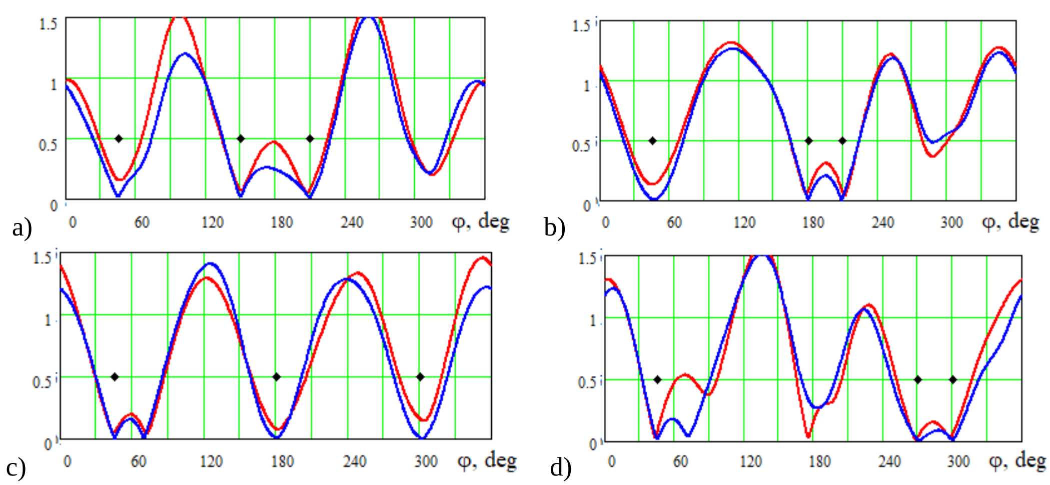

Figure 7: Antenna patterns after nulling three interference sources

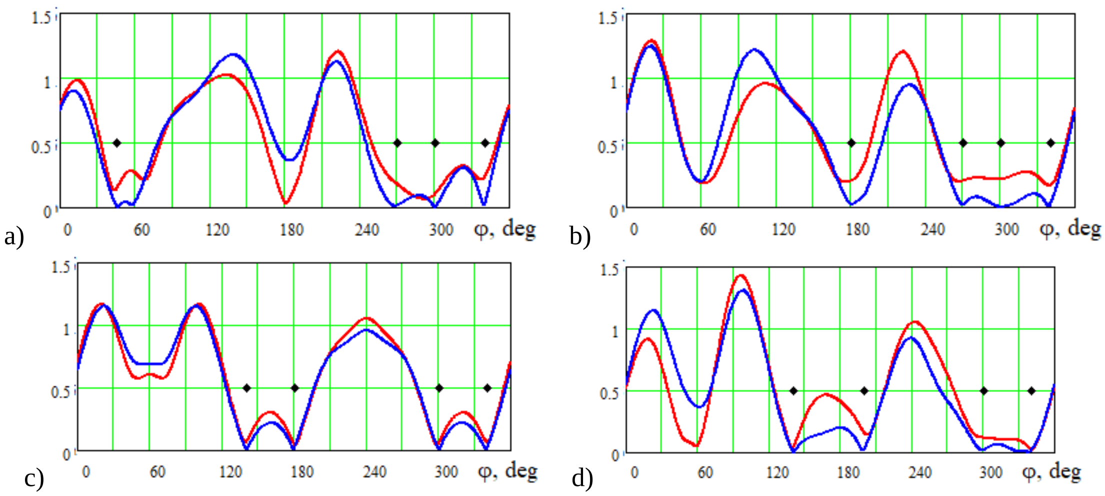

Figure 8: Antenna patterns after nulling four interference sources

The black diamonds on the 0.5 line indicate the position of the interference sources. For the only interference, no more than two situations are of interest: the location of the source is at the angle of the compensator or between it and the neighboring. For a larger number of interference, four situations have been selected. It is not easy to count the value of curves in the direction of interference, especially when it is close to zero.

Table 1 contains numerical data corresponding to Figures 5-8. Here, G is the achieved value of the goal function (4), P_{out} is the ratio (in decibels) the power of interference after adaptation, to its value before adaptation. In the case of a single interference (Figure 5), two situations are under consideration, and the Table 1 has two rows for the corresponding data. In cases with a larger number of interference (Figures 6-8), there are four situations, and Table 1 has four rows of data in the corresponding columns.

Table 1: The values of goal function g and interference power pout

M = 1				*M* = 2			
Linear		Non-linear		Linear		Non-linear	
G	P_{out}	G	P_{out}	G	P_{out}	G	P_{out}
0.174	-34.3	0.190	-43.4	0.25	-36.8	0.32	-19.3
				0.40	-31.4	0.41	-18.4
0.172	-34.3	0.192	-42.4	0.34	-33.4	0.48	-13.7
				0.29	-34.7	0.32	-26.0
M = 3				*M* = 4			
Linear		Non-linear		Linear		Non-linear	
G	P_{out}	G	P_{out}	G	P_{out}	G	P_{out}
0,42	-33.9	0.47	-19.2	0.45	-34.8	0.62	-15.3
0.29	-38.2	0.32	-19.9	0.44	-33.9	0.54	-13.9
0.27	-36.9	0.29	-19.2	0.40	-37.5	0.45	-24.2
0.38	-33.8	0.46	-26.3	0.49	-33.9	0.58	-19.6

In general, the calculation results confirm the obvious fact that nonlinearity reduces the adaptation efficiency and increases the interference power at the output of AAA. An unexpected exception is the situation with a single interference. When replacing a linear receiver with a nonlinear one, the value of the penalty function G(W) increases (from 0.17 to

0.19), as it should be. However, the interference power decreases from about –34 dB to –43 dB. First, on a linear scale this difference is negligible. Secondly, as follows from the difference in amplitude characteristics (Figure 4), the cause of this anomaly may be an increase in the amplitudes of weaker signals at the outputs of all elements of the antenna array, except for the one oriented toward the interference source.

Naturally, statistical estimates of the effectiveness of interference cancellation for a large number of random combinations of their locations are more consistent than the values given above for several specific combinations. Table 2 shows the values of the mathematical expectation ("mean" for brevity) and standard deviation (as RMS) for the ratio of the interference power after adaptation to the interference power before it. The generation of random values, uniformly distributed in the interval 0…2π, set the angular coordinates of each of the interference sources.

Table 2: Mean and RMS values of P_{out} [dB] for 500 random spatial distributions of sources

P_{int}/noise		P = 10						P = 20					
M sources		M =1	M =2	M =3	M =4	M =6	M =8	M =1	M =2	M =3	M =4	M =6	M =8
Lin	Mean	-34	-35	-34	-33	-29	-24	-40	-42	-39	-38	-33	-25
	RMS	0	2.6	2.3	2.6	3.8	4.1	0	2.6	2.4	3.1	4.6	4.9
Non	Mean	-49	=23	-18	-17	-15	-15	-29	-21	-17	-16	-14	-14
	RMS	7.8	6.3	3.6	2.8	2.2	1.8	2.1	5.1	3.4	2.8	2.5	1.9
P_{int} / noise		P = 6						P = 3					
M sources		M=1	M=2	M=3	M =4	M =6	M =8	M =1	M =2	M =3	M =4	M =6	M =8
Lin	Mean	-30	-31	-30	-29	-26	-23	-24	-25	-24	-24	-22	-21
	RMS	0	2.6	2.1	2.3	3.3	3.4	0	2.4	2.2	2.3	2.4	2.5
Non	Mean	-35	-23	-19	-18	-16	-16	-30	-25	-21	-19	-18	-17
	RMS	1.4	4.7	3.9	2.9	2.0	1.6	0.3	5.6	3.7	3.2	2.1	1.7

As expected, receiver's nonlinearity has an increasing impact as the interference power increases. Thus, for interference power P/Noise = 3, the deterioration is on average about 4 dB, while for P/Noise = 20 it increases to 20 dB. Finally, we note that the standard deviation of the values is significantly less than the mathematical expectation, which allows us to ignore their variability.

4.3. Gradient Descent Algorithm

Unlike "direct action" algorithms, such as the correlation matrix inversion discussed above, iterative algorithms are characterized not only by the parameters of the steady state to which the regulation process converges, but also by the dynamics of the descent process. When assessing the influence of nonlinearity of receiver's transmission coefficient on the effectiveness of interference cancellation, the difference in the "rout" and the descent speed plays a secondary role. Moreover, there are a number of means to speed up the descent to the optimal point. Therefore, we will limit ourselves to demonstrating the dynamics of gradient descent for linear and nonlinear receivers only in a situation with three interference sources located at angles of 70°, 110° and 230°. Let the interference power exceed the internal noise power by 10 times.

In Figure 9, the dotted line shows the initial isotropic pattern corresponding to the zero vector of compensator weights $W_n = 0$; thin blue lines show patterns at five iterations (8); and the bold line shows the pattern at the tenth iteration step, which practically coincides with the optimal CWV to which the descent process converges. At step five, the pattern almost merges with the pattern at step ten and is therefore highlighted in black for greater visibility. To equalize the descent speed of both versions, the step values h in (8) were set to 0.0055 and 0.0095, respectively, for linear and nonlinear receivers.

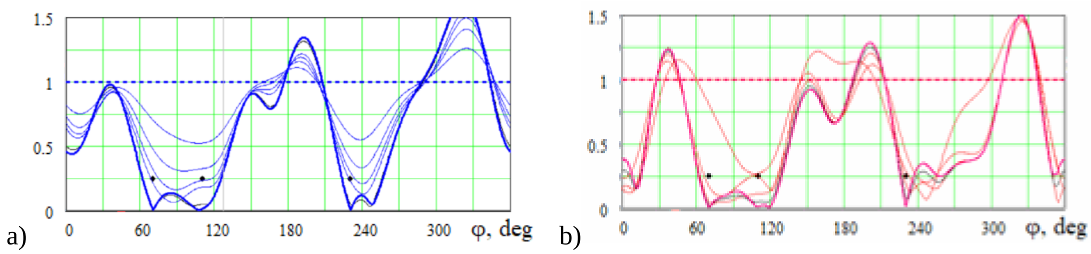

Figure 9: Antenna patterns during descent with receivers: a) linear, b) nonlinear

It is noteworthy that the interference suppression occurs equally deeply in both variants, but the shape of the steady-state pattern deviates less from the initial one for linear receivers. In Table 3, for the above-mentioned series of successive iterations k, the first of the three rows of the two options under consideration shows the values of the deviation of the current CWV W_k from the optimal vector W_∞ to which the gradient descent converges. These data indicate that convergence speed is almost the same.

Table 3: Dynamics of the gradient descent process with linear and nonlinear receivers

Iteration number		$k = 1$	$k = 2$	$k = 3$	$k = 4$	$k = 5$	$k = 10$
Linear	$\|\|W_k - W_\infty\|\|^2$	0.341	0.145	0.068	0.034	0.017	$3.7\ 10^{-4}$
	$P_{out}(W_k)$	0.283	0.110	0.049	0.024	0.018	$5.6\ 10^{-4}$
	$G(W_k)$	0.324	0.196	0.168	0.167	0.171	0.184
Nonlinear	$\|\|W_k - W_\infty\|\|^2$	0.407	0.193	0.098	0.051	0.027	$5.2\ 10^{-4}$
	$P_{out}(W_k)$	0.338	0.149	0.075	0.040	0.022	$1.4\ 10^{-3}$
	$G(W_k)$	0.443	0.0347	0.361	0.391	0.421	0.51

The second rows characterize the attenuation of the interference power at the output of the antenna array, which again differs little in both variants. The third rows contain the values of the goal function (4) for μ = 0.5, i.e. $G(W_k) = P_{out} + 0.5\ ||W_k||^2$. The non-monotonic dependence of these values is due to the fact that at the initial stage of iterations, the attenuation/compensation of interference plays a primary role, and then the factor of deviation of the weights W_k from the initial zero values prevails. Moreover, the nonlinearity of the receivers causes large deviations in the weights with the same attenuation of interference. This is also evident in Figure 9 as a deterioration in the uniformity of the current AP compared to the variant of linear receivers.

It is clear that the parameters reflecting the convergence process and the final efficiency of interference cancellation depend not only on the algorithm used, but also on the number of interferences, their power, and the location of their sources. However, the universal property of compensators is that the more powerful the interference, the deeper is cancellation. The presence of weak interference has a lesser effect on the adaptation process, which makes it possible to limit ourselves to a situation with interference of equal intensity. Calculations show that the above-mentioned feature of the influence of receiver nonlinearity on the efficiency of gradient descent (deterioration of the AP with the same level of interference attenuation) depends on the number of sources, but their specific location has a weak effect.

Therefore, Figure 10 shows steady-state APs for a different number *M* of interference sources for one deliberately chosen combination of their locations. Moreover, too close placement of sources was not allowed, since such sources are equivalent to one and are easily nulling. In our opinion, Figure 10 is clearer and easier to perceive than a set of statistical characteristics like Table 2.

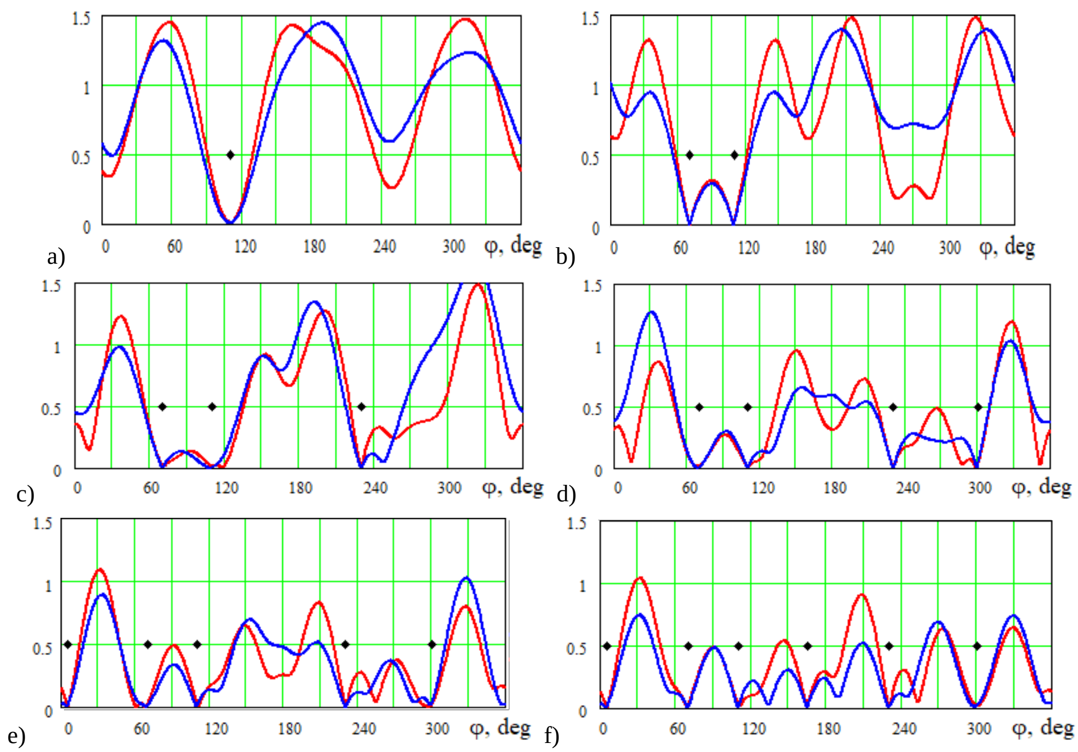

Figure 10: The results of descending for various numbers of interference sources with linear receivers (blue lines) and nonlinear receivers (red line)

The main function of the AAA is to cancel out interferences at its output[3]. Therefore, for the six situations shown in Figure 10, Table 4 presents the values of the interference power[4] P_{out} (in decibels) for the linear and nonlinear receivers.

Table 4: Effectiveness of Interference Cancellation

Situation	M = 1	M = 2	M = 3	M = 4	M = 5	M = 6
Linear	-39.3	-38.8	-37.4	-34.9	-36.5	-37.4
Non-linear	-36.7	-33.6	-31.6	-32.8	-28.4	-30.8

[3] Deterioration of the antenna pattern is an inevitable price for interference nulling.
[4] Power normalized to the power before adaptation.

As follows from the data of tables 4 and 5, the non-linearity of the receivers leads to a noticeably smaller deterioration of interference cancellation if the gradient descent algorithm is used, and not the inversion algorithm of the correlation matrix.

5. Conclusion

The gradient descent algorithm corresponds to a feedback-type block diagram (Figure 3). In contrast to this, the command-type block diagram (Figure 2) realizes the algorithm of correlation matrix inversion. This circumstance determines the lesser influence of receivers' nonlinearity on the efficiency of interference cancellation, since feedback ensures insensitivity to changes in the properties of the regulated object.

The findings presented here, firstly, caution against ignoring receiver nonlinearities when assessing the effectiveness of spatial interference cancellation. Secondly, they encourage the development of more advanced adaptation algorithms that take into account the amplitude characteristics of real receivers. This may be the subject of our future research.

References

[1] Bickmore, R. W. (1964). Adaptive antenna arrays. IEEE Spectrum, 1(8), 78-88. DOI: 10.1109/MSPEC.1964.6500772.

[2] Applebaum, S. P. (1966). Adaptive arrays. – Syracuse University Research Corporation. Rep. SPL TR66-1.

[3] Widrow, B., Mantey, P. E., Griffiths, L. J., & Goode, B. B. (1967). Adaptive antenna systems. Proceedings of the IEEE, 55(12), 2143-2159.

[4] Compton, R. T., Jr. (1971). Adaptive arrays: on power equalization with proportional control. – Ohio State University, Report 3234-1, December 1971.

[5] Pistolkors, A. A, & Litvinov, O. S. (1979). Introduction to the theory of adaptive antenna arrays. Radio Engineering, 34(5), 7-15 (in Russian).

[6] Pistolkors, A. A. (1979). On the calculation of the static mode of an adaptive antenna array. Technical Physics. Reports of the Academy of Sciences of the USSR. 244(3), 590-594, (in Russian)

[7] Gabriel, W. F. (1980). Spectral analysis and adaptive array superresolution techniques. Proc. IEEE, 68(6), 654-666.

[8] Choni, Yu I. & Hassan, A. (2012). Optimal adaptive antenna arrays for asynchronous communication systems. IEEE Trans. on Antennas and Propagation, 60(6), 3071-3076. DOI: 10.1109/TAP.2012.2194667.

[9] Bao, J., Wang, P., Liu, C., Wu, J. & Jiang, B. (2023). Decentralized multisubsystem weighted interference cancellation with coded caching. IEEE Internet Things Journal. 11(2), 3175-3189. DOI:10.1109/JIOT.2023.3295128

[10] Mori, S., Mizutani, K. & Harada, H. (2023). A digital self-interference cancellation scheme for in-band full-duplex-applied 5G system and its software-defined radio implementation. IEEE Open Journal of Vehicular Technology. 4, 444-456.

[11] Lohan, P., Kantarci, B., Ferrag, M. A., Tihanyi, N. & Shi, Y. (2024). From 5G to 6G networks, a survey on AI-Based jamming and interference detection and mitigation. IEEE Open Journal of the Communications Society, 5, 3920-3974. DOI:10.1109/OJCOMS.2024.3416808

[12] Zhu, M., Guo, P., Liu, X., Zhang, H., Othmen, S., Lhioui, Ch., Flah, A., & Perg, A. (2025). A new approach to interference cancellation in D2D 5G uplink via non orthogonal convex optimization. Scientific Reports, 15(1), 7253. DOI:10.1038/s41598-025-92026-4.

[13] Monzingo R. A. & Miller T.W. (1980). Introduction to adaptive arrays. // John Wile & Sons, NY, 541 pages.

[14] Paliy A. I. (1981). Electronic warfare. Means and methods of suppression and protection of electronic systems.// Voenizdat, Moscow, 320 pages (in Russian).

[15] Zhuravlev, A. K., Lukoshin, A. P., & Poddubny, S. S. (1983). Signal processing in adaptive antenna arrays. // Leningrad State University Publishing House. Leningrad. 240 pages (in Russian).

[16] Shchesnyak, S. S. & Popov, M. P. (1995) Adaptive antennas. // Publishing house of the Military Space Academy named after A.F. Mozhaisky, St. Petersburg, 800 pages (in Russian).

[17] Ratynsky, M. V. (2003). Adaptation and super-resolution in antenna arrays. // Radio and Communications, Moscow, 200 pages (in Russian).

[18] Monzingo, R. A., & Miller, T. W. (2004). Introduction to adaptive arrays. // SciTech Publishing, 543 pages.

[19] Chandran, S. (2004). Adaptive antenna arrays. Trends and applications. // Springer Berlin, Heidelberg. 660 pages. DOI: 10.1007/978-3-662-05592-2.