A Novel Method for Increasing the Noise Immunity of Military Radio Systems via Self-Tuned Phased Array Antennas

Yalçın İsayev *, Mustafa Emre Aydemir **‡,
Ahed İsayev *, L.H. Mammadova*

* War College of Armed Forces of the Azerbaijan Republic Azerbaijan Military High School after H.Aliev, Azerbaijan

** Department of Computer Eng., Faculty of Engineering, Istanbul Gelisim University, Avcılar, Istanbul, Turkey

(yalchin.isaev.73@mail.ru, meaydemir@gelisim.edu.tr, ahadisayev@mail.ru, nazrinb97@mail.ru)

‡ Corresponding Author; Mustafa Emre Aydemir, Department of Computer Eng., Faculty of Engineering, Istanbul Gelisim University, Avcılar, Istanbul, Turkey, Tel: +90 212 422 70 00

Fax: +90 212 422 74 01, meaydemir@gelisim.edu.tr

Received: 17.04.2018 Accepted: 08.06.2018

Abstract- The noise immunity of radio systems is one of the most important topics in military science. In this article, the methods for increasing the noise immunity of military-purpose radio systems in connection with increasing the accuracy and reliability requirements of transmitted and received information using modern information technologies have been investigated. A novel analysis method to increase the noise immunity of radio systems for military purposes has been presented.

Keywords Additive interference, antenna patterns, active-noise interference, correlation, spatial selection

1. Introduction

The detection and tracking of military targets by radar is realized in presence of various noise that are created by means of electronic warfare or natural sources. Therefore, both at development and target applications of radar systems, safety precautions for noise immunity must be taken, which can be masking, misinforming or combined, that acts on both main and side directional lobes of radar antenna [1].

The results of the evaluations of noise immunity can be used as a base for determination of interference and its parameters. On the other hand, the results of these investigations are needed during development of noise-protected radars.

2. Active Masking Immunity and Safety Principles

It is known that, when the coming f and heterodyne f_h frequencies enter the mixer detector then the string of $|nf \pm mf_h|$ frequencies is formed at the output. If some of these frequencies coincide with intermediate f_{mid} one on which following stages of receiver are adjusted, then it is amplified and the receiving channel is created. In real conditions, when $f_h >> f_{mid}$, contingent receiving channels are formed on the input frequencies [1]:

$$f_{mn} = \frac{1}{n}(mf_h \pm f_{mid})$$

The characteristics of directivity of pickup and transmitting antennas for out-of-band emission, side emission and receiving channels differ for main emission and receiving channels by much level of side lobes.

In many cases, in the same district the transmitter of radio electronic emits out-of-band and contingent signals, but receiving means also have contingent receiving channels. If main and contingent receiving channel coincide accidentally with main or contingent emission channels and the power of emission signal is high, then there is bilateral masking interference.

The electromagnetic compatibility provides an exclusion of bilateral interference. The electromagnetic compatibility is implemented by filtration of side emissions in transmitting sets, by heterodyne frequencies in receiving stages taking into an account right using propagation conditions, features of terrain, choice of radio-electronic means working regimes.

3. Possible principles for masking active interference

The defence activity from masking active interference can be effective in for case the signal suppression does not occur due to narrow range of receiver. Here, some activities can be applied using frequency, spatial, polarization selection etc. At sufficient dynamic range of receiver, the condition of target detection in masking stationary active interferences of type of white noise is:

$$E_{input} \geq \theta\,(N_0 + N_{ind}) \qquad (1)$$

where E_{input} is energy of received signal on radar detector input; θ is an observability coefficient at given detection or meusurement factors; N_0 is a spectral density of internal noisy of reciever; N_{ind} is a spectral density of masking interference on reciever input. If r_{max} is the limiting range of radar then we take radiolocation equation at precence of interference:

$$\frac{EG_\sigma A}{(4\pi r_{max}^2)2} = \Box\left(N_0 + \sum_{i=1}^{m} \frac{1}{4\pi} \frac{P_{\text{п}i} G_{\text{п}i} A_i^*}{r_{\text{п}i}^2 \Delta f_{\text{п}i}} \gamma_i \alpha_i\right) \qquad (2)$$

This equation is also called as “anti-radar one”. As we can see from (1) and (2), the increasing of probing signal energy increases a range of action in interferences in proportion to $\sqrt[4]{\boldsymbol{E}}$ in mode of external cover and to $\sqrt{\mathbf{E}}$ in mode of self-recover. The increasing of transmission antenna power gain to target direction allows to increase a range of action in interferences also in proportion to $\sqrt[4]{\boldsymbol{E}}$ in mode of external cover and to $\sqrt{\mathbf{E}}$ in mode of self-recover [1].

The decreasing of polarization coefficient $\boldsymbol{\gamma}$ can decrease interference. The decreasing of observability coefficient θ also help to solve this problem. In whole, the action range in mode of self-recover is inversely proportional to $\sqrt{\boldsymbol{\gamma}}$ and $\sqrt{\boldsymbol{\theta}}$. Finally, the decreasing of relativity level of side lobes of directional pattern A'/A (or even, the formation of gaps in main lobe to direction of interferences source) allows to increase the action range in mode of external cover by proportional to $\sqrt[4]{\mathrm{A}'/\mathrm{A}}$.

The increasing of the coefficient of antenna power gain to target direction concentrates useful energy and slows down space survey if such concentration will be provide for all directions. In present, methods of controlling survey with sequential analysis have been developed, when the time of antenna directed to target depends on detection conditions in particular on interference conditions. The application of transmitting antenna with electronic control of ray beam in form of phased array [2] has wide possibilities.

It is known, that receiving antenna is usually in tune with some specified polarization of receivable signal: linear, circular, elliptical. Antennas with controlled polarization. If the polarization of antenna is alligned with polarization of reference then the effect of interference is maximum. For instance, the interference effect will be maximum for vertical polarization if there is a receiver on the vertical vibrator. For circular polarization with field vector clockwise rotation, the the impact effect will be maximum if the antenna is alligned for same kind of polarization. Knowing this, the we can retune antenna on orthogonal polarization that is on the horizontal polarization or on the circular polarization with counterclockwise rotation.

For the elliptically polarized wave also the elliptically polarized oscillation is orthogonal, but with displaced polarization of 90^0. For all indicated noise attenuation is present. As, since (even for not controlling polarization on emmision) the reflected from real targets signal polarization is casual, then there are possibilities to weaken a interference more than signal.

For increasing of a noise immunity it is rational to decrease the coefficient of observability θ for account of optimal receiving. If the disturbance is a stationary noise such as white disturbance, then the decreasing of θ is implemented by recieving optimization for such disturbance. The filtering is done at the recieving stage by using the optimal frequency characteristic, that is, optimal frequency selection. The spot jammings (with less frequency range), as a rule, are more effectivite, but are hard to implement. The spot jamming creation is much more difficult in the case of rapid frequency tuning of radar, at multifrequency or wide broadband probing signal etc. [3]. If the frequency band of disturbance is much narrower than bandwidth of recieving signal, then resulting noise is not considered as white. In this case the frequency characteristic with rejection in interference frequency range is optimal, that is, it is rational to use various kind of tuned rejector filters for disturbance ripples, and it leads to essential decreasing of observability coefficient θ [4].

The improving of spatial selection is a major method for all kinds of active disturbance in radar protection. It is implemented in order to taper of main lobe and decrease the levels of side lobes of antenna diagram up to 25 dB and less relatively to maximize the main lobe in normalized antenna diagram. In result, tapering of sector of effectivety suppression and decreasing of compression ratio of the detection zone of radar is implemented [3]. For improving of spatial selection of signal on disturbance, background noise must come from same direction. The methods of coherent and non-coherent compensation of disturbance oscillations can be used. To do this, subsidiary antennas can be used (phased-array antenna type) [6].

4. Receiver Models

The system including main and two subsidiary antennas is shown on the Fig. 1. Each antenna has own receiving channel. The corresponding receiving channels oscillations are input into adder. Here, complex transfer ratios *K1* and *K2* are regulated on amplitude and phases at least in two subsidiary channels.

If the complex characteristics of channels directivity have shapes $F_0(\Theta)$, $F_1(\Theta)$ and $F_2(\Theta)$, then the cumulative complex characteristic of directivity can be presented as:

$$F_{\sum}(\Theta)= F_0(\Theta)+ K_1F_1 (\Theta + K_2 F_2 (\Theta)) \tag{3}$$

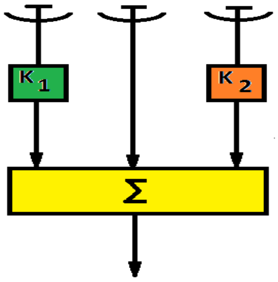

Fig. 1. The system with two subsidiary receiving channels for dips formation in resulted antenna diagram**.**

For the angle coordinates of disturbance sources Θ_1 and Θ_2 we can reach formation of dips in resulted characteristic of directivity for these directions. K_1 and K_2 are defined as:

$$F_0(\Theta_1) + K_1F_1 (\Theta_1) + K_2 F_2 (\Theta_1) = 0, \tag{4a}$$

$$F_0(\Theta_2) + K_1F_1 (\Theta_2) + K_2 F_2 (\Theta_2) = 0. \tag{4b}$$

Due to coherent compensation of disturbance in directivity characteristic, spatial disturbance appears on both main and side lobes. When receiving antennas as phased ones are used, application of compensated methods becomes widely available.

The selection of coefficients in multichannel charts can be realized using the principle of correlation feedback. The chart with two inputs, on which the voltages with same frequence and complex amplitudes $U_0(t)$ and $U_1(t)$ (for example, main and subsidiary antennas), is shown on Fig. 2. On the summer a voltage is formed:

$$U_{\sum}(t) = U_0(t)\text{-KU}_1\text{(t)} \tag{5}$$

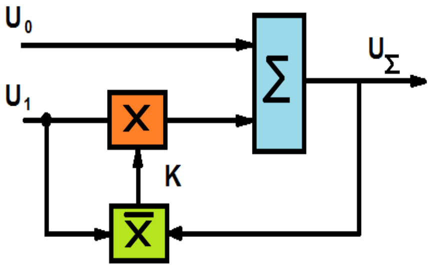

Fig. 2. The chart correlation feedback.

There is a feedback circuit in output of summer to controlling element (multiplier in circuit of first voltage supply). The device of correlation moment calculation $\overline{U_{\sum}\, U_1^*}$ is included in this circuit. The latter with accurate within χ is used as controlling multiplier K supplied on the controlled element. From two equations $K = \chi\, \overline{U_{\sum}\, U_1^*}$ and (5), we can find

$$K = \frac{\chi \overline{U_0\, U_1^*}}{1+\chi|\overline{U_1}|^2} \tag{6}$$

$$U_{\sum} = U_0 - \frac{\chi \overline{U_0 U_1^*}}{1+\chi|\overline{U_1}|^2} U_1. \tag{7}$$

When $\chi \to \infty$ and enough U_0 and U_1 correlation (for example, at $U_1 = CU_0$, where C=constant) the full compensation occurs, that is $U_{\sum}$ becomes zero. As known, the multiplication of complex amplitudes can be realized, for example, by frequency transformation; the averaging can be realized by integration in bandlimited filter [2].

The disturbance compensation effect is provided if each of circuit inputs is involved in correlation feedback (Fig. 3). The voltage U_0 is applied in output of summer at the absence of correlation (when controlling voltage K_0 becomes zero), the weighting voltage α is applied on it. Then, equations are:

$$U_{\sum}= (-K_0+ \alpha\ _1 U_0\text{-KU}_1) \tag{8}$$

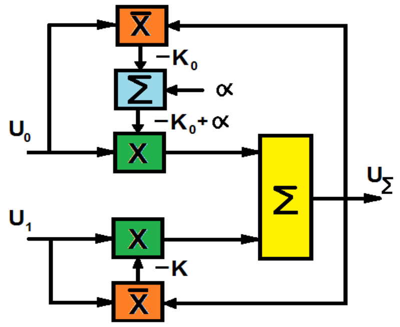

Fig. 3. The compensation chart with correlation feedback on the both inputs.

$$K_0 = \chi \overline{U_{\sum} U_0^*} \tag{9}$$

$$K = \chi \overline{U_{\sum} U_1^*} \tag{10}$$

Substitute (8) in (9) and (10), gives:

$$K_0 = (1+\chi|\overline{U_0}|^2) + K\,\chi\overline{U_1U_0^*} = \alpha\chi|\overline{U_0}|^2 \qquad (11)$$

$$K_0\chi = \overline{U_0U_1^*} + K(1+\chi|\overline{U_1}|^2) = \alpha\chi|\overline{U_1}|^2 \qquad (12)$$

At $\chi \to \infty$, $\alpha = \alpha_0 = \text{const} \neq 0$ and full correlation of voltages U_0 and U_1 when $U_1 = CU_0$, from (8) and (11) we get, that $U_\Sigma \to 0$, in this case the disturbances are compensated.

Along with compensating of disturbances, in both circuits signal compensation occurs in case the duration of the later is enough for circuit's transformation. In the case of a very short signal, both circuits will be tuned only on disturbance compensation [7]. If there is absence of disturbance, both circuits give K and K_0 which are equal zero. Output voltage of second circuit becomes U_Σ - α U_0, when disturbances absence each other, the circuit transmits oscillation applied on the main channel. When $\alpha = 1$, both circuits are identical. If $\alpha = \alpha_0$ (Fig. 8), the weighting α_1 is added to voltage of correlation feedback then output effect in conditions of disturbances absence is

$$U_\Sigma = \alpha_0\, U_0 + \alpha_1\, U_1 \qquad (12)$$

On the base of stated, we can recommend the circuit below with the self-tuned phased antenna (Fig. 4)

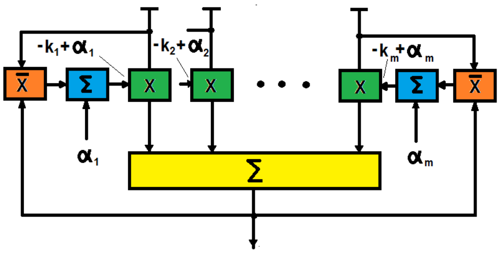

Fig. 4. Multichannel circuit of disturbance compensation using correlation feedback.

In each element of phased antenna, the correlation feedback is used. The correlation feedback is shown in the chart only for the last (left and right) elements. Summands of $\alpha_1, \alpha_2 \ldots \alpha_m$ provide the best effect of signal receiving in absence of disturbance (analogous to component α in Fig. 3). When disturbances come from maximum m directions there are possible formation of side-lobes in directivity characteristic in these directions. As the detailed analysis shows for discrete case, the directivity characteristic is optimized with taking an account disturbances providing the most profitable spatial selection [5].

5. Conclusion

In this paper a novel method to overcome disturbances is proposed. It is necessary to apply disturbance compensation to provide effective interference rejection which depends on character of active disturbances acting on a radar. The results of analysis methods to increase the noise immunity of radio systems for military and civilian purposes have been presented. The possible principles of active disturbances protection by application of coherent and non-coherent compensation of interference oscillations are investigated. It is shown that improvement of signal to noise ratio may be implemented in presence of spatial selection on backround disturbances coming from different directions. It is seen that when the recieving antenna is of phased arry type, there are the optimal compensation is implemented.

References

[1] Daniel W. O'Hagan, Shaun R. Doughty, Michael R. Inggs, Multistatic radar systems, Academic Press Library in Signal Processing, Volume 7, 2018, Pages 253-275,

[2] Shirman Ya.D. Theoretical basis of radiolocation. - M.: Sov. radio, 1970, p.560

[3] Ibragimov B.G., Isayev Ya.S. The analysis of parameters of signals of the noise immunity in radio systems // National security and military sciences. Baku, 2015. № 1(1). p. 145 – 149

[4] Bakulev P. A. Radiolocation systems. –M.: Radiotechnics, 2004, p. 320

[5] Botov M.I., Vaxirev V.A. Basis of theory of radiolocation systems and complexes. Krasnoyarsk SFU, 2013, p.504

[6] Shirman Ya.D., Manjos V.N. Theory and technics of development of radiolocation information with the noise immunity. - Moscow: Radio and communications, 1981, p. 406

[7] Nilov M.A. The multipurpose countermeasures-safe ship radar system with pseudo-continuous broadband sounding. http://www.raspletin.com/NOC/vko/VKO_3(3).pdf