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ESTIMATION OF LOSSES IN JAMMERS COMPENSATION AT THE TRAINING SAMPLE FORMATION BY THE FREQUENCY METHOD

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Background. Under the influence of combined interference, the effectiveness of radar performance significantly deteriorates. This is preconditioned by decorrelation of active noise interference by passive one that has a spatially distributed spectrum. To reduce the influence of passive interference on the active interference compensation process, it is necessary in one way or another to form a classified training sample generated only by the active interference and to assess the possible losses that arise with this case.

Objective. The aim of the paper is to estimate losses for the case of adaptive spatial filtering of the active component of combined interference in the frequency method of generating a classified training sample.

Methods. Analytical method of losses estimation simultaneously with the method of simulation.

Results. The estimation of losses in compensation of active interference arising for different values of the base and the width of the interference spectrum coming from different angular directions has been made. The losses have been estimated which were preconditioned with introduction of notch filters in the chain for forming the weight factor of the autocompensator are estimated.

Conclusions. The scientific novelty is the possibility to estimate the losses in active interference compensation in spatial signal filtering using the frequency method of classified training sample generation. The practical significance is to provide the possibility to choose parameters of the jamming system when designing the radar.

Keywords: adaptive spatial filtering; classified training set; combined disturbance.

INTRODUCTION

The most complicated mode of radar operation is the case of simultaneous (combined) exposure to active and passive noise interference. At simultaneous exposure the passive inference that has spatially distributed spectrum, destroys spatial signal correlation of signals [1-3] that affects significantly on the radio location station noise immunity of point sources of active interference. This results in significant worsening in the noise immunity of the radar. Moreover, when the dispersion of passive interference exceeds the active one the compensation of the latter is generally problematic [4]. That is why, in order to reduce the influence of passive interference in adaptive spatial filtering, it is necessary, one way or another, to formulate a classified training sample, which is generated only by active interference. Obviously, when introducing these restrictions, potentiality to suppress active noise interference reduces. Therefore, when designing interference protection systems, it is necessary to estimate the losses considering the formation of a classified training sample. This task is actual in modern conditions.

PROBLEM FORMULATION

The frequency method for the classified training sample formulation in adapting the weight coefficients of a polarization filter has been proposed in [5] while protecting the main beam of the antenna pattern. This method is realized with the use of frequency distinctions in the structure of active and passive interference, which is determined by the wider spectrum widths of active interference as compared to passive one. With this, it became possible to formulate a classified training sample by rejection of passive interference in the chain of forming the weight factors of the autocompensator. Experimental studies [6] has proved significantly high efficiency of compensating active noise interference acting on the main beam of antenna pattern with use an adaptive polarization filter with rejection passive interference. This was ensured by the fact that during polarization filtration the phase centers of the used dually polarized antenna were combined. When protecting the radio location station against the active noise interference acting in the direction of the side lobes, spatial filtering is used, which is realized by using antenna spaced apart. When scanning such an antenna inter-channel delays of interfering signals occur, which leads to deterioration in the noise immunity of the radar. For this reason, the objective of this research is to estimate losses in compensation of active interferences acting in the direction of the antenna pattern side lobes when the classified training sample is formulated with the frequency method.

MAIN PART

Let us consider an adaptive spatial filter that comprises an antenna system (AS) including the main and compensation antenna, as well as interference autocompensator. A practicable design of the AC shown in Fig.1 and Fig.2 presents active noise interference receiving diagram for the main A_1 and A_2 compensation antennas separated for a distance of d. The distance d is called AS base. The distances from the active noise interference source to the antenna phase centers are denoted as R_1 and R_2. If $R_1=R_2$, then the active noise interference is supplied to the A_1 and A_2 antenna simultaneously.

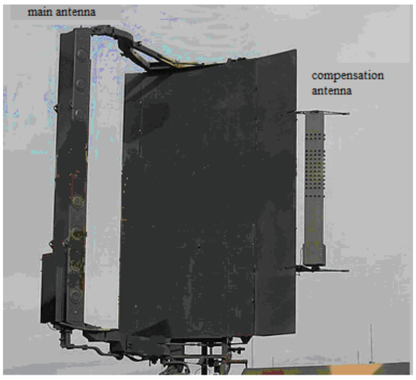

Fig. 1 - Antenna system design

With this the angle θ is zero. However, when scanning the AS, the condition $R_1=R_2$ is violated, angle $\theta \neq 0$ and inter-channel delay of signals active noise interference arises $\tau = \frac{d}{c}\sin\theta$, where c – is the propagation speed of the electromagnetic wave.

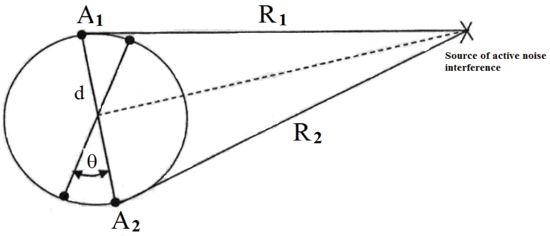

Fig. 2 – Diagram of receiving active interference with antenna system.

The arising inter-channel delay lowers the active noise interference efficiency compensation. To assess the effect of inter-channel signal delay on operation of the spatial filter, we use the formula [7], enabling to calculate the ratio of interference/natural-noise in the output of the autocompensator for frequency components f of the active noise interference spectrum:

:

$$\frac{\sigma^2_{\Sigma}}{2\sigma^2_{\text{С.Ш.}}}(f) = 1+\left(1-\cos\left[\frac{2\pi d}{c}(f-f_0)\sin\theta\right]\right)\frac{\sigma^2_{\text{АШП}}}{\sigma^2_{\text{С.Ш.}}}, \qquad (1)$$

where f_0 – is the center frequency of the active noise interference spectrum, and $\sigma^2_{\text{АШП}}$ – - is it's dispersion, $\sigma^2_{\text{С.Ш.}}$ – is the dispersion of natural noise in the auto-compensator channels. σ^2_{Σ} – is signal dispersion in the autocompensator output. The suppression factor of interference $K_{П}$ is further calculated by the ratio

$$K_{П} = \frac{\sigma^2_{\text{АШП}}}{\sigma^2_{\text{С.Ш.}}} - \frac{\sigma^2_{\Sigma}}{2\sigma^2_{\text{С.Ш.}}}. \qquad (2)$$

Fig. 3 presents the results of computation of the active noise interference suppression factor for several values of angular position of antenna system θ with relative active noise interference dispersion equal to 40 dB and a located base value d = 2 m, for different values of frequency spectrum components f. From Fig. 3 it follows that the losses in active noise interference compensation are proportional to θ and reach a maximum when θ = 90°. In the area of the first side lobes which as a rule have the highest level these losses are significantly less. Losses in the in active noise interference compensation can also be reduced when the spectrum width of the signals being processed is less.

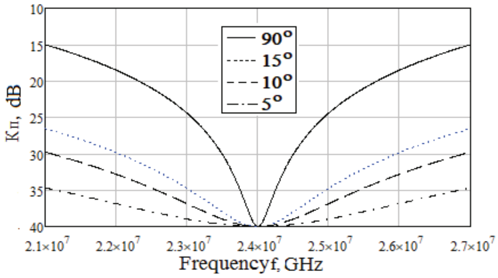

Fig. 3 – Relationship of the active noise interference suppression factor to frequency at the angular position of noise relatively to the antenna normal θ = 5 °, 10 °, 15 °, 90 °

Fig. 4 presents the computation of active noise interference suppression factor relatively to the base value d when relative active noise interference dispersion is 40 dB and a located angle θ equals to 15 degrees. From Fig.4 it follows that losses in the active noise interference compensation are proportional to the base d magnitude and the spectrum width of the interference being compensated.

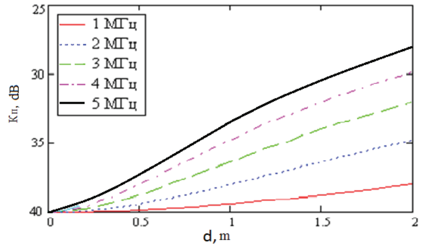

Fig. 4 – Relationship of the active noise interference suppression factor to the distance between receiving antennas having different widths of the interference spectrum.

In antenna system presented in Fig. 1, the antenna spacing of d = 2 m distance is preconditioned by the design of the antenna main channel, where a mirror antenna is used as. However, when using a phased antenna array, the formation of diagram of compensation antenna direction may be provided by the emitters that make up base radio location station antenna which gives an opportunity to decrease base d magnitude. With these the losses in interference compensation, as it follows from the above calculations, can be significantly reduced.

Fig.5 presents structural diagram of spatial filter that contains an interference auto-compensator with correlation of feedback and rejection passive interference in the circuits of weight formations. The autocompensator includes the device for complex conjugation of signals 1, the complex multiplier 3, the integrated signal conjugation signal 1, the first notch filter 2, integrated multiplier 3, integrated multiplier accumulator 4, the adder 5, the multiplier 6 and the second notch filter 7.

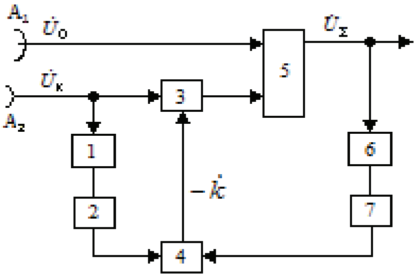

Fig. 5 - Structural diagram for spatial filter with correlation feedback

Output signal of the autocompensator $\dot U_\Sigma$ is determined with the difference between the integrated signal amplitude of basic channel $\dot U_0$ and the weighted factor $\dot k$, integrated signal value of the compensation channel $\dot U_k$

$$\dot U_\Sigma = \dot U_0 - \dot k \dot U_k . \qquad (3)$$

The weight factor multiplier-drive 4 is calculated with known formula

$$\dot k = \mu \dot U_\Sigma \dot U_k , \qquad (4)$$

where μ – is a scalar value determining the depth of the correlation feedback. The notch filters 2 and 7 providing suppression of passive interference in the circuits of weight factor $\dot k$ have amplitude-frequency characteristics with a band of rejection ΔF as shown in Fig. 6.

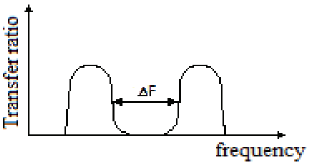

Fig. 6 - Amplitude-frequency characteristic of the notch filter

When forming a classified training sample by the frequency method, the circuits for forming weight factors and formation circuits and the autocompensator signal circuits operate with different frequencies. Therefore, it was of interest to estimate the losses in active noise interference compensation arising as a result of rejecting passive interference in circuits of the formation of the autocompensator weight factors. To estimate the losses a simulation of modeling of autocompensator interference has been carried out as with notch filters in circuit correlation connection as well as without them.

The simulation was carried out in the Matlab system SimuLink graphic extension environment. The active noise interference dispersion of the interference in the main and compensation channels of the autocompensator was taken as equal to 40 dB relatively natural noise of the receiving channels. With this the active noise interference spectrum width made 6 MHz on the central frequency of 30 MHz. To account for losses arising from active noise interference compensation in case of passive interference rejection in the circuits of weight autocompensator factor formations when classifying the training sample, notch filters with attenuation band of 1 MHz were used at the center frequency of 30 MHz.

When modeling, the modulus of the normalized inter-channel factor of correlation and the relationship of active noise interference suppression factor to time were controlled both in the presence of notch filters and without them. Fig. 7 presents the result of modulus estimation of the inter-channel correlation factor $|\dot\rho|$ in the input of the autocompensator

$$|\dot\rho| = \frac{\overline{|\dot U_0 \;\; \dot U_k^*|}}{\sqrt{\overline{|\dot U_0|^2} \;\; \overline{|\dot U_k|^2}}}, \qquad (5)$$

where $\dot U_0$, $\dot U_k$ – are the integrated active noise interference values at inputs of the basic and compensation channels, * – is the sign of the integrated conjugation; the bar above is the averaging sign.

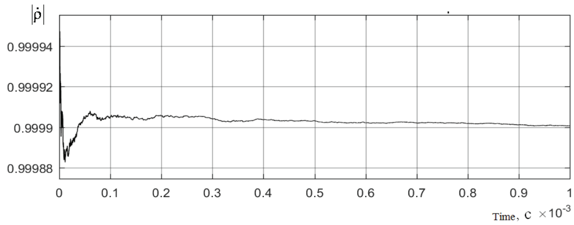

Fig. 7 - The relationship of the inter-channel rated correlation factor $|\dot\rho|$ to time

The solid line in Fig. 8 represents the result of estimation of active noise interference factor of suppression Кп in function of time at the output of the autocompensator without notch filters in the circuits of weight factor formation.

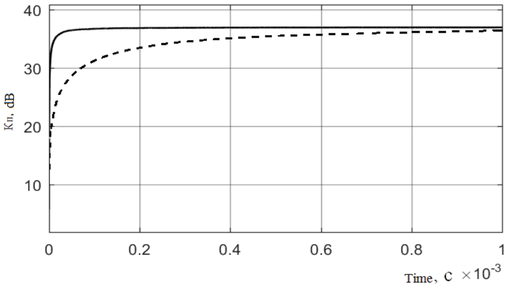

Fig. 8 - Relationship of $K_П$ suppression factor to time: the solid line - without notch filters, the dotted line – filters are present

The dotted line shows the relationship of the Кп suppression factor to time in the presence of notch filters. From Fig. 8 it follows that the presence of notch filters results in pulling transfer process of autocompensator adaptation that is stipulated with integrated characteristics of notch filters. With this, losses in active noise interference compensation vary from 5 dB in the adaptation interval equal to 100 μs to 1.1 dB in the adaptation interval equaled to 1 ms. These losses can probably be partially reduced with integrators parameters changes making up autocompensator components and this requres additional research being continued.

Analysis of the relationship of the suppression factor of the spatial filter to the width of the active noise interference spectrum being compensated (Fig. 3) gives the idea to consider that the wider the spectrum of signals being compensated, the less is the suppression factor of the . This is preconditioned with the use of spatial differences in the structure of the useful signals and the active noise interference acting on the side lobes of the antenna pattern. The consequence of this is the presence of variable signal delay between the main and compensation channels when scanning AS.

A possible option to improve the efficiency of noise compensation is the narowing bandwidths of the main and compensation channels by using coordinated signals and band-filters. However, the using of coordinated filters in structural diagram of Fig. 5 before the inputs of the adder 5 results in decorrelation of the signals at the inputs of integrated multiplier-accumulator 4 for the reason of active noise interference band diversity of signals being supplied to its inputs.

The authors proposed another option to construct a spatial filter, the structural diagram of which is given in Fig. 9.

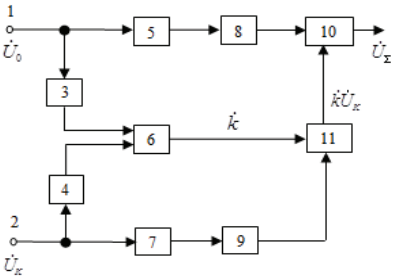

Fig. 9 - Structural diagram of the spatial filter with direct calculation of the weight factor

The diagram contains the basic 1 and compensation 2 channels, notch filters 3 and 4, coordinated filters 5 and 7, the device for calculation of weight factor 6, the delay line of the basic channel 8, the delay line of the compensation channel 9, the subtraction unit 10, the multiplication unit 11. The diagram is based on using autocompensation with direct calculation of weight factor. With this, its calculation is realized directly the moment after rejection of passive interference in channel signals but coordinated filters limit the spectrum of signals at the inputs of the subtraction unit that limit the spectra of signals being compensated. Apparently, we can assume that the achievable gain in the compensation factor is determined by the ratio of the active noise interference spectrum width at the input of coordinated filter and its bandwidth.

Simulation modeling that the authors are planning to realize in further research will make it possible to assess the relationship of the gain in compensation active noise interference to band narrowing of interferences being compensated in adaptive spatial filter.

Conclusions

The scientific novelty of the conducted research is in determining the losses of active noise interference compensation arising from different base values and the width of the active noise interference spectrum coming from different angular directions θ when AS scanning. Developed is simulation model for autocompensator interference with the formation of a classified training sample with the frequency method. The evaluation of losses in active noise interference compensation has been carried out, the latter were preconditioned with the introduction of rejection filters into the circuit of autocompensator weight factor formation while forming classified training sample with the frequency method. The practical significance of the results obtained gives the possibility to choose the parameters for the system of noise protection when designing radio location station.

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Піза Д.М., Романенко С.М., Мороз Г.В., Семенов Д.С.

Оцінка втрат в компенсації завад при формуванні навчаючої вибірки частотним методом

Проблематика. При впливі комбінованих завад ефективність функціонування радіолокаційної станції істотно погіршується. Це обумовлено декорреляцією активної шумової завади пасивною завадою, котра має просторово-розподілений спектр. Для зменшення впливу пасивної завади на процес компенсації активної шумової завади необхідно тим чи іншим чином сформувати класифікаційну навчаючу вибірку, породжену тільки активною завадою, і оцінити можливі втрати, які при цьому виникають.

Мета. Оцінка втрат при адаптивній просторовій фільтрації активної складової комбінованої завади при частотному методі формування класифікаційної навчаючої вибірки.

Методи. Аналітичний метод оцінки втрат спільно з методом імітаційного моделювання.

Результати. Виконано оцінку втрат в компенсації активної шумової завади, які виникають при різних значеннях бази антенної системи і ширини спектра завади, котра надходить з різних кутових напрямків. Оцінені втрати, зумовлені запровадженням режекторних фільтрів в ланцюзі формування вагового коефіцієнта автокомпенсатора.

Висновки. Наукова новизна полягає в оцінці втрат в компенсації активної шумової завади при просторовій фільтрації сигналів з використанням частотного методу формування класифікаційної навчаючої вибірки. Практична значимість полягає в можливості вибору параметрів системи завадозахисту при проектуванні радіолокаційної станції.

Ключові слова: адаптивна просторова фільтрація; класифікаційна навчаюча вибірка; комбінована завада.

Пиза Д.М., Романенко С.Н., Мороз Г.В., Семенов Д.С.

Оценка потерь в компенсации помех при формировании обучающей выборки частотным методом

Проблематика. При воздействии комбинированных помех эффективность функционирования радиолокационной станции существенно ухудшается. Это обусловлено декорреляцией активной шумовой помехи пассивной помехой, имеющей пространственно-распределенный спектр. Для уменьшения влияния пассивной помехи на процесс компенсации активной шумовой помехи необходимо тем или иным образом сформировать классифицированную обучающую выборку, порожденную только активной помехой, и оценить возможные потери, которые при этом возникают.

Цель. Оценка потерь при адаптивной пространственной фильтрации активной составляющей комбинированной помехи при частотном методе формирования классифицированной обучающей выборки.

Методы. Аналитический метод оценки потерь совместно с методом имитационного моделирования.

Результаты. Выполнена оценка потерь в компенсации активной шумовой помехи, возникающих при различных значениях базы антенной системы и ширины спектра помехи, поступающей с различных угловых направлений. Оценены потери, обусловленные введением режекторных фильтров в цепи формирования весового коэффициента автокомпенсатора.

Выводы. Научная новизна состоит в оценке потерь в компенсации активной шумовой помехи при пространственной фильтрации сигналов с использованием частотного метода формирования классифицированной обучающей выборки. Практическая значимость состоит в возможности выбора параметров системы помехозащиты при проектировании РЛС.

Ключевые слова: адаптивная пространственная фильтрация; классифицированная обучающая выборка; комбинированная помеха.