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COMPARATIVE EVALUATION OF METHODS FOR COMPENSATION OF PASSIVE INTERFERENCE IN RADAR LOCATION STATIONS

The work deals with the known filters for selection of moving targets in conditions of a limited time sample of input signals and varying accuracy of data presentation. A method of deterministic compensation is proposed, and this method suggests suppression of passive interference in rejection zone in line with the principle, which is close to compensation of point active interference (ACP) with autocompensators having a seamless access of the interference correlation matrix in the conditions described in the work.

Keywords: *amplitude-frequency characteristic, width of the interference spectrum, rejection zone, interference correlation matrix, limited optimization method, vector of weighting coefficients.*

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The issue of countermeasures against passive interference of natural or artificial origin arose along with the period when first Radar Location Stations (RLS) appeared and it is still relevant now. Passive interference means radio signals, reflected from underlying terrain, hydrometeors and local objects when they are radiated by RLS probing signals. Their impact is represented by suppressing and hiding signals reflected from the observed target. The intensity of interference may substantially supersede not only the inherent noise level of the receiver, but also the target's useful signal. This complicates radar observation and sometimes makes it impossible.

According current assessment [1] in such situation the ratio «signal/interference» will be 60 dB or less. Depending on different parameters, which include RLS carrier frequency, pulse period, range of wind speed etc. the passive interference bandwidth can be 10 and more per cent of the bandwidth determined by RLS pulse repetition rate.

In order to separate the useful signal bandwidth and passive interference bandwidth under such conditions it is practical to use MTI filters with close to rectangular shape of amplitude-frequency characteristics (AFC). The depth of rejection zones for such filters must be 60 or more dB.

In this context the purpose of the article is to analyze advantages and disadvantages of some of well-known methods of creation of MTI system filters AFC of which meet the listed requirements and to describe the method of deterministic compensation of passive

In modern RLS the systems of moving target selections are used to protect the receiving path from passive interference. The main role in suppressing interference is played by frequency filters (FF).

It is well known that filters with infinite impulse response (IIR) in the form of elliptical or similar filters have close-to-rectangular AFC [2, 3]. If there are four feedbacks or more then such filters guarantee almost rectangular rejection zone with sufficient depth. But IIR filters have a substantial disadvantage – long transient period. Frequently this does not allow using them in real life situations. Due to the length of transient period IIR filters cannot switch into stable running. In the situation when the number of impulses received from RLS is limited. In practice such limits are imposed by strict requirements to the speed of detection area surveillance when there is no chance for observing one direction for quite a long time.

So, on Fig. 1 we can see AFC of an elliptical quartic filter, the description of which is given in [4]. The bandwidth on horizontal axis is limited by the value of $\Delta F = \pm 1/2T_{\Pi}$, where T_{Π} is pulse period. AFC shown on Fig. 1a–1c respectively were received under conditions when batches of 200, 100 and 30 impulses were sent to the filter input. So, from Fig. 1a–1c we can see that when the number of impulses $N_{и} = 200$ the depth of rejection zone is 60 dB, which coincides with the results, given in [4].

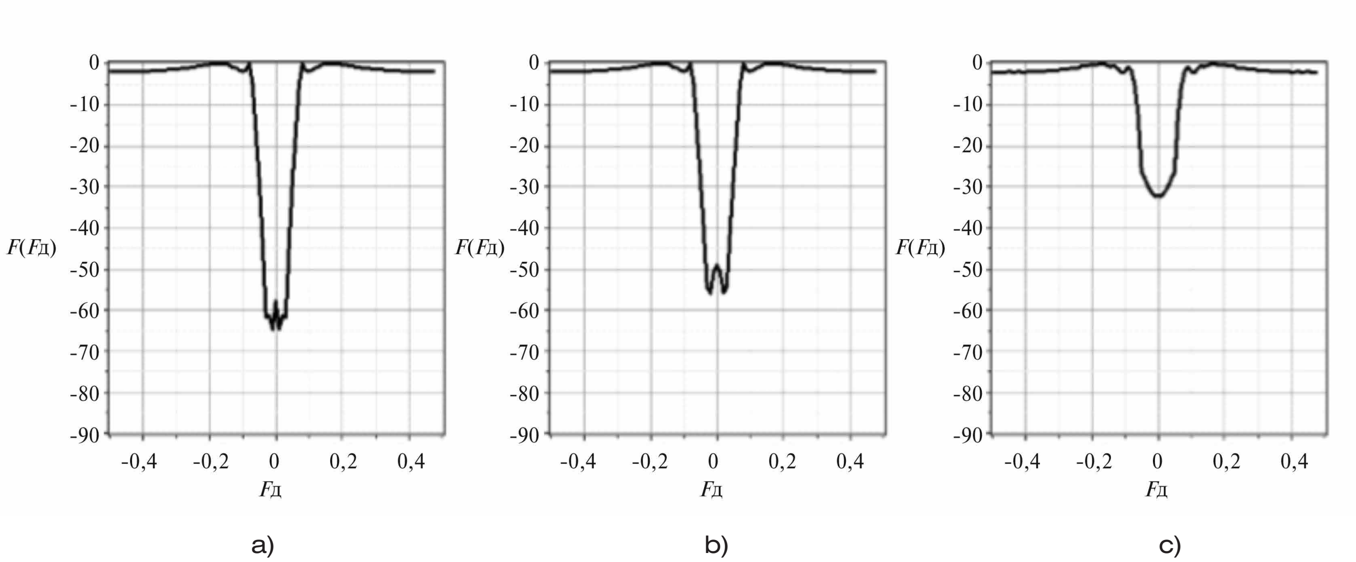


Figure 1. The elliptical quartic filter AFC dependence on the number of input impulses when $N_{и}$ = 200 (a), 100 (b) and 32 (c)

When we have such number of impulses the filter is in stable running. When we reduce the number of input impulses to 100 the depth of rejection zone is also reduced to 50 dB and if the number of input impulses is 32 the rejection zone becomes approximately 30 dB, which is not enough for work when you have passive interference.

When we have short input samples the more efficient approach will be the one based on creating MTI filters with AFC of a desired shape by using limited optimization method [4]. The essence of this approach is the following: the bandwidth DF is covered with parallel set of narrow bandwidth frequency filters, the maximums of which are tuned to the corresponding frequencies beyond the rejection zone. In the rejection zone, located near zero Doppler frequencies, the AFC of each filter have poor frequency responses with a certain width and depth. When creating AFC a successive search of phase coefficients $e^{j\varphi_s^n}$ is carried out. These phase coefficients are necessary for creating a frequency characteristic of a filter $\dot{F}_n(X)$ with a number n on frequency X with the required shape by using the criteria, described by the expression

$$\left|\dot{F}_n(X)\right|^2 = \left|\sum_{s=0}^{S-1} e^{j\,{}_s^n} e^{j\frac{2\pi}{S}(X-n)s}\right|^2 = \left|\begin{matrix}\min, X_{p1} \le X < X_{p2} \\ \max, X = n\end{matrix}\right., -0,5 \le X < 0,5, \quad (1)$$

where S is the number of impulses; X_{p1} and X_{p2} represent border frequencies of the rejection zone in the area of zero frequencies. The search of phase coefficient φ_s^n is carried out until the filter characteristic $\dot{F}_n(X)$ of the required shape is formed.

But despite the irresistible advantages the method of limited optimization has a disadvantage connected with the reduction of zone rejection depth when it is widened. So, on Fig, 2a, 2b and 2c AFC of filters with resonant frequency 0.25 F and rejection zones ±0.025 ΔF, ±0.05 ΔF and 0.15 ΔF respectively are represented.

We can see that when widening rejection zone its depth is reduced from 80 dB with the rejection zone width ±0.025 ΔF to 40 dB with the rejection zone width 0.15 ΔF. So the most efficient filters do not meet the increased requirements to the quality of passive interference suppression under the condition of time limited input samples.

One of the latest methods of passive interference compensation is the projection method [1], the essence of which is the approximation of reverse correlation interference matrix by projector matrix (projection operator) to the subspace, which is orthogonal to the space of the interference. In accordance with this the projection operators that provide the calculation of weight vector (WV) will look like

$$U^{-1} \approx E - P, \quad (2)$$

where E is a unity matrix; $P = M(M^H M)^{-1} M^H$ is a matrix-projector onto the subspace of interference; H is a dagger; $M = [S(f_1), S(f_2), \ldots S(f_L)]$ is the matrix made of column-vectors of signals, the Doppler frequencies $f_1,\ldots, f_L$ of which cover the passive interference bandwidth in certain increment; U_0 is the vector of useful signal with the Doppler frequency f. If we take into account the approximation (2) the optimal weighting vector of inter-period processing will look the following way

$$b = (E - P)U_0, \quad (3)$$

and the optimal processing procedure will be the calculation of module of the expression

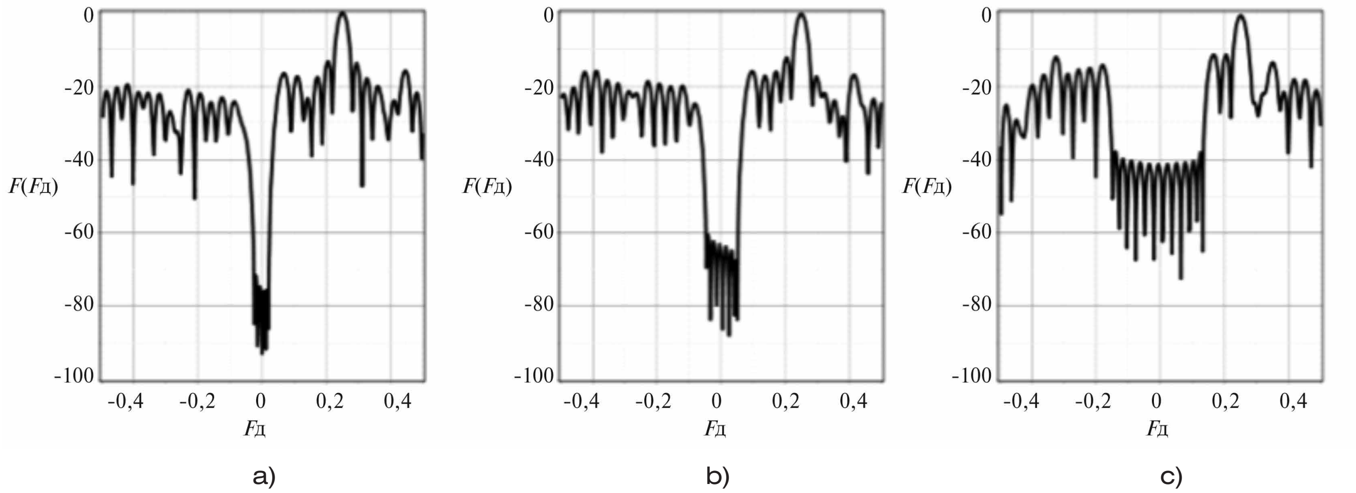


Figure 2. AFC of frequency filters with rejection zone width ±0.025 Δ*F* (a), ±0.05 Δ*F* (b), 0.15 Δ*F* (c), received using the method of limited optimization for the batch of 32 impulses

$$y = X^H (E - P) U_0, \quad (4)$$

where X is the vector that corresponds to the received azimuthal packet.

Meanwhile the matrix-projector (2) acts as the rejecter of passive interference and is common for all Doppler filters. Zeros of the rejection zones are defined by the values of vector frequencies $f_1,...,f_L$, which form the matrix M in the expression (2). But such a method also has a disadvantage, which is critical in respect of data accuracy. For effective work of projection MTI with creation of 5 poor frequency responses the accuracy of no less than 16 digits after decimal point is required. When there are 7 poor frequency responses the accuracy must be no less than 26 digits after decimal point. So, om Fig. 3 the AFC of projection MTI RLS is given in the situation when the mixture of useful signal and passive interference is sent to the input. The signal frequency was equal to 0.045 of the value, which is inverse to the pulse period. In the rejection zone 5 poor frequency responses were formed at the data accuracy equal to 14 and 16 digits after decimal point (Fig. 3a, 3b) and 7 poor frequency responses at the data accuracy of 24 and 26 digits after decimal point (Fig. 3c, 3d).

So the projection MTI allows creating AFC of the rectangular shape with the rejection depth no less than 60 dB at the passive interference bandwidth, equal to 10 or more per cent of the frequency bandwidth, determined by RLS pulse frequency, but the data accuracy must be 20 digits after decimal point. When this method is used for processing the signals with lower accuracy, the efficiency of this method will actually be the efficiency of alternate-period tertiary compensator. In order to overcome this disadvantage and to meet the requirements to filters of MTI systems on width and depth of the rejection zone another method was developed. This method is called deterministic compensation

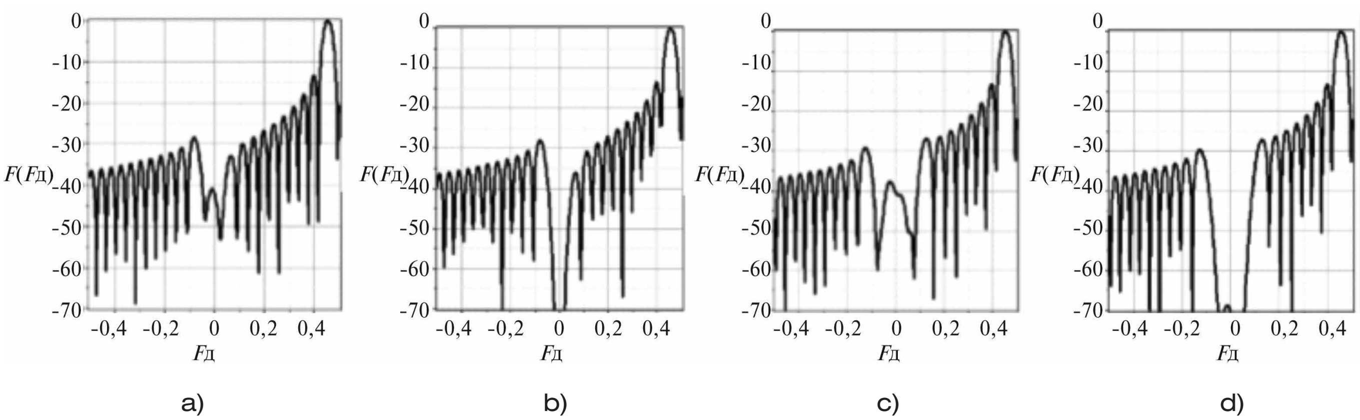


Figure 3. AFC of MTI RLS1L122 for rejection zone with five poor frequency responses for data accuracy: a – 14 digits after decimal point and b – 16 digits after decimal point; with seven poor frequency responses for data accuracy: c) – 24 and d) – 26 digits after decimal point

method the essence of which is described below. This method provides passive interference suppression in the rejection zone using the principles, close to compensating point-source active interference (AI) by automatic compensator with direct conversion of correlation interference matrix [5, 6].

In [7] there is evidence that when the number of noise jammers is equal to the number of compensating channels of automatic compensator the weight vector (WV) is defined only by the values of directional characteristics of protected and compensating channels in the direction of noise jammer. WV in this situation will look the following way:

$$b = F^{-1}F_n,$$

$$F = \left\| \begin{matrix} \dot{F}_1(Y_1) & \dot{F}_2(Y_1) & \cdots & \dot{F}_M(Y_1) \\ \dot{F}_1(Y_2) & \dot{F}_2(Y_2) & \cdots & \dot{F}_M(Y_2) \\ \vdots & \ddots & \ddots & \vdots \\ \dot{F}_1(Y_M) & \dot{F}_2(Y_M) & \cdots & \dot{F}_M(Y_M) \end{matrix} \right\|, \quad (5)$$

$$F_n = \left\| \begin{matrix} \dot{F}_n(Y_1) \\ \dot{F}_n(Y_2) \\ \vdots \\ \dot{F}_n(Y_M) \end{matrix} \right\|$$

Where $\dot{F}_n(Y_m)$ is the value of directional characteristics of a channel with number n in the direction of interference Y_m number m.

Interference compensation is carried out according to the expression

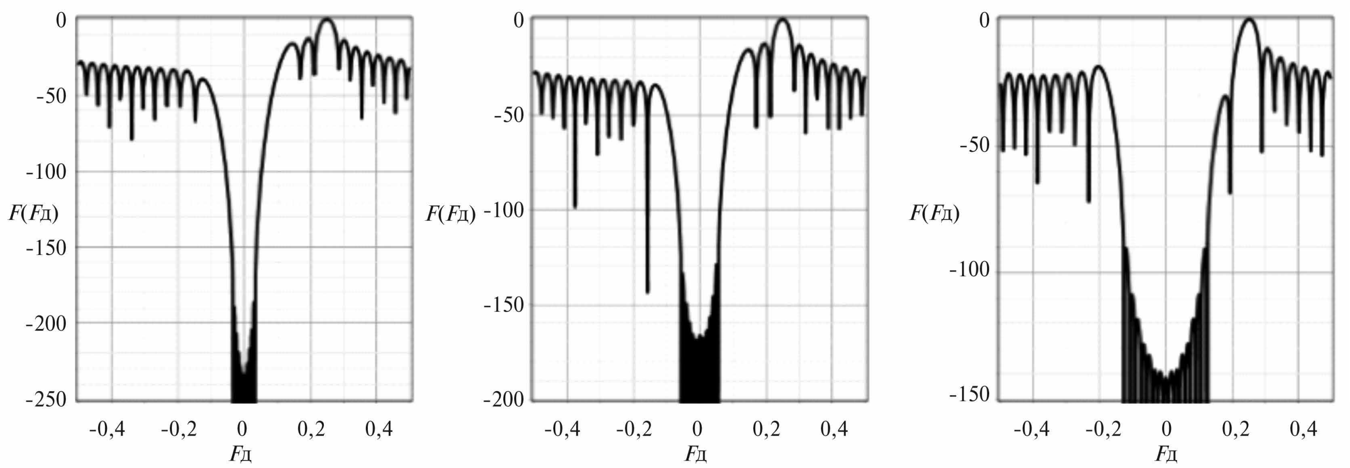
$$\dot{U}_n^{\text{комп}} = \dot{U}_n - \sum_{m=1}^{M} \dot{b}_m \dot{U}_m, \quad (6)$$

where $\dot{U}_n$ is the signal of the protected channel; $\dot{U}_m$ is the signal of compensation channel with number m. As the result of such compensation M poor frequency responses are formed in the directional characteristic of protected channel in the direction to the source of interference.

When frequency filtering of signals is used the tension on the output of the filter with number n will look the following way:

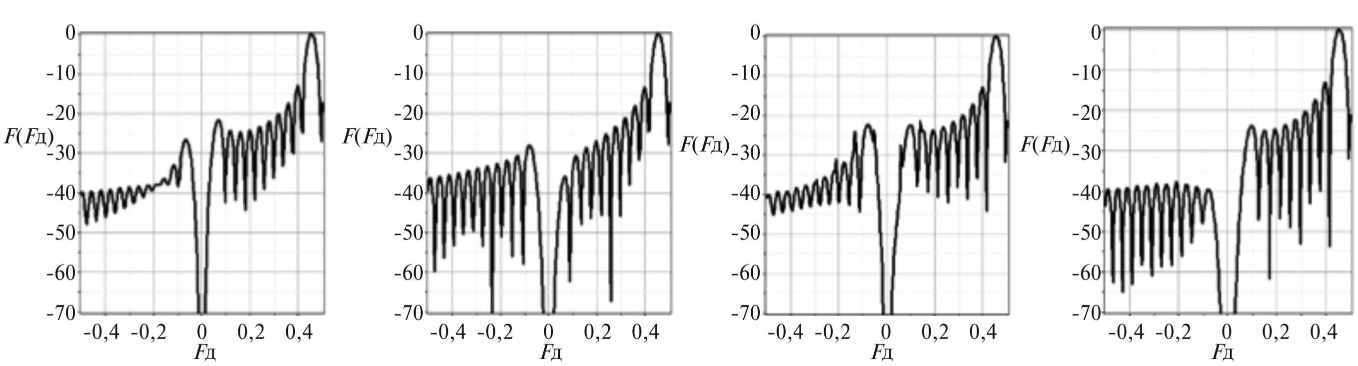
$$\dot{U}_n = \sum_{m=1}^{M} \dot{a}_m \dot{F}_n(X_m) + \sum_{p=1}^{P} \dot{a}_p \dot{F}_n(X_p). \quad (7)$$

Due to the well-known equivalence of spatial and time signal processing [2] we can say that in expression (6) the frequency filter characteristics act as spatial channels and frequencies of signals and interference act as directions from which signals and interference come in space. When the signals are digitally processed the shapes of characteristics of frequency filters $\dot{F}_n(X_m)$ and $\dot{F}_n(X_p)$ are already known with high accuracy. The passive interference bandwidth can also be measured accurately enough. This fact combined with the equivalence of signal processing in time and space allows us to deterministically assign the frequencies near zero Doppler frequencies. On these frequencies in the characteristics of frequency filters poor frequency responses will be formed. Knowing these frequencies and the shape of frequency characteristic of filters according to expression (5) a WV is formed. After this according to expression (6), in which instead of values of signals of spatial channels we put the values of signals from the filters' outputs, the compensation of passive interference is carried out. On Fig. 4, 5 AFC of filters are represented. Those AFC were received using the method of deterministic compensation of passive interference with the same rejection zone width as the one



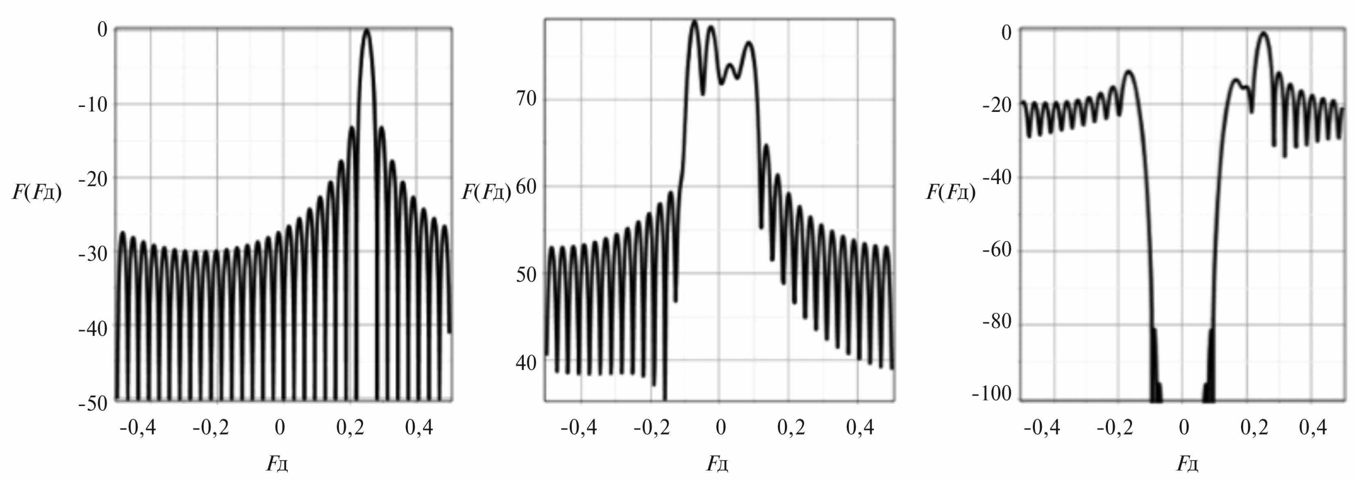
a) b) c)

Figure 4. AFC of frequency filters with rejection zone width ±0.025 Δ*F* (a), ±0.05 Δ*F* (b), 0.15 Δ*F* (c), for the batch of 32 impulses, received by deterministic compensation method



a) b) c) d)

Figure 5. AFC of deterministic MTI for the rejection zone with 5 poor frequency responses (a, b) and 7 poor frequency responses (c, d) with data accuracy 10 and 12 digits after decimal point.



a) b) c)

Figure 6. Bandwidth of useful signal with frequency 0.25 ΔF (a), the mixture of signals with interference (b) and useful signal after compensating passive interference at the passive interference bandwidth equal to $\pm 0.1\ \Delta F$ and signal/interference ration –80 db (c)

on Fig. 2, 3. The comparison of the results received by methods of limited optimization and deterministic compensation give us evidence of substantial superiority of the latter.

Fig. 6 shows the bandwidth of useful signal with frequency 0.25 DF (Fig. 6a), the mixture of signals with interference (Fig. 6b) and useful signal after compensating passive interference using the proposed method (Fig. 6c) at the passive interference bandwidth equal to ± 0.1 DF and signal/interference ration –80 db.

From the results presented here we can see that compensation of broadband passive interference lets us to select useful signal. That confirms the efficiency of deterministic compensation method. Deterministic compensation method guarantees suppression of broadband passive interference. Ta the same time the required depth and width of rejection zone is supported with much lower requirements to data accuracy.

Conclusion

The result of this research show that from the point of view of providing required rejection zone with limited input signal sample, the deterministic compensation method is the most efficient one. It allows us to efficiently compensate passive interference under the conditions of limited in length input samples of signals. At the same time the high data accuracy (10–9) is not required for implementing this method.

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