Knowledge Representation Method for Object Recognition in Nonlinear Radar Systems

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Abstract

Substantiation of the technical appearance of nonlinear short-range radar system designed to detect and measure the characteristics of objects with nonlinear electrical properties is the main topic of this article. The general principles of constructing short-range radar system are described in the form of their structural diagrams and algorithms for their operation, which ensure the maximization of the signal-to-noise power ratio at the output of the receiving device. An optimal procedure for distinguishing a noise-like signal against a background of noise and interference was proposed on the basis of measuring the moment characteristics of the probability distributions of signals and interference.

Keywords 1

Radiolocation, Nonlinear Radar, Correlation Filtering, Radar Information Processing.

1. Correlation filtering algorithm in nonlinear radar systems

The rapid development of methods and techniques for radar sounding of objects with electrically nonlinear properties stimulates the search for ways to optimize the structures of detecting receivers of nonlinear radar devices and algorithms for optimal signal processing in them. The relevance of these problems is due to the small range of action of modern nonlinear radars even when the power levels of the emitted signal are increased to values of the order of tens and hundreds of kilowatts when a pulsed signal is emitted. Let us list the main reasons for the low level of the signal-to-noise power ratio at the receiver input:

- a weak level of nonlinear responses from an object with nonlinear properties at the frequencies of harmonics or combination components of emitted signals;
- overlap of the spectrum of the emitted signal and the spectra of nonlinear responses in the reception band of the nonlinear locator (the reception of the useful response signal from the nonlinear object is carried out against the background of its own interference);
- low values of the gain of the locator antenna (especially in the range of radiation of the emitted signal);
- congestion of the radio frequency range with sources of radio emissions for various purposes in the frequency range optimal for use in non-linear radar.

We propose a procedure for synthesizing an optimal algorithm for detecting a nonlinear object by the method of nonlinear radar against the background of additive noise and interference caused by the influence of the above factors.

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As a criterion for optimality of detection, let us take the Neyman-Pearson criterion traditionally used in radar. The optimal filter receiver – the detector calculates the values of the correlation integral and compares them with a threshold to make a decision about the presence of a target.

The correlation integral in the case of receiving a signal with completely known parameters is determined by the expression

$$Z(t) = \int_{-\infty}^{\infty} X(t, f_K) Y(t) dt \qquad (1)$$

where $X(t, f_k)$ - expected response signal from a nonlinear object at the frequency of the k-th harmonic of the emitted signal.

$$Y(t) = n_{rand}(t) + n_{reg}(t) + AX(t, f_{Ktrue}) \qquad (2)$$

In expression (2), the parameter A takes the values 1 (there is a target) and 0 (there is no target). The random noise component $n_{rand}(t)$ includes unremovable intrinsic internal and external noises of the radar receiver, which have a probabilistic irregular nature (noises of receiver elements, atmospheric noise, etc.) The interference component $n_{reg}(t)$ is due to the contribution to the additive mixture (2) of the regular components of the spectrum of the emitted signal with an average frequency (f_0), falling into the receiver's passband, as well as the influence of external unavoidable regular interference.

It can be shown that the elimination of the regular interference component $n_{reg}(t)$ from the additive mixture (2) in the process of special processing of signals and interference in the receiver leads to an improvement in the reception quality indicators. The block diagram of such an optimal detector, which implements the algorithm for compensating its own regular interference components in the adopted implementation, is shown in Figure 1.

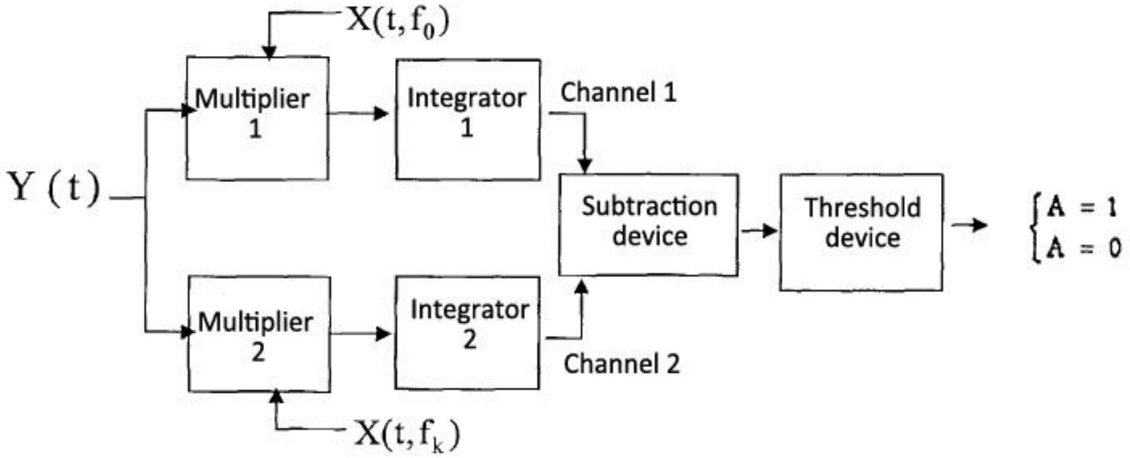

Figure 1: Block diagram of detector

The proposed scheme of the optimal filter for detecting objects with nonlinear properties differs from the known ones by the presence of a special channel 1 for calculating the correlation integral corresponding to the quantitative contribution to the noise + interference mixture of the regular component $n_{reg}(t)$.

Subtraction of this component leads to an increase in the signal to noise + interference ratio at the output of the signal processing device.

The main elements of the circuit shown in Figure 1 are multipliers, integrators, a subtractor and a threshold (decision) device.

To the first multiplier, together with the received mixture Y (t), a reference oscillation $X(t, f_0)$ is supplied, corresponding to the emitted signal, which is the source of the occurrence of a regular component of its own interference $n_{reg}(t)$.

The second multiplier of the main receiving channel 2, together with the oscillation Y (t), receives the reference oscillation $X(t, f_K)$, which corresponds to the expected response signal from the nonlinear object at the frequency f_K.

The reference expected oscillation $X(t, f_0)$ is formed in the nonlinear radar transceiver by converting the signal at the emitted radiation frequency f_0 at the built-in nonlinear element into the harmonic component expected as a response at the frequency f_K.

Direct integration of the products $X(t, f_0)Y(t)$ and $X(t, f_K)Y(t)$ gives the values of the correlation integrals in the corresponding channels of the signal receiving and processing device.

Mathematically, the algorithm of the optimal filter (Figure 2) is described as follows. The correlation integral at the output of the first integrator of the receiving device contains three components:

$$Z_1(t) = \int_{-\infty}^{\infty} n_{rand}(t)X(t, f_0)dt + \int_{-\infty}^{\infty} X(t, f_{0true})X(t, f_0)dt + A\int_{-\infty}^{\infty} X(t, f_{Ktrue})X(t, f_0)dt \qquad (3)$$

On the right-hand side of equation (3), in the second integral, the first factor $X(t, f_{0true})$ corresponds to the regular component $n_{reg}(t)$, and the second factor $X(t, f_0)$ corresponds to the reference emitted oscillation.

The correlation integral of the second (main) integrator of the optimal filter has the form:

$$Z_2(t) = \int_{-\infty}^{\infty} n_{rand}(t)X(t, f_K)dt + A\int_{-\infty}^{\infty} X(t, f_{Ktrue})X(t, f_K)dt + \int_{-\infty}^{\infty} X(t, f_0)X(t, f_K)dt \qquad (4)$$

The resulting correlation integral $Z_r(t) = Z_2(t) - Z_1(t)$ at the output of the subtractor does not contain mutually exclusive components $\int_{-\infty}^{\infty} X(t, f_K)X(t, f_0)dt$ and $\int_{-\infty}^{\infty} X(t, f_{Ktrue})X(t, f_0)dt$.

The resulting correlation integral, calculated as the difference between expressions (4) and (3), is a combination of signal and noise components (with a plus sign) and noise and interference components eliminated by the receiving structure (Figure 1) (with a minus sign):

$$\begin{aligned} Z_r(t) = A\int_{-\infty}^{\infty} X^2(t, f_K)dt + \int_{-\infty}^{\infty} n_{rand}(t)X(t, f_K)dt - \int_{-\infty}^{\infty} n_{rand}(t)X(t, f_0)dt \\ - \int_{-\infty}^{\infty} X^2(t, f_0)dt \end{aligned} \qquad (5)$$

The signal component $A\int_{-\infty}^{\infty} X^2(t, f_K)dt$ of the correlation integral $Z_r(t)$ is determined by the energy of the useful response signal from the nonlinear element received in the mixture (2) at the frequency f_K. The greater the value of $Z_r(t)$, the higher the probability of correct detection P_{CD} with a fixed value of the false alarm probability P_{FA}. P_{FA} is unambiguously related to the threshold level set for making a decision on the presence of a goal.

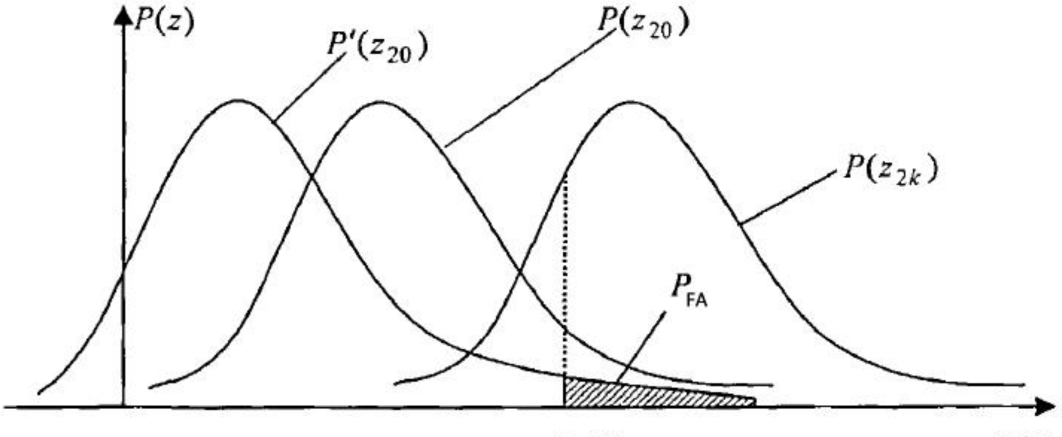

Figure 2: The physical interpretation of the detecting procedure

The physical interpretation of the optimal filter procedure for detecting a response signal from a nonlinear element in accordance with algorithm (3) - (5) is as follows. The presence or absence of a useful signal in the received additive mixture (2) results in the corresponding distribution of the probability distribution density of the correlation integral at the output of the second integrator of the filter circuit $p(Z_{2k})$ and $p(Z_{20})$ (Figure 2).

In accordance with this algorithm for optimal processing of the signal-noise mixture, the features of the target detection process characteristic of nonlinear radar, which will be discussed below, are considered.

The false alarm probability P_{FA} corresponds to the area limited by the indicated PDF and the threshold $Z_t(t)$. The presence of channel 1 and a subtracting device ensures the elimination of the regular component from the aggregate of interference and noise, which leads to a shift of the PDF $p(Z_{20})$ to the left along the z axis by a value, corresponding to the constant component of the process $n_{reg}(t)$. Figure 2 the corresponding process PDF is denoted as $p'(Z_{20})$.The probability of a false alarm in the first and second cases (with the traditional method of reception and reception according to the considered algorithm) corresponds to the area limited by the specified PDF and the threshold $Z_t(t)$. The figure shows that at a fixed threshold level, the probability of a false alarm (shaded area) decreases. In this situation, by fixing the false alarm probability level, it is possible to reduce the value of the threshold $Z_t(t)$, which will lead to an increase in the signal / (noise + interference) ratio at the output of the considered filter receiver.

In the absence of a useful signal in the adopted implementation (5), at the output of the circuit there are only random noise components with the probability density of the amplitude distribution $p'(Z_{20})$. In this case, the resulting PDF obeys the normal law, and the probability of a false alarm in accordance with the Neyman-Pearson criterion is calculated by the formula:

$$P_{FA} = \int_{Z_t(t)}^{\infty} p'(Z_{20})dz = 1 - F\left(-\frac{Z_n(t)}{\sqrt{\frac{2E}{N_0}}}\right) \tag{6}$$

where F(*) - tabular probability integral;

$\frac{2E}{N_0}$ – signal / noise power ratio.

Based on (6), it is possible to determine the quantitative effect of applying the proposed algorithm for detecting a useful signal against the background of noise and interference.

The graphs of the dependences of the measurement of the false alarm probability on the signal-to-noise ratio obtained based on (6) for various values of the parameter $h = \frac{Z_n(t) - Z_{reg}(t)}{Z_t(t)} 100\%$ are shown in Figure 3.

The parameter h has the meaning of a relative threshold and characterizes the influence of the excluded interference component during signal and interference processing.

The rapid development of the theory and technique of nonlinear radar dictates the need to develop and improve methods for optimal detection of targets with nonlinear electrical properties. By analogy with the methods of linear radar, the optimal detection of targets in nonlinear radar is carried out by implementing procedures of accumulation, agreed filtering or correlation reception. In all cases, the consequence of optimal signal processing is an increase in the energy ratio signal / background (signal / noise, signal / interference), which provides a given signal detection efficiency according to the selected detection quality criterion (eg, Neumann-Pearson criterion). However, with nonlinear radar, it is not the reflection but the conversion of the probe signal, as a result of which the signal / background ratio is usually small. In this case, the detection of the response (signal) with a given efficiency with the direct application of linear radar algorithms becomes problematic.

It is known from the theory of linear radar that in cases of pronounced fluctuation of signal and background reflections and radiation, the efficiency of distinguishing the useful signal against the background of interference of natural or artificial origin is significantly reduced due to increased probabilities of fictitious alarms. The latter occur when the level of the established detection threshold of accidental background fluctuations or interference is exceeded. This situation is typical, for example, for the detection of small or masked radar targets (RLC) against the background of wind-swaying vegetation, the disturbed water surface, etc. The most noticeable deterioration in the detection quality of the RLC at small angles of the radar sounding of targets with a high level of specific effective scattering area (EPR). In nonlinear radar, a similar situation is observed when searching for targets with nonlinear electrical properties against the background of objects with unstable oxide contacts. The analysis shows that the problem of detecting objects with nonlinear electrical properties under interference conditions has much in common with the problem of distinguishing between fluctuating radar targets on the background of underlying surfaces with high levels of specific EPR.

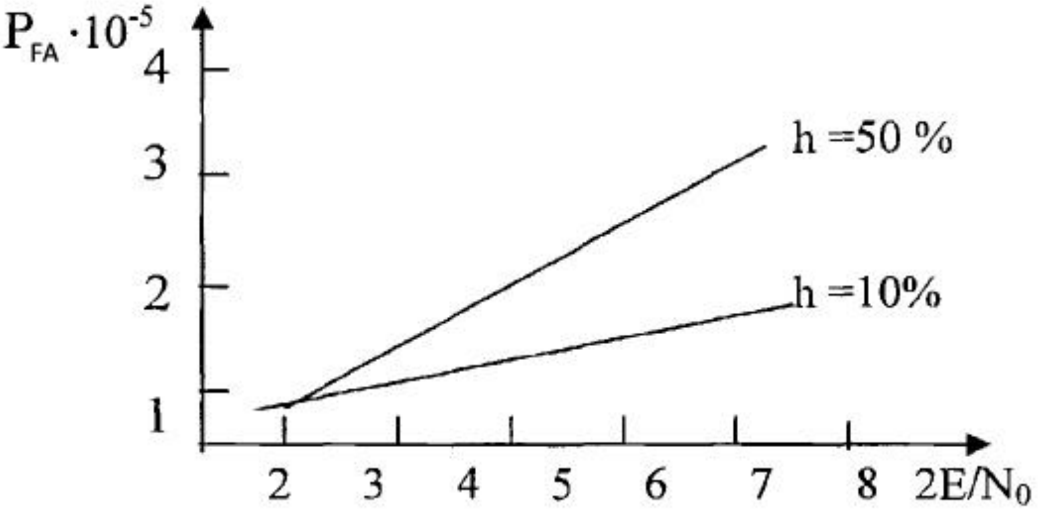

Figure 3: Dependences of the false alarm probability on the signal-to-noise ratio

The analysis of the obtained dependences shows that a decrease in the probability of a false alarm in accordance with the processing algorithm (3) - (5) is manifested in the region of low values of the signal-to-noise ratio, and the greater the relative contribution of the excluded component, the more pronounced this pattern is.

Thus, the receiver structure shown in Figure 1 and relations (3) - (5) are, respectively, an optimal filter and an algorithm for detecting an object with electrically nonlinear properties. The practical implementation of the principles of signal and interference processing proposed here provides the possibility of improving the quality of detection of useful signals by eliminating the regular components of intrinsic or external interference. The consequence of these circumstances is the possibility of increasing the range of detection nonlinear radar devices while maintaining the performance indicators of the used receivers within the required limits.

2. Quasi-optimal algorithm of nonlinear radar information processing

The analysis of current publications on the problems of the theory and technology of nonlinear radiolocation shows that, despite the rapid development of the technique of radar sounding of objects with nonlinear electrical properties, the problem of improving the main indicators of the quality of nonlinear radars is still urgent, such as the probability of correct detection, range, etc. The most radical way to improve these characteristics is developing optimal principles for constructing nonlinear radar systems.

Let us give a description of the technical appearance of a multifrequency nonlinear radar, which differs from the known ones in the implementation of the method for increasing the signal-to-noise ratio at the output of the nonlinear radar receiver by combining the frequency of the side receiving channels with the response frequencies.

A typical nonlinear locator contains a serially connected master pulse generator, a high-frequency emitted signal conditioner, a transceiver antenna, as well as a receiver connected to it, tuned to the second or third harmonic of the emitted signal.

The principle of operation of the nonlinear locator is based on the fact that when objects containing nonlinear elements are irradiated (p-n - junction, oxide-metal transition, diode, transistor, etc.), the energy of the emitted signal is converted into the energy of higher multiple harmonics. The response signals converted by the nonlinear element are registered by the detecting device regardless of the operating mode of the nonlinear object (on – off).

The power of the emitted pulse signal is limited due to the need to ensure an acceptable level of the high-frequency radiation field affecting the operator. The conversion factor of the energy of the emitted signal into the energy of higher harmonics is very small. Therefore, the main disadvantage of the existing nonlinear radars is its short range. To increase the range of the nonlinear radar, multi-frequency location is used, in which the nonlinear element converts the emitted signal into a signal containing combined frequencies:

$$f_{comb.i} = \pm n f_1 \pm m f_2 \pm k f_3 \pm \cdots \pm q f_N \qquad (7)$$

where $n, m, k, \ldots, q = \overline{0, \infty}$;

$f_{comb.i}$ - frequency of i-th emitted signal, $i = \overline{1, N}$.

The signal is received at the combined frequency $f_1 + f_N$, and the receiver bandwidth Δf_{rec} is selected from the condition:

$$\Delta \frac{f_N - f_1}{N - 1} \le \frac{\Delta f_{rec}}{2} \qquad (8)$$

The fulfillment of (2) ensures the simultaneous reception of two more response signals from the nonlinear element (multiples of the frequencies of the emitted signal or the combinational components of the reflected signal) through the main reception channel of the superheterodyne receiver. The bandwidth of the receiver, as follows from (2), is very wide, which reduces its noise immunity.

With dual-frequency sounding, the signal at the combination frequency $f_1 + f_2$ and the components $2f_1$ and $2f_2$ comes into the passband of the receiver, i.e., in comparison with a single-frequency locator, multifrequency nonlinear radar provides reception of three components of the response signal. The result is an increase in the range of the nonlinear radar.

Reception of response signals from a nonlinear element (products of nonlinear transformation of emitted signals on a nonlinear element) is provided by transferring them to the intermediate frequency region in the mixer of the superheterodyne receiver of the locator. In this case, frequency conversion is included in the arbitrary transfer of a part of the spectrum of the received signals to the intermediate frequency region to ensure the required amplification of signals and their frequency selection.

However, the presence of side channels of reception in the locator (mirror, direct, etc.) with the appropriate frequency conversion in the receiver allows you to receive more than three components of the response signal. This can be achieved by combining the frequency of the receiving channels of the receiver with the frequencies of the responses from the nonlinear element by imposing additional requirements on the choice of the intermediate frequency rating and the frequency of the local oscillator of the receiver of the detecting device. One of the requirements is that they must be rigidly related to the nominal frequencies of the emitted signals. In this case, the practical implementation of the combination of the reception channels with the response frequencies from the nonlinear element can be achieved by various hardware options. There can be many such options.

Let us consider the structures most often used in practice in receivers for radio communication, radar, radio navigation, electronic warfare, electronic intelligence, structures for constructing detection devices, measuring the parameters of signals and interference, and extracting information. These mainly include spectrum analyzers and measurement receivers.

Each specific version of the detection device will be determined by the type of the emitted signal (dual-frequency, multi-frequency), the type of frequency conversion ("up", "down", single, multiple), the frequency of the local oscillator tuning (upper, lower), the type of conversion (linear $f_1 \pm f_2$; nonlinear $nf_1 \pm mf_2$), etc. Therefore, for the purpose of definiteness, concretization and the possibility of industrial application, we have to consider a particular situation of two-frequency sounding of an object by a locator with a single linear frequency conversion with a lower local oscillator setting and with a downward frequency shift. The interpretation of the principle of frequency matching of the receiver channels with the response frequencies is graphically shown in Figure 4.

Figure 4 shows that if the nominal intermediate frequency is selected from the condition

$$f_{IF} = f_2 - f_1, (f_2 > f_1) \tag{9}$$

the differential component of the response at the frequency $f_p = f_2 - f_1$ is received via the intermediate frequency channel (forward channel). This is achieved by combining the most sensitive side receiving channel of the receiver at an intermediate frequency with one of the most powerful responses from a nonlinear element at a frequency $f_p = f_2 - f_1$. The combination of the main and mirror reception channel with other of the most powerful frequency components (7) is ensured by a special choice of the heterodyne frequency rate.

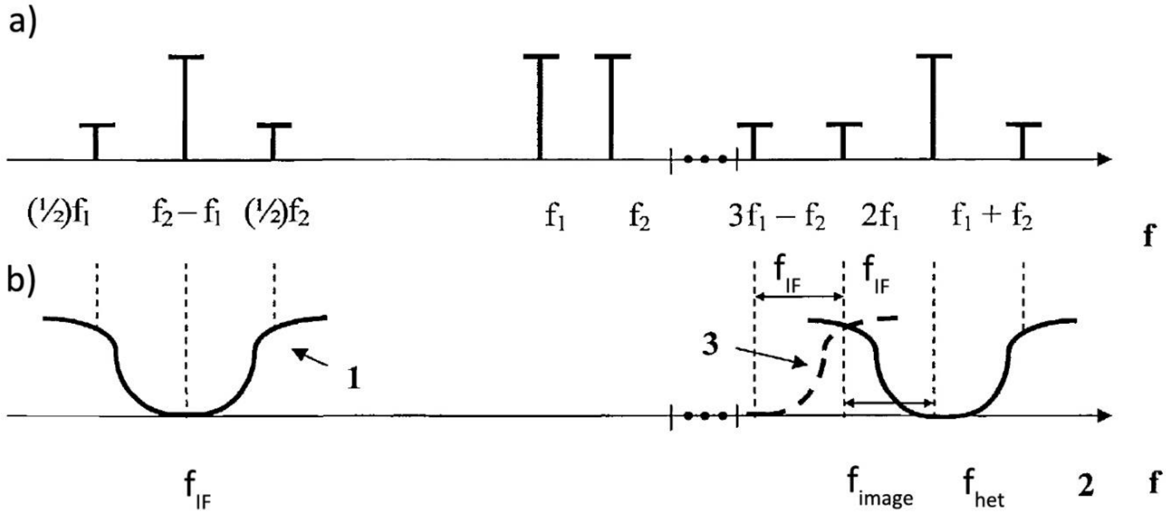

Figure 4: Principle of frequency matching

a) - radiation spectrum of responses from a nonlinear element (sensing object);
b) - frequency selectivity characteristic of a nonlinear radar receiver:
1 – reception channel on the intermediate frequency;
2 – main reception channel;
3 – image frequency reception channel.

If you select the frequency of tuning the local oscillator of the locator receiver equal to the doubled frequency of the emitted signal f_1, $f_{het} = 2f_1$, then the total component of the response from the nonlinear element at frequency $f_1 + f_2$ will be received through the main receiving channel:

$$f_S = f_{het} + f_{IF} = 2f_1 + f_2 - f_1 \tag{10}$$

In this case, via the image reception channel of the receiver, a signal at the next frequency will be received:

$$f_{image} = f_{het} - f_{IF} = 2f_1 - f_2 + f_1 \tag{11}$$

which is one of the intermodulation frequencies of the products of nonlinear conversion of emitted signals by the target object.

In addition, when choosing the receiver bandwidth from the condition

$$2f_2 - 2f_1 \geq \Delta f_{IF} \tag{12}$$

reception of signals at frequencies $2f_1$ and $2f_2$ is provided (Figure 4). Moreover, due to the fulfillment of condition (12), the subharmonics of emissions at frequencies f_1 and f_2, and more specifically $\frac{1}{2}f_1$ and $\frac{1}{2}f_2$ are received through the passband of the receiver on the intermediate frequency channel.

Thus, due to the fulfillment of conditions (12), (9) and $f_{het} = 2f_1$ in the dual-frequency nonlinear radar, the reception of seven products of nonlinear conversion by the nonlinear element of the emitted signal is provided through the most sensitive reception channels, and the reception of the most powerful responses at frequencies $f_1 + f_2$ and $f_2 - f_1$ is provided. In practice, when designing a multi-frequency nonlinear radar, this can be achieved by increasing the sensitivity of the side reception channels (excluding the filter notch tuned to f_{IF}; excluding the preselector to improve the sensitivity along the mirror channel), while in a traditional superheterodyne receiver, measures are taken to weakening unwanted side channels of reception by these measures.

The combination of the passbands of the side and main channels of the nonlinear locator receiver with the most significant spectral components formed on the nonlinear element (7) and an increase in the sensitivity of the side reception channels lead to the fact that the locator receiver becomes largely consistent in its amplitude-frequency characteristics with the spectrum of the received signal, i.e. filter quasi-optimal. The consequence of this circumstance is an increase in the signal-to-noise ratio at its output, an increase in the range of the locator, and an improvement in the probability of correct detection of an object.

The first important condition for achieving this goal (increasing the range of nonlinear radar) is such a choice of an intermediate frequency in a superheterodyne receiver with one linear frequency conversion downward so that the most sensitive reception channel (at the intermediate frequency) coincides (on the frequency axis) with the difference the combination frequency of radiation from the nonlinear element $f_2 - f_1$.

The second important requirement for nonlinear radar is the choice of the receiver local oscillator frequency equal to the value of $2f_1$.

The next important requirement for the receiver of the proposed nonlinear radar system structure is to take measures to improve the sensitivity of the radar receiver over the intermediate frequency channel and other side reception channels. Due to the reception of signals in the receiver through a large number of channels, the receiver of a nonlinear radar must have a threshold device to exclude the receiver's response to extraneous signals (detection device).

Thus, the new distinctive features of nonlinear radar include the choice of the nominal intermediate frequency in accordance with the condition $f_2 - f_1$, as well as the choice of the frequency of the receiver local oscillator equal to the frequency $2f_2$, increasing the sensitivity of the side receiving channels in the nonlinear radar.

The possibility of practical implementation of the proposed device is confirmed by the following. The results of theoretical and experimental studies show that the highest intensity among the conversion products on a nonlinear element is the combination components at frequencies | $f_1, \pm f_N$ |. On the other hand, it is known that of all possible reception channels of a superheterodyne receiver, the most sensitive is the forward channel at the intermediate frequency. Therefore, the frequency coincidence of this most sensitive direct channel for receiving a nonlinear radar with one of the most significant in amplitude frequency component of re-radiation of a nonlinear element at a frequency $f_2 - f_1$, provides an increased level of the useful signal at the output of the detector's receiver and, consequently, it's increased range.

The appropriate choice of the local oscillator tuning frequency ($f_{het} = 2f_1$) also contributes to an increase in the detection range due to the coincidence of the main and image reception channels with the response frequencies from the object.

Thus, in the proposed locating device, when these measures are implemented, the number of responses received through various receiving channels of a nonlinear radar increases, and the most sensitive receiving channels correspond to high amplitude frequency responses from a nonlinear element.

The proposed structure of the nonlinear radar provides an increase in the quality indicators of the detection of a nonlinear element by increasing the signal-to-noise ratio at the output of the intermediate frequency receiver's path, which is due to the optimization of the principles of the receiver design (matching the multi-frequency characteristics of the frequency selectivity of the receiver with the radiation spectrum of the nonlinear element).

The possibility of implementing the proposed principles of constructing the nonlinear radar was studied experimentally. For this purpose, a setup was assembled, which included two “G4-18A” signal generators tuned to frequencies $f_1 = 248$ and $f_2 = 252$ kHz, respectively. The generators were loaded onto one directional loop antenna of the “APK-15M” aviation radio compass. The receiver was “P-880M” with an intermediate frequency of 500 kHz. The detection of a single nonlinear element (diode of the “GC-13A” type) by the receiving unit (P-880M with a whip antenna) was confidently carried out at distances up to 10 m at any receiver setting (via the intermediate frequency channel). When tuning the local oscillator frequency $f_{het} = f_{sig} - f_{IF}$ to values of 252 and 248 kHz ($f_{s1} = 2f_2 + f_1 = 752\, kHz\, and\, f_{s2} = 2f_1 + f_2 = 748$ kHz), the signal at the output of the receiver increased, which indicated additional reception of components in the main and image reception channels.

The block diagram of the presented dual-frequency detection device is shown in Figure 5.

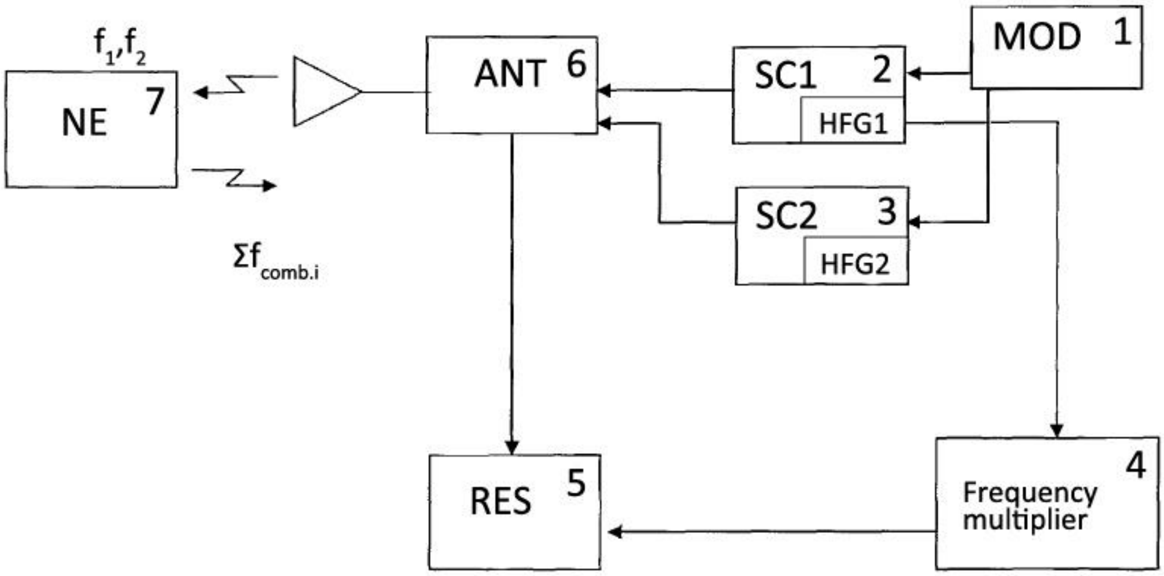

Figure 5: Block diagram of a two-frequency detector

1. Modulator.
2. The first conditioner of a high-frequency signal at a frequency f_1 (consists of the high-frequency generator f_1 HFG1 and a power amplifier).
3. The second conditioner of the high-frequency signal at the frequency f_2 (consists of the high-frequency generator f_2 HFG2 and a power amplifier).
4. Frequency multiplier f_1 by two.
5. Receiver with a detection device.
6. Broadband antenna.
7. Detectable nonlinear element.

The frequency multiplier acts as a local heterodyne in the receiver. The signal from the high-frequency generator of the first signal conditioner is fed to the receiver mixer for use as a local oscillator signal, providing, together with the appropriate choice of the intermediate frequency and bandwidth, the alignment on the axis of the response frequencies from the non-linear element with the most sensitive receiving channels of the receiver.

One of the characteristic features of the development of modern radio engineering is the increasing use of noise-like signals (NLS) to solve problems of information transmission in telecommunications and information retrieval of targets and sounding objects in radar. Recently, NLS is increasingly used in nonlinear radar and communications. The use of NLS in these radio and radio equipment is due to the possibility of improving the characteristics of energy availability of radios and objects due to the optimal processing of signals with a large base by compressing them in time or coherent accumulation.

The widespread use of nonlinear radar methods necessitates the improvement of means and methods for optimal detection of targets with nonlinear electrical properties. The currently used correlation and filter algorithms for optimal signal processing in relation to nonlinear radar have a number of significant limitations, which are as follows. In the optimal receiving structures of linear radars, the processing of the received "signal + noise" mixture is carried out, as is known, at the frequency of the probing signal. In nonlinear radar, reception is carried out at the harmonics of the sounding signal or combination frequencies. This significantly complicates filter or correlation receiver circuits.

In addition, in nonlinear radar, the sounding signal is converted, as a result of which the signal-to-noise ratio, as a rule, decreases significantly. In this case, the detection of a signal response from a target with a given efficiency with the direct application of linear radar algorithms becomes problematic.

It is known that when a noise-like signal passes through a non-linear element, the form of the distribution law of the initial noise changes. This property can be used as the basis for the principle of target detection with nonlinear electrical characteristics. The noise generator included in the setup generates stationary quasi-white noise with known characteristics:

$$P_1(U) = \frac{1}{\sqrt{2\pi}\sigma_U} e^{\frac{U^2}{2\sigma_U^2}}$$

where $P(U)$ is the probability distribution density of the noise voltage amplitudes, σ_U is the amplitude dispersion. The noise signal amplified in the amplifier is radiated through the directional antenna in the direction of the target. If the target is characterized by a nonlinear dependence of the level of the scattered signal on the level of the probe, approximated by a quadratic polynomial, then the PDF of the response signal is described by the Rayleigh distribution law

$$P_2(U) = \frac{U}{\sigma_U^2} e^{\frac{U^2}{2\sigma_U^2}}$$

A response signal with an average response frequency F_{response} Equal to the average frequency of the probing signal F_{emitted}, but having a PDF of amplitudes of the form, is received by the antenna, amplified in the receiver and fed to the probability characteristics meter to determine the degree of difference in the noise realizations probing signal and response signal.

A significant difference between the proposed detector of nonlinear targets, in contrast to the known detectors, is the reception not at harmonics, but at the fundamental frequency of the probing signal - as in linear radar. The latter circumstance makes it possible to significantly simplify the procedure for optimal signal processing in the receiving part of the detector. It is also important that the parameters of the distribution law of the form carry information not only about the presence of a nonlinear radar target in the detector's field of view, but also about the properties of this target, which can be used for target recognition.

Since the information about the presence of a nonlinear target is contained in the change in the PDF form of the adopted implementation relative to the initial one, the optimal detection algorithm should include a threshold device for making a decision on the presence of a target in case the established degree of difference between the PDF forms of the form and is exceeded. In this situation, it is advisable to use the entropy criterion as the decisive rule, which, as is known, is most sensitive to changes in the shape of the distribution law. In this regard, as the criterion for the difference in the PDF of amplitudes at the output of the proposed information-statistical detector, we will take the difference in the entropy of the PDF:

$$\delta H(U) = H_1(U)/H_2(U)$$

As the analysis shows, modern digital equipment provides the measurement of PDF and their entropy in a time scale close to the real one, with a practically acceptable error not exceeding one percent.

The main difference of this detector from similar known ones is the presence of devices for calculating and distinguishing noise signals. We emphasize that the proposed detector does not contain a detector, because it distorts the shape of the voltage amplitude.

The possibility of practical implementation of the information-statistical algorithm for detecting a nonlinear radar target by the method of sounding a noise-like signal has been confirmed experimentally. The white noise generator G2-59 was used as a noise source with a distribution close to normal stationary in the frequency band (H6.5 MHz). Through the ferrite antenna, the noise signal was emitted towards a passive ferrite antenna located at a distance of 1 m, simulating the target.

An oscillographic method based on measuring the probability density by the luminosity of the cathode ray tube screen was used to measure the type of voltage amplitudes. According to this method, the investigated random signal was applied to the vertical plates of the oscilloscope. The vertical deflection of the tube beam was interpreted as a value proportional to the probability p (U) · ΔU of the implementation of U (t) in the interval U, U + ΔU. The luminosity intensity of the oscilloscope screen was interpreted as a value proportional to the time the beam is in the U + ΔU region in the first approximation. Therefore, if when applying to the plates of the vertical deviation of the randomly varying voltage U (t) horizontal unfolding is excluded, the law of change of the intensity of the screen along the vertical axis coincides with the one-dimensional voltage probability density.

Thus, the proposed nonlinear radar structure, due to the combination of the most sensitive reception channels of the superheterodyne receiver of the detecting device with the most powerful frequency components of the response of the nonlinear element to the dual-frequency emitted signal, provides an increase in the quality indicators of the nonlinear element detection in comparison with radars that implement reception according to the traditional superheterodyne scheme.

The obtained results confirm the types of distribution laws of the probing signal (Gaussian) and the response signal from a nonlinear radar target (Reyleigh).

Thus, the proposed information and statistical algorithm for optimal detection of nonlinear radar by sound-like sounding and structural diagram of the detector are practically implemented and differ from the known not only high informativeness, but also lower technical requirements for the detector equipment.

3. Conclusion

The specificity of nonlinear radar measurements is considered in the technological procedure for synthesizing optimal structures and algorithms for detecting and measuring the characteristics of objects with nonlinear electrical properties by identifying possible reserves for increasing the signal-to-noise energy ratio at the receiver output. One of the main such reserves is the elimination of the regular component of radio interference caused by the influence of the frequency harmonics of the probing signal formed in the transmitter of the nonlinear locator.

It is shown that the use of noise and noise-like signals in non-linear radio engineering systems in combination with the methods of their information-probabilistic processing makes it possible to improve the technical characteristics of the systems.

The proposed set of new technical solutions in the field of the theory of nonlinear radar measurements is presented in the form of structural diagrams and algorithms for optimal signal reception in advanced technology of radar sensing and measuring the coordinates of objects with nonlinear electrical properties.

4. References

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