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RESEARCH ARTICLE

DEVELOPMENT OF A SOFTWARE ALGORITHM FOR AUTOMATIC DETECTION OF NONLINEAR DISTORTIONS OF A USEFUL SIGNAL IN THE RECEIVING CHANNEL OF A FIRE CONTROL RADAR WITH A LARGE DYNAMIC RANGE

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Abstract

The paper presents the results of developing a software algorithm for automatic detection of nonlinear distortion of video signals at the output of the receiving path of a fire control radar due to temporary overloads of the receiver when changing the range to the target in a wide range, as well as when changing the effective scattering area (ESA) of the radio wave.The detector of nonlinear distortion of video signals operates on the principle of recognizing and measuring the amplitudes of individual spectral components in the spectrum of a video pulse packet at the receiver output. The distinguished advantages of this type of detector are reliability, accuracy and simplicity in practical implementation

Introduction:-

As is known, in all fire control radars of the SAM guidance station type, one of the importantrequirements for the input signals of the autorangefinder and autoangle meters is their constancy of amplitude with a large dynamic range at the input of the receiving path. Such a requirement is necessary to ensure a specified error in measuring the target coordinates by the radar when its range changes over a large range, as well as with different values of its effective scattering area (ESA) of radio waves.

In all radars, the role of maintaining a constant amplitude of signals at the outputs of the receiving device (RD) is played by automatic gain control (AGC) circuits using manual adjustment (MA) or input attenuators (IA). Here it should be noted that the adjustment of the MA and IA is mainly carried out manually, i.e. it completely depends on the feelingand operator's vision when observing the target mark on the tracking indicators. This may lead to additional errors in measuring the target coordinates due to the delay in preventing the operator from temporary overloading the receiver. The latter leads to the appearance of nonlinear distortion of signals at the inputs of automatic measuring devices [8].

In order to fully automatically adjust the gain of the receiving path by automating the processes of regulating the MA and IA, the task is set of timely detection of nonlinear distortion of signals at the receiver outputs, which will be considered the initial sign of the output of the amplitude of the signal processed in the receiver outside the AGC regulation.

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The stated task can be solved by software through digital analysis of the spectrum of a packet of video pulses at the receiver output and implemented by a software algorithm in the radar's digital computer.

Solution to the problem of detecting nonlinear signal distortion

1. *Structure and spectrum of reflected signals*

Let us assume that the radar under consideration is a monopulse Doppler radar emitting into space packets of quasi-continuous probing radio pulses of rectangular shape. Mathematically, the assumed packets of probing radio pulses are presented in the following form [9]:

$$S_T(t) = \left(p_{\tau_p}(t) \sum_{-\infty}^{\infty} p_\tau (t - nT_0) \right) e^{-j2\pi f_0 t} \quad (1)$$

Where: τ_p– duration of a pulse packet; τ – duration of a radio pulse; T_0 – pulse repetition period in a packet; f_0 – radio carrier frequency of pulses (frequency generated by the transmitter); $p_{\tau_p}(t)$ - law of amplitude modulation of the packet envelope; $p_\tau(t - nT_0)$ - law of amplitude modulation of the envelope of a single pulse.

The signals reflected from the target, received at the input of the receiving device (RD), are packets of reflected pulses of a bell shape. Mathematically, packets of radio pulses reflected from the target are presented in the form [9]:

$$S_R(t) = A(t) \left(p_{\tau_p}(t - \tau_d) \sum_{-\infty}^{\infty} p_\tau (t - \tau_d - nT_0) \right) e^{-j2\pi(f_0 + f_D)(t - \tau_d)} \quad (2)$$

Where: *A(t)* – the secondary law of amplitude modulation of the packet of reflected signals (RS); τ_d is the delay time of the RS relative to the probing signal (PS); f_D is the Doppler frequency introduced into the carrier frequency of the signal.

The law of amplitude modulation of the envelope of the reflected pulse is expressed by:

$$p_\tau(t - \tau_d - nT_0) = \begin{cases} 1 \quad at \quad (\tau_d - \tau) + nT_0 \le t \le (\tau_d + \tau) + nT_0 \\ 0 \quad at \quad t < (\tau_d - \tau) + nT_0 \; and \quad t > (\tau_d + \tau) + nT_0 \end{cases}$$

The secondary law of amplitude modulation of the RS determines their bell-shaped form and is written in the following form [1, 2]:

$$A(t) \approx \sqrt{P_T} = \sqrt{\frac{P_0 G_T G_R \lambda^2 \sigma_{esa}}{(4\pi)^3 D^4 L_S}}$$

Where: P_T - the transmitter power; P_0 - the signal pulse power; G_T - the gain of the transmitting antenna; G_R - the gain of the receiving antenna; λ - the carrier radio wave length; σ_{esa} - the effective scattering area of the target radio wave; D - the range to the target; L_s - the consistency index between the transmitting and receiving antennas.

In accordance with (2), we have an expression for the amplitude spectrum of the RS [6, 7]:

$$S_R(f) = Ae^{-j2\pi f \tau_d} \frac{\tau . \tau_p}{T_n} \sum_{n=1}^{\infty} \sin c(\pi \tau n F_0) \sin c \left[\pi \tau_p (f - nF_0 - f_0^{'}) \right] \quad (3)$$

Where: F_0 - the repetition frequency of the RS in a packet ($F_0=1/T_0$); f'_0 - the carrier frequency of the RS, numerically equal to ($f_0+f_{\partial on}$). From (3) follows the expression for the spectrum of a packet of video pulses (VP) at the receiver output taking into account $nf = (f - nF_n)$:

$$S_{VP}(nf) = \frac{\tau.(\tau_p - \tau_d)}{T_0} \sum_{n=1}^{\infty} \sin c(\pi \tau n \frac{\tau}{T_0}) \sin c\left[\pi(\tau_p - \tau_d) nf\right] \tag{4}$$

2. Overload of the receiving path and nonlinear distortion of signals

The overload of the receiver is caused by the amplitude of the processed signal exceeding the linear section of the gain characteristic, i.e. the receiver operates in a nonlinear mode, as a result of which the shape of the processed signal is distorted [4,5]. Since it is known that useful information for the radar about the target and the spatial situation is contained precisely in the shape of the signal, the distortion of which leads to the loss of useful information and an increase in errors in determining the target coordinates.

Let us consider the process of amplification of the feedback from the target in the receiving path in order to reveal their nonlinear distortion, see Fig.1.

From the explanation in Fig.1 it is clear that the output signal of the receiver is not distorted in those cases in which the amplitude of the input signal does not go beyond the limit of the linear section of the gain characteristic (case 1), and otherwise 2 and 3 the output signal begins to distort and the bell-shaped signal shape is observed to transform into a trapezoidal one.

And so, with an increase in the amplitude of the input signal, exceeding the upper threshold of the linear section of the gain characteristic of the receiver, a series of nonlinearly distorted video pulses are formed at its output, which are fed to the radar coordinate meters. The error in measuring the target coordinates by the radar increases in proportion to the degree of nonlinear distortion of the signals.

3. Method and algorithm for detecting nonlinear distortion of signals

In order to prevent the loss of useful information and ensure the accuracy of determining the target coordinates in measuring systems, a method for automatically detecting the moment of receiver overload is required for radar. Using the above analysis of the signal processing and structure taking into account their spectral features, we propose the following method for analyzing signals to detect the moment of the onset of nonlinear distortion.

The proposed method consists of a digital Fast Fourier Transform (FFT) of a packet of RS video pulses at the output of the receiving path with subsequent storage of data, on the basis of which an analysis of the amplitude spectrum of signals is performed to isolate the moment of their distortion.

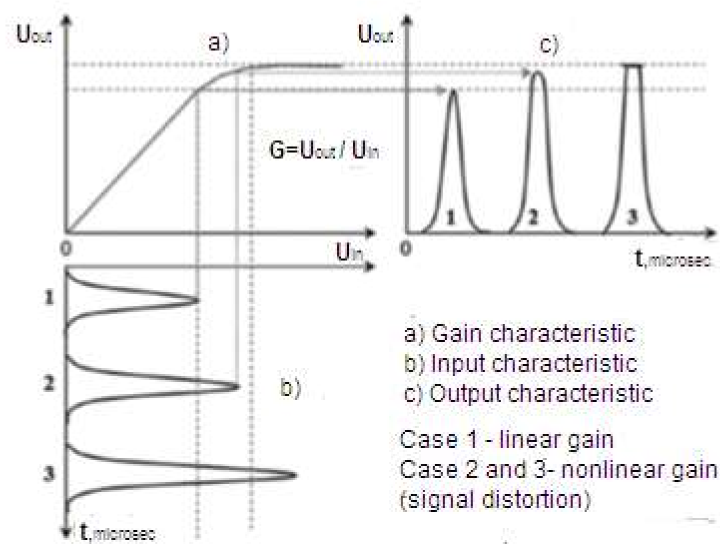


Fig.1 -To explain the nonlinear distortion of the signal in the receiving path

From (4) follows the expression for the maximum amplitude of the first spectral component (*n=1*) of the RS at zero frequency (*f=0*):

$$S_{VP}(0) = \frac{\tau.(\tau_p - \tau_d)}{T_0}$$

(5)

By normalizing (4) by amplitude (5), we obtain the amplitude-normalized spectrum of a packet of video signals in the form:

$$S_{VP}(nf) = \frac{S_{VP}(f)}{S_{VP}(0)} = \sum_{n=1}^{\infty} \sin c(\pi \tau n \frac{\tau}{T_0}) \sin c\left[\pi(\tau_p - \tau_d) nf\right]$$

(6)

From (6) it is clear that $\bar{S}_{VP}(nf) \le 1$ and $\sin c\left[\pi(\tau_p - \tau_d)nf\right]$ determines the location of the n-th spectral component,and $\sin c(\pi \tau n \frac{\tau}{T_0})$ determines its amplitude.

Based on the fact that in the linear gain mode of the receiver the ratio $\left(\frac{\tau}{T_0}\right)$ is almost constant due to the unchanged shape (constant duration) of the video signal. In the nonlinear gain mode, i.e. when the receiver is overloaded, this ratio increases, which leads to an increase in the value

Using the above reasoning, we can create an algorithm for detecting nonlinear distortion of video signals at the receiver output based on fast transformation into a Fourier series (4) and spectral analysis according to (6) of a continuous sequence of video pulse packets. This algorithm has the form shown in Fig. 2.

4. Evaluation of the algorithm's performance

To evaluate the performance of the developed algorithm, we will use the parameters and characteristics of the receiver of the monopulse-Doppler radar known to us [8], which are given in Table 1.

Table 1Data for research

Name	Unit	Meaning	Name	Unit	Meaning
Dynamic range	dB	72	Gain factor,G_T	-	42
AGC operating range	dB	12	IndicatorLs	dB	10
Changing the target range	km	300-155	ESA target, σesa	m^2	1.4
Probe pulse power	kW	75	Gain factor, GR	-	42
Duration of receiver pulse	µS	1.5	Length carrier waves, λ	cm	3
RP repetition period	µS	10	Number RP in a pack, N	-	270

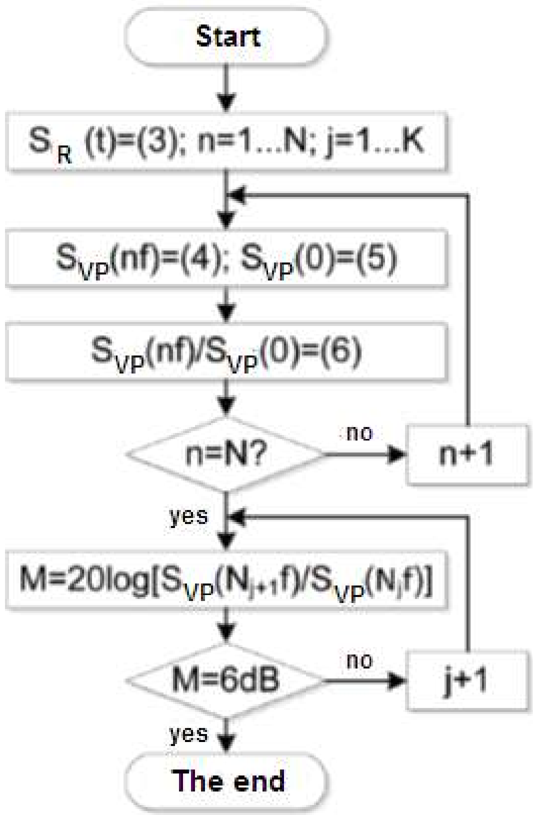


Fig.2. Detection algorithm

The structural diagram of the simulation of the developed algorithm using the MatLab SIMULINK program has the form shown in Fig. 3.

The results obtained from the mathematical simulation of the algorithm are shown in Fig. 4.

The detection characteristic, constructed on the basis of the logarithmic ratio of the amplitudes of the last spectral components in the spectrum of subsequent packets, has the form:

$$M = 20\log\left[\frac{\bar{S}_{VP}(N_{(j+1)}, f)}{\bar{S}_{VP}(N_{(j)}, f)}\right] \quad (7)$$

The results of digital transformation of a video signal packet into a Fourier series (FFT) according to (4) and normalization of the amplitude spectrum of signals according to (6) clearly show the change in the amplitudes of the spectral components in two cases: before overload (Fig. 4a) and during receiver overload (Fig. 4b). If we select a certain high-multiple componentspectrum in a number of subsequent packets and compare their amplitudes according to (7), then it is quite possible to construct a characteristic for detecting nonlinear distortion of signals.

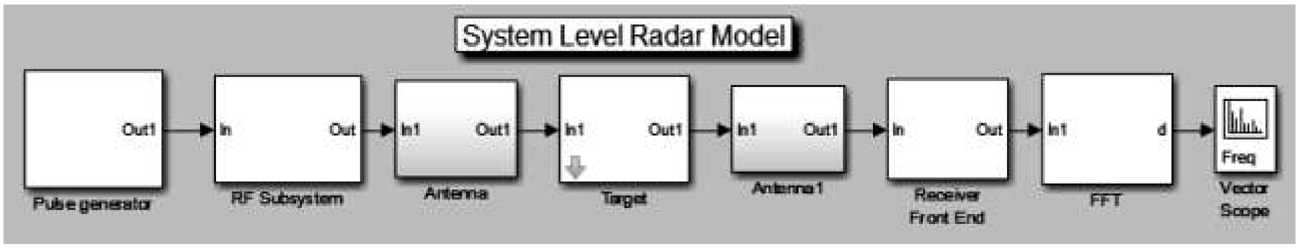
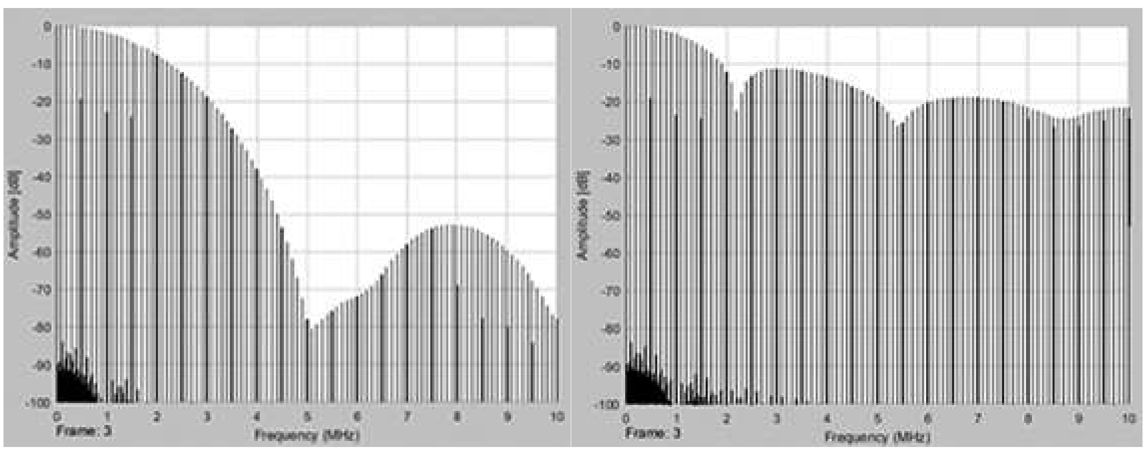


Fig.3. Structural diagram of the SIMULINK study



a) Spectrum RS before distortion

b) Spectrum RS after distortion

Fig.4. Spectrum of RS packets at the receiver output

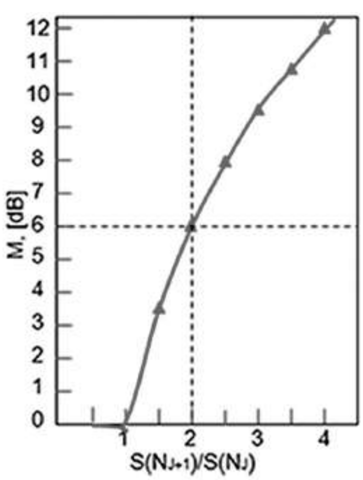


Fig.5. Detection characteristics

Conclusion

By studying the dependence (7) on the degree of nonlinear distortion of signals, it was possible to obtain a characteristic of detecting the moment of receiver overload (Fig.5). The characteristic has a fairly high steepness, which allows early detection of the moment of overload depending on the choice of the comparison threshold. In this example, we choose this threshold M=6dB, corresponding to an excess of 2 times the amplitude of the 265th spectral component in 5 subsequent packets.The dynamic range of all fire control radar receivers is wide, due to the wide range of target range variation. At the same time, its AGC operating range was limited, which requires the additional use of MA and IA.The algorithm for detecting the moment of receiver overload developed in the article gives us the opportunity, instead of MA and IA, to implement automatic stabilization of the receiver's dynamic range corresponding to the AGC range.In addition, in the future, this simple algorithm can be included in the automatic adjustment of the radar transmitter parameters in order to regulate the receiver's dynamic range by reducing the power of the probing pulses (PP) when the range to the tracked target decreases.

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