Analysis results of radar system with positive feedback through target

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Abstract: *The multichannel radar system with positive feedback through target is proposed in the text below. If there is no target in the space only noise signal with low power arise. If target presents in the space self-oscillations arise and during processing time they become more powerful. This system analysis is presented for pulse and complex signals.*

In the text below radar station that includes a power amplifier, low-noise amplifier and digital processing block with high gain, which input is connected to the output of low-noise amplifier and output – to the input of the transmitter, is considered. Transmitter outputs and inputs of the amplifier connected to the transmitting and receiving antennas. Broadband noise is forming in the system due to internal noise LNA (linear noise amplifier) on the input, which is radiated into the space. If there is no target in the space the system oscillations do not arise, otherwise they arise. Two types of digital processing blocks are studied. The first one is based on the serial signal processing, the second one is based on the parallel signal processing. When the target is absent (the system is not closed), the output noise signal is low, making it difficult to detect radiation.

The low probability of radar signal interception can be achieved by low down of the emitted signal power. But at the same time it is necessary to have high detection probabilities of distant target. If irradiation time of target is limited, high detection probabilities of distant targets can be achieved by raising up the power of the emitted signal.

The significant reduction of the radiated power can be achieved by use of the system with positive feedback through target [1, 2, 4]. The alternate way of raising stealthiness of radar station is using of wideband signals.

Physical model of the radar with positive feedback through target is the active oscillator with delayed feedback. In the transition mode establishing of the oscillations can be mathematically presented by linear second order differential equation with retarded argument:

$$\frac{d^2x(t)}{dt^2} + \alpha\frac{dx(t)}{dt} + \omega_0^2 x(t) = \alpha K_g \frac{dx(t-T_d)}{dt}, \qquad (1)$$

where $x(t)$ is the transitional process, α and ω_0 – passband (determined by the time constant) and resonant frequency of the oscillatory circuit in the feedback loop of the active oscillator, K_g – gain of feedback loop, T_d – total time delay of the signal during its propagation in the space and in the radar system. The circuit in the feedback loop has the pulse response of the next form:

$$h(t) = \alpha \exp\{-\alpha t\} \cos \omega_0 t\,. \qquad (2)$$

It is shown [3], that solution of the equation (1) is presented by narrowband function $A(t)\cos\omega_0 t$, where $\omega_0 = 2\pi n / T_3$, (n=1,2,3...).

By low down the differential equation order and by using envelope instead of instantaneous values we receive next equation:

$$\frac{dA(t)}{dt} + \frac{\omega_0}{2}A(t) = \alpha K_g A(t - T_d). \qquad (3)$$

Solution of equation (1) approximately can be presented by exponential process of form:

$$A(t) = \gamma \exp\{\gamma t\}, \qquad (4)$$

where γ - exponent index, which determines the speed of oscillations increase while the magnitude and phase balances are kept. Thus, signal oscillations with increasing magnitude arise in the radar with positive feedback through target and compensation of signal energy loss in the space. By comparison of that signal magnitude with threshold the decision about the presence of target in the space can be taken.

Two generating signal schemes were researched: serial and parallel. Common structure, serial and parallel schemes are shown at the fig. 1, 2, 3. Both schemes were realized by usage of MatLab tools. To model work of radar station is necessary to divide all the distance to N resolved by the distance elements, where target can be located. At the first scheme (fig. 2) radar uses serial analysis of distant elements, therefore time of processing can be presented as the multiplication result of elements amount and analysis time of each element. At the second scheme (fig. 3) analysis of distant elements carried out in parallel, so, the analysis time of all the elements is equal to analysis time of one element.

The common structure of radar station is presented at the fig. 1. The principle of this scheme work is next: signal from digital signal processing block comes to modulator, where it transforms into hi-frequency signal, and then antenna transmits it to the space. Then receiving antenna receives responding signal, and after transformation to the lower frequencies signal comes to the digital signal processing block. Unlike typical amplifiers used in radars, power amplifier in that scheme supposes to have linear response with a large scale linear portion (80-90 dB). Scheme, shown on figure 2, consists of: ADC – analog-digital converter, X – correlator multiplier, CF – cumulative filter, τ - time delay (300 μs), X – modulator multiplier, DAC – digital-analog converter. Scheme, shown on figure 3, consists of: ComF – compression filter, $\tau 1, \tau 2 .... \tau n$ - time delays in distant channels, GC – gating cascade, which starts on the pulse of synchronizer, FST – filter of signal tension, Σ - adder.

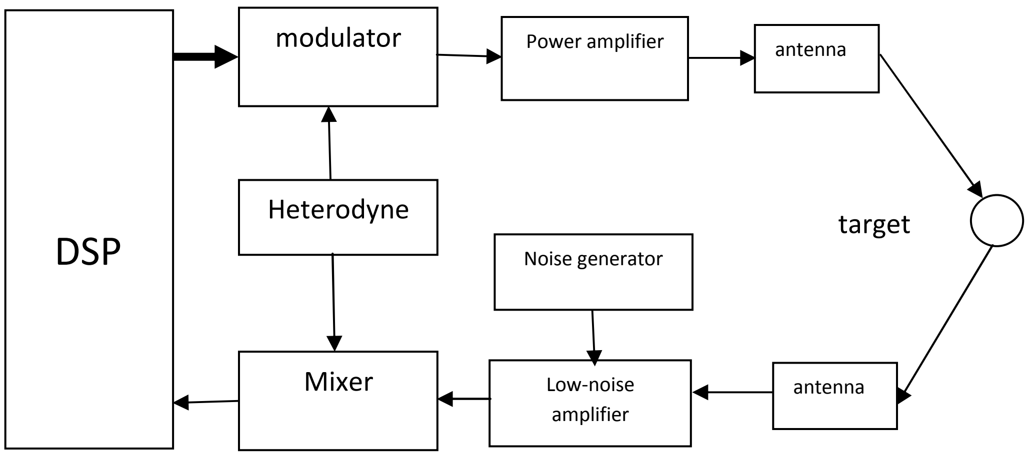


Figure 1. Common radar station scheme with positive feedback through target

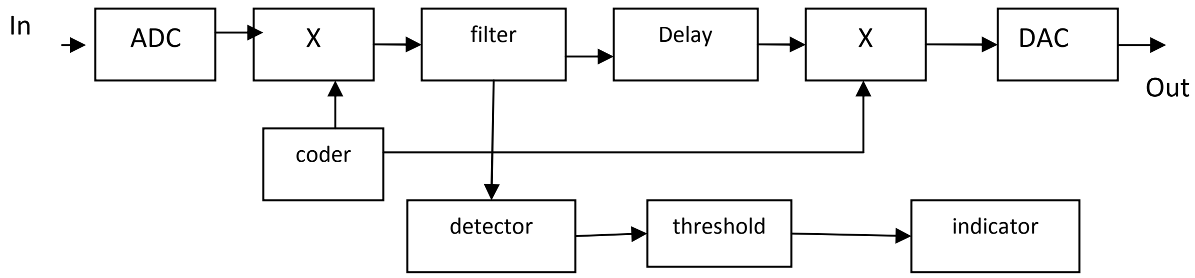


Figure 2. Digital Signal Processing block of radar station with positive feedback and serial type of signal processing

Both schemes work is based on the principle of positive feedback through target. That means that in the absence of target in the space only the low-power noise comes to the receiving antenna. When the target arise the circuit, containing radar and target, becomes closed, reflected from the target signal comes to the receiving antenna, radar process received signal, take the decision about the presence of target and generate the transmitting signal.

Radar model, which work based on the principle of serial analysis of information from different distant elements, is shown at the figure 2. Output signal from ADC comes to correlator multiplier, which convolute it and etalon signal of coder, after this signal comes to accumulator, detector after accumulation take a decision if any target present in the space by analysis of accumulated signal. After accumulator signal comes to delay line and to multiplier, which multiplies it and etalon signal, which comes from coder of the system. The accumulator output signal is sampled and recorded on the drive (the amplitude and phase are stored for one period before entering a new signal when they are coherently summed up and continues to accumulate).

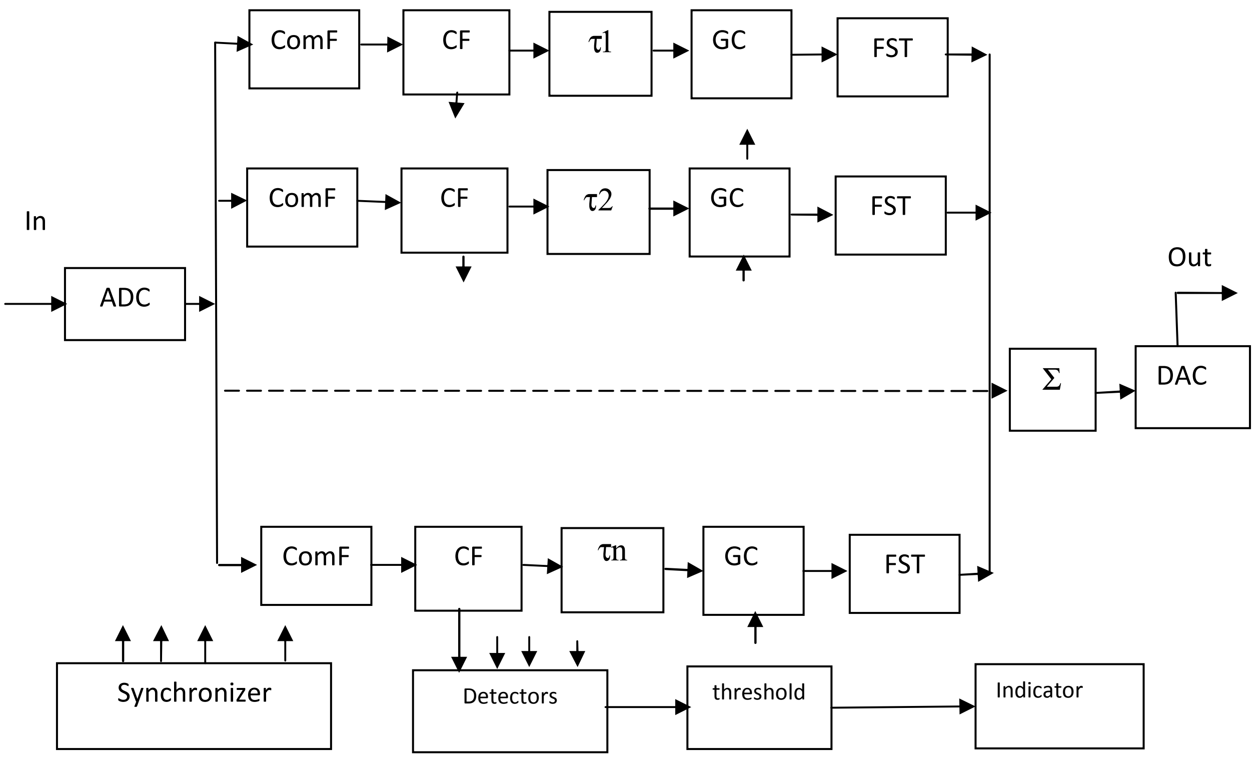
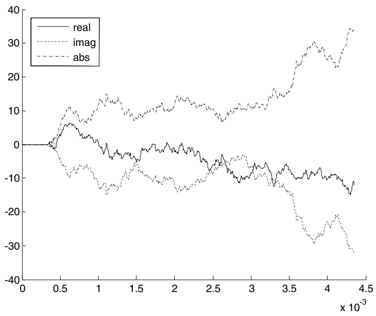
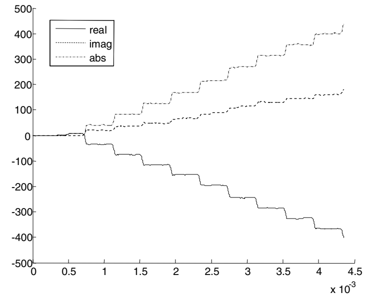


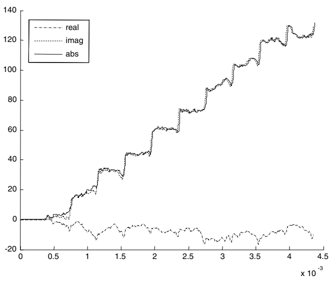
Figure 3. Digital Signal Processing block of radar station with positive feedback and parallel signal processing



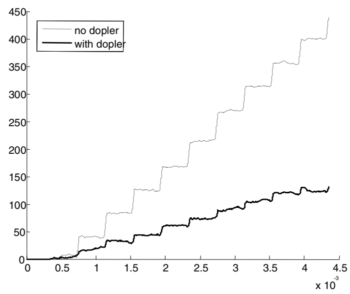
a. Open circuit (no target)



b. Closed circuit (target is not moving)



c. Target is moving



d. Moving and not moving target graphics at the same diagram

Figure 4. Results of signal processing by radar station with serial DSP block for pulse signal

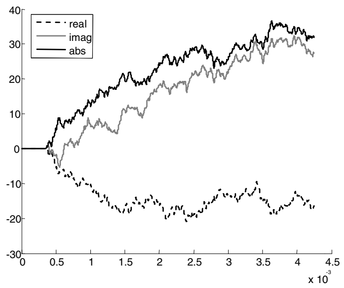
Diagrams, presenting principle of scheme work, are shown at fig. 4. Results of pulse signal processing for different situation are presented at these diagrams. System parameters for model were next: time discrete element – 1 μs, duration of frame – 0.2 μs, gain coefficient – 1.0, number of circulations – 10, period of processing – 400 μs (includes 100 μs – analysis time, and 300 μs – system delay).

It is also possible to use complex signals for that scheme. That allows improving power, stealth, detection parameters of radar. Diagrams presenting results of processing complex signal, which is based on the 13 elements Barker code, shown at fig. 5. System parameters were kept the same as in previous diagram.

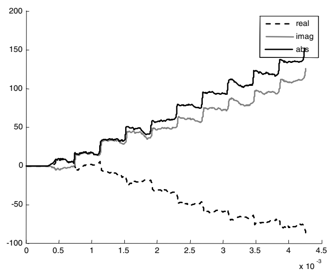
Dignity of serial model of radar station is simplicity of realization, but at the same time this system requires pretty much time for processing of reflected signals from all the distant elements.

The way to decrease time dependencies for calculation is usage of multichannel processing model, which illustrated on fig. 3. Usage of few parallel distant analyzing channels, which accumulate signal from different distance elements, is principal innovation which allows to low down the processing time. According to the level of accumulated signal from each distance element detector takes decision about the presence of target at that distance. At the same time to form the transmitting signal system uses pulse, which comes from accumulator for delayed signals from different distances. Each delay is chosen according to distance to analyzing element. That summary pulse comes to spreading filter, which form complex signal with magnitude depending on the input signal.

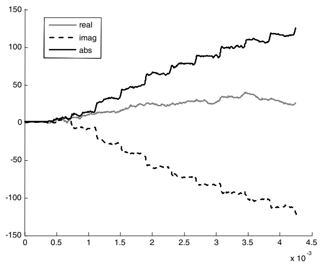
The multichannel system principle of work is illustrated at the diagrams on the figure 6. System parameters were changed to next values: time discrete element – 1 μs, duration of frame – 0.2 μs, gain coefficient – 5.0, number of circulation – 20, period of processing – 100 μs.



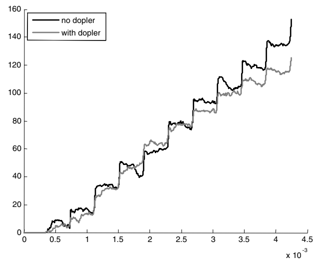
a. Open circuit (no target)



b. Closed circuit (target is not moving)

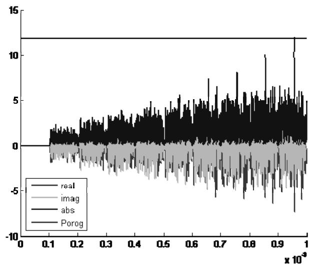


c. Target is moving

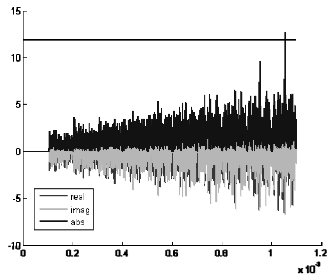


d. Moving and not moving target graphics at the same diagram

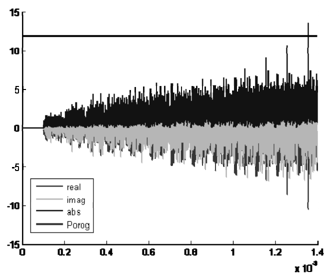
Figure 5. Modeling Results of signal processing by radar station with serial signal processing block for signal Barker 13



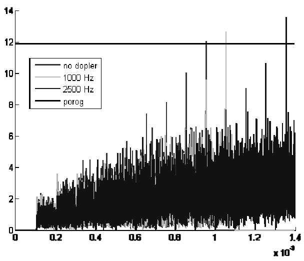
a. Closed circuit (target is not moving)



b. Target is moving (Doppler Frequency = 1 kHz)



c. Target is moving (Doppler Frequency = 2.5 kHz)



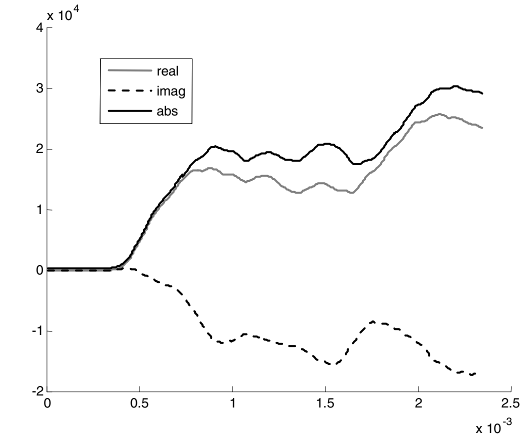
d. All the results at the same diagram

Figure 6. Modeling Results of signal processing by radar station with parallel signal processing block for pulse signal

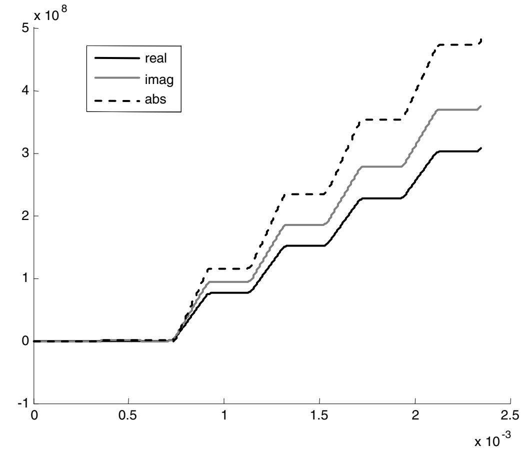
As it follows from the information presented on graphics, speed of achieving by the accumulated signal of threshold is really dependent on a lot of factors, which shows that scheme has good frequency selectivity.

Thus, both schemes allow detection the target at the exact distant. They allow to improve system stealth, as most of work time radar transmit only low-power noise-equivalent signal, and only with arising of the target at the analyzing distances power of transmitting signal rises, and it stops to rise when the level of signal achieves threshold level, then scheme resets the accumulated signal.

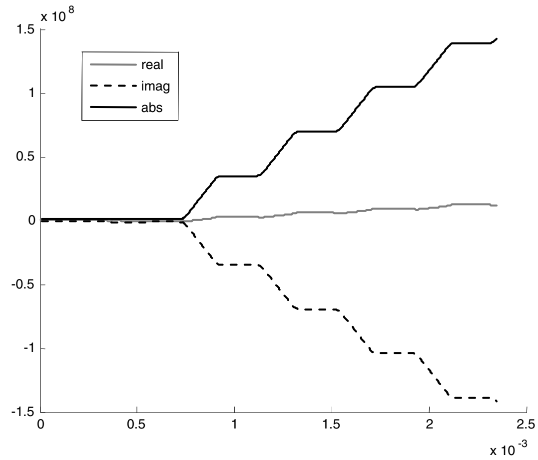
It is also very interesting from the practical point of view to analyze scheme work with LFM (Linear Frequency Modulation) signal. At the diagrams at figure 7 results of LFM signal processing presented. System parameters were next: Dopler Frequency – 1 kHz, discrete time – 0.2 μs, LFM pulse duration – 20 μs. LFM frequency deviation – 2 MHz



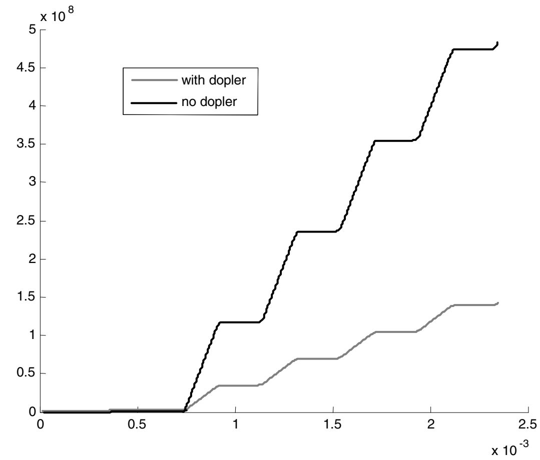
a. Circuit is opened



b. Circuit is closed, target is not moving



c. Target is moving



d. Comparison of the results with and without Dopler shift

Figure 7. Diagrams of processing results of LFM signal

References

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