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RESEARCH ARTICLE

JAMMING IMMUNITY RESEARCH OF A RADAR OPERATING WITH CHIRP SIGNAL

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Abstract

Pulse compressed signal enhances the jamming immunity of a radar operating with such a signal. The matched filter is one of the most important elements in the pulse compression technique. A model of a matched filter for a chirp signal was synthesized using the Simulink tool of the Matlab software. Interference signals were fed to the input of the matched filter and output signals were measured. The matched filter's degree of suppression of these interference signals was assessed. Conclusions were made about the jamming immunity of radar operating with chirp signal.

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Introduction:-

Jamming signals which possess a high cross-correlation function with radar's transmitted linear frequency modulated signal would be effective to jam this radar (Spassov2006), (Velkov2004). The correlation properties of linear frequency modulated signals are analyzed by (Korobko2003) and (Nenging1984). Here are presented only the most essential analytical expressions needed to study their properties as counteracting signals. The absolute integrability (finite energy) of the signal $a(t) = A(t) \cdot \cos\phi(t)$ is a condition for finding the correlation function of any modulated oscillation $a(t)$. The chirp signal's correlation function having the form shown in Fig. 1. is calculated on this basis.

The radar has a big Time-Bandwidth Product (Levanon2004) $TBP = T_{trans} \cdot (f_{max} - f_{min})$, where T_{trans} is a pulse length of the transmitter, f_{max} and f_{min} are upper and the lower frequency.

The low efficiency of a noise-like signal on a chirp filter is proved in (Spassov2005), even at very high values of the power spectral density. Linear frequency modulated signals were used to simulate jamming signals. The chirp filter's degree of suppression of these types of jamming signals was assessed here. The research was made at different ratios of the characteristics of the filter and chirp signal.

The simulation uses a matched filter for a chirp signal (filter matched to linear frequency modulated signal of the radar) as a part of the radar's receiver. The receiver is a functional element of typical radar that uses compressed signal (linear frequency modulated signal). Some of the radar's parameters are implemented in the simulation of the chirp filter's operation.

Simulation Setup:

A simulation of a chirp filter's reaction to chirp jamming signal was made using the Matlab software.

The Simulink tool of the Matlab software was used to create a model of the matched filter for a chirp signal, according to (Spassov2005) and similar to the real matched filter of typical military air defense radar. Linear

frequency modulated signals were synthesized as jamming signals. These signals were feed to the input of the matched filter and output signals were measured. The matched filter's degree of suppression of these interference signals was assessed.

The study of the jamming immunity of a filter matched to chirp signal of the radar to jamming chirp signals was done in the following order:

1. A model of optimal chirp filter matched with the radar's signal was synthesized, and the parameters of the signals in the radar receiver were determined;
2. Jamming chirp signals have been selected, and the limits of their changes have been determined;
3. Jamming chirp signals have been feed to the input of the matched filter and output signals have been measured;
4. The obtained results have been evaluated and conclusions have been made;
5. The functional diagram of the simulation model of the process has shown in Fig. 2. A 7-unit matched filter for a linear frequency modulated signal was synthesized according to the block diagram shown in Fig. 3. The filter has a bandwidth $B = 57 \div 63$ kHz, and its parameters have given in Table 2.

The level at the output of the receiving system or the input of the ADC is about 20÷30 mV for radars operating with compressed signal ($TBP = B \cdot \tau \gg 1$). These radars usually have the bandwidth at intermediate frequency $B \approx (8 \div 10)$ MHz or more, and a noise factor of the receiver's input stages about 3÷6 dB (Traveling Wave Tubes, parametric amplifiers, microwave solid-state receivers).

A level of 60÷90 mV has obtained, by taking into account the signal-to-noise ratio 3:1 of the automatic detector's threshold. Therefore, the threshold for comparison and evaluation is fixed at 100 mV.

In the time domain, the evaluation rate is $\tau = 200 \pm 100$ ns, which is a typical duration of the compressed pulse or the single element of the compressed signal code (determined by the distance resolution requirements).

The levels, thresholds, and time values of the parameters of typical radar operating with compressed signal determine the value of the respective values in the model as follows:

1. In terms of energy, the model's threshold level is 100 mV (for the input power of the tested filters 2.10-4 W accepted in the experiments - normalized amplitude 0.1V on a load of 50 Ω). The amplitude of the jamming chirp signal is normalized to 0.1V at the input of the filter at all of the experiments;
2. A scale of 1000:1 between the real system and the model has been chosen at the time domain, due to a limitation in the software product's speed. The ratio between the values of the parameters and their tolerances in the radar and the model is strictly preserved. The modeling has been performed at the ratio of the parameters between the real radar and the model by Table 1.

Results and Discussions:-

A 7-element filter was synthesized by parallel connection of standard bandpass filters, delay line in each unit, and adders. The bandwidth and delay time in each unit are selected, optimized, and adjusted according to the general characteristics of the filter (given in Table 2) and the theoretical requirements defined by (Barton2004) and (Korobko2003). The chirp filter is a dispersion type filter with a lower cutoff frequency of 57 kHz, a center frequency of 60 kHz, and an upper cutoff frequency of 63 kHz. The matched filter's parameters are selected by the filter's parameters of typical radar operating with a chirp signal.

Each simulation experiment has figures with obtained results. The oscillograms and spectrograms of the studies are shown from Fig. 4 to Fig. 7. In each figure a) is the input jamming chirp signal, b) is the response of the filter at the time domain, and c) is the response of the filter at the frequency domain.

A jamming chirp signal was applied to the filter input with a frequency deviation $B = 54 \div 66$ kHz, which is twice large as that of the filter. Figure 4 a) shows the input jamming chirp signal; figures 4 b) and 4 c) show the output signal of a 7-element chirp filter. The level of the output signal is 0,16V. The output signal exceeds the detector threshold 1,6 times (4 dBU). The filter accumulates 1,6 times jamming chirp signal instead of suppressing it.

A second experiment was made. A jamming chirp signal was applied to the filter input with a frequency deviation $B = 57 \div 63$ kHz, which is the same as that of the filter. Figure 5 a) shows the input jamming chirp signal, figures 5 b) and 5 c) show the output signal of a 7-element chirp filter. The level of the output signal is 0,56V. The output signal

exceeds the detector threshold 5,6 times (15 dBu). The filter accumulates 5,6 times chirp jamming signal instead of suppressing it.

The third experiment included a jamming chirp signal, applied to the filter input with a frequency deviation $B = 58\div 62$ kHz, which is 1,5 times smaller than that of the filter. Figure 6 a) shows the input jamming chirp signal; Figures 6 b) and 5 c) show the output signal of a 7-element chirp filter. The level of the output signal is 0,28 V. The output signal exceeds the detector threshold 2,8 times (9 dBu). The filter accumulates 2,8 times chirp jamming signal instead of suppressing it.

A fourth experiment was made. A jamming chirp signal, applied to the filter input with a frequency deviation $B = 59\div 61$ kHz, which is 3 times smaller than that of the filter. Figure 7 a) shows the input jamming chirp signal; Figures 7 b) and 7 c) show the output signal of a 7-element chirp filter. The level of the output signal is 0,18 V. The output signal exceeds the detector threshold of 1,8 times (5 dBu). The filter accumulates 1,8 times jamming chirp signal instead of suppressing it.

Table 1:- The parameters ratio between the real radar and the model at the modeling process.

Parameters	Intermediate Frequency IF	Transmitted pulse Duration T_{trans}	Pulse Repetition Frequency f_{PRF}	Compressed pulse Duration τ	Repetition Interval T_{rep}	Time
Radar	60 [MHz]	10 [μ s]	1 [kHz]	0,2 [μ s]	1 [ms]	
Model	60 [kHz]	10 [ms]	1 [Hz]	0,2 [ms]	1 [s]	

Table 2:- Specifications of the the 7-element matched filter to linear frequency modulated signal.

Element	1	2	3	4	5	6	7
Bandpass [Hz]	57000-57857,1	57857,1-58714,29	58714,2-59571,43	59571,4-60428,57	60428,57-61285,71	61285,7-62142,86	62142,8-63000
Delay Time [s]	0.024285	0.022857	0.021428	0.020	0.018571	0.017142	0.01571

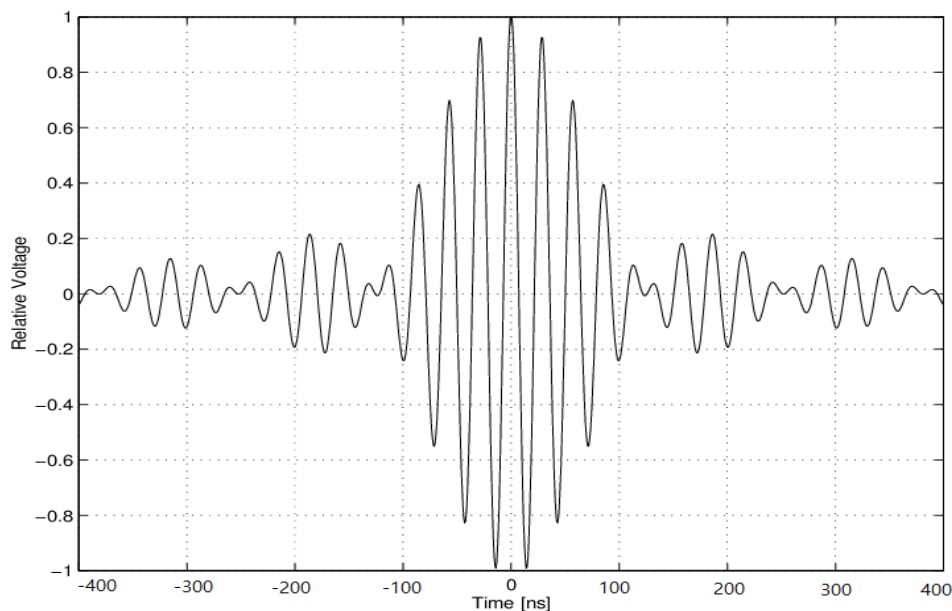


Fig. 1:-An example of an autocorrelation function of a 5-element filter matched to linear frequency modulated (chirp) signal.

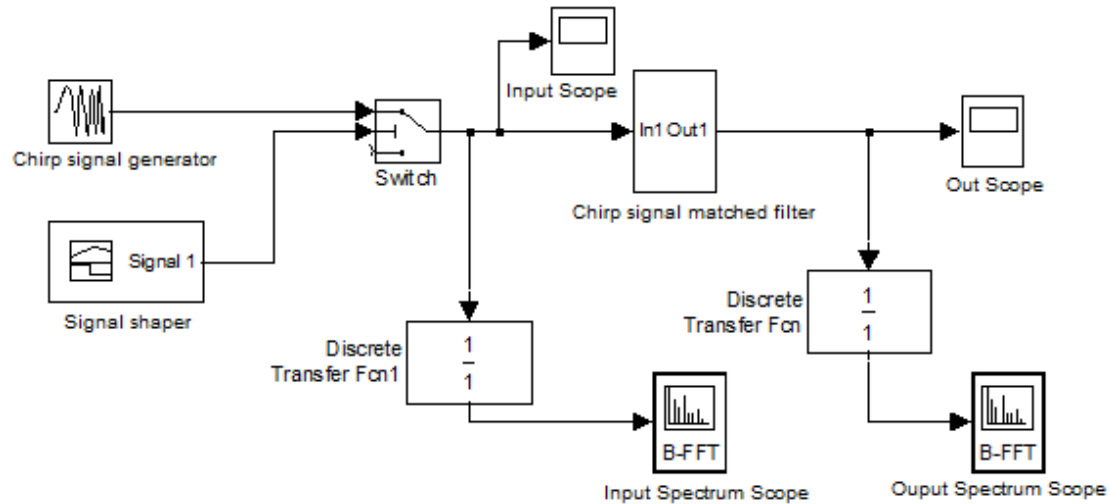


Fig. 2:- Thefunctional diagram of the imitation modeling of the jamming process.

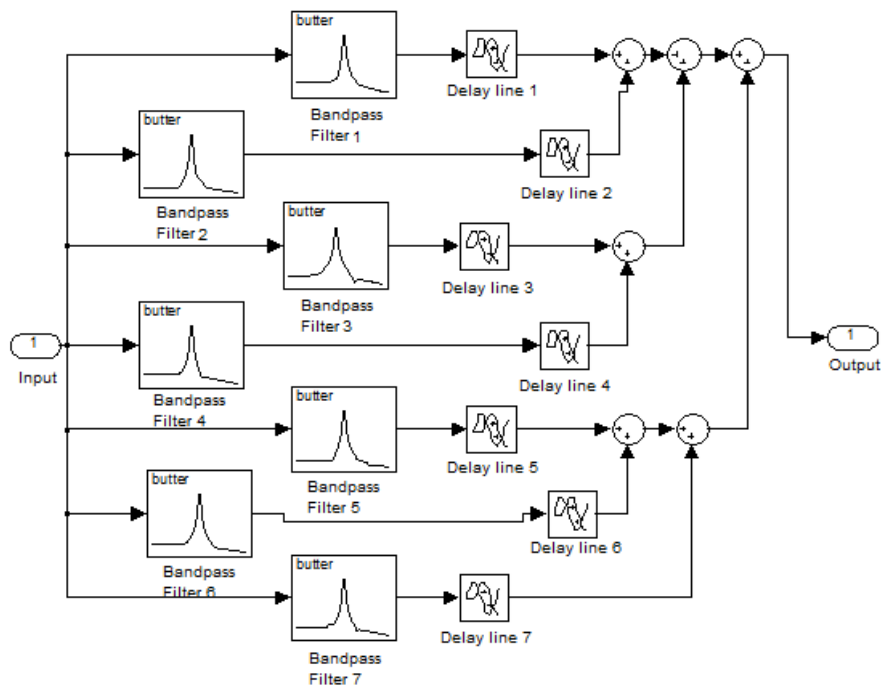


Fig. 3:- Thechirp matched filter structural diagram.

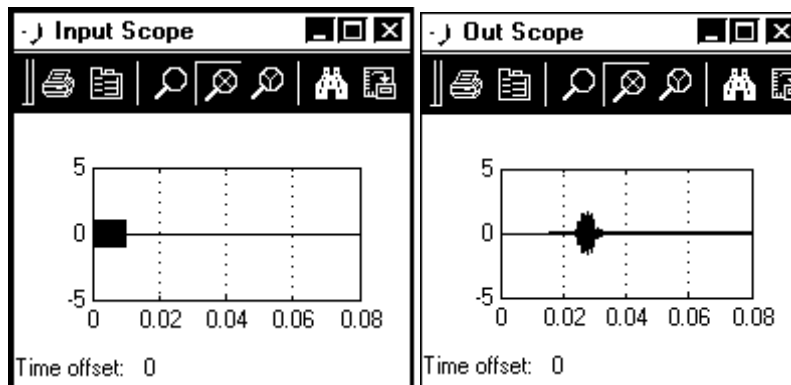


fig. 4 a):-Thechirp jamming signal at the input.

fig. 4 b):-Thesignal at the output on the filter.

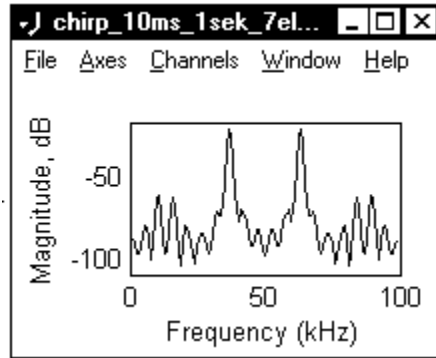


fig. 4 c):-Thesignal's spectrum at the output on the filter.

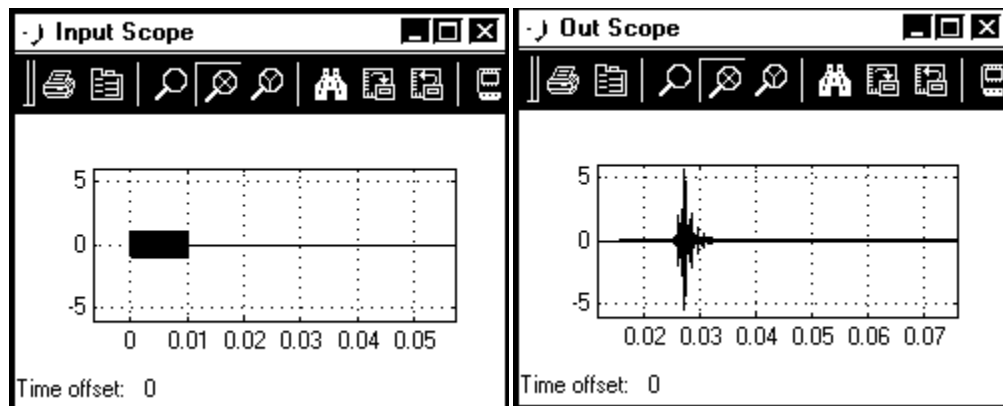


fig. 5 a):- Thechirp jamming signal at the input.

fig. 5:b):- Thesignal at the output on the filter.

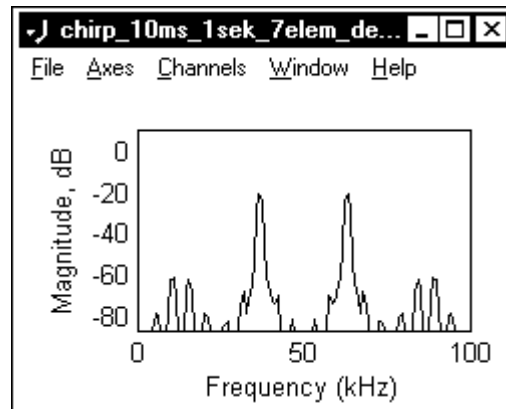


fig. 5 c):- Thesignal's spectrum at the output on the filter.

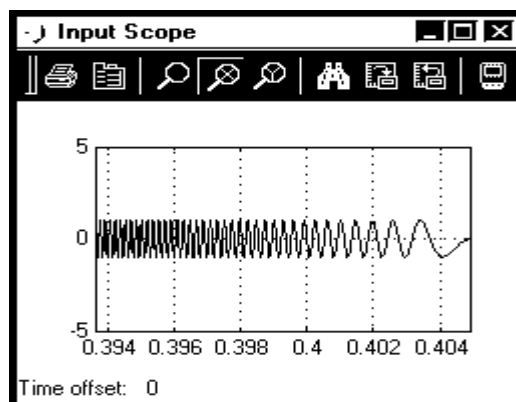


fig. 6 a):-Thechirp jamming signal at the input.

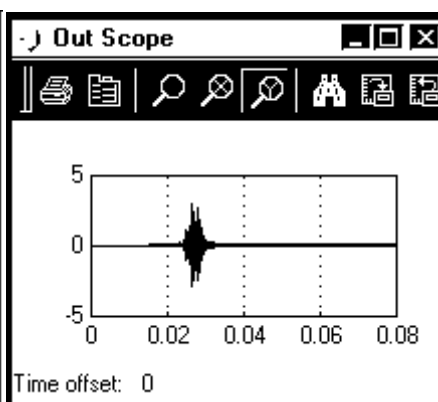


fig. 6:b):-Thesignal at the output on the filter.

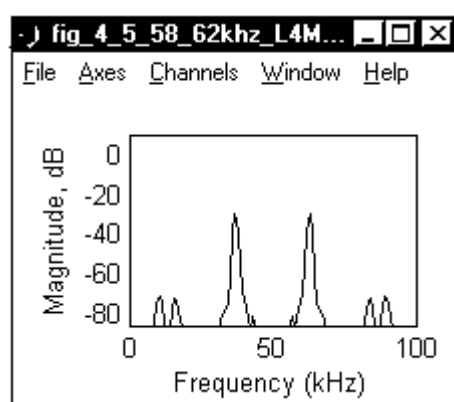


fig. 6 c):-Thesignal's spectrum at the output on the filter.

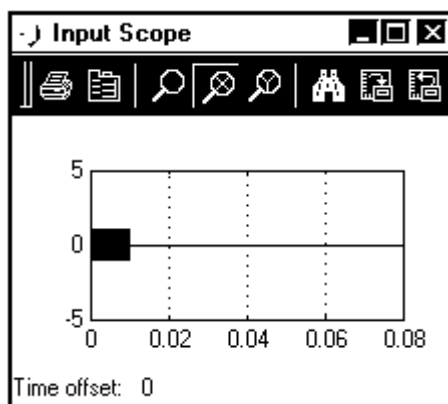


fig. 7 a):-Thechirp jamming signal at the input.

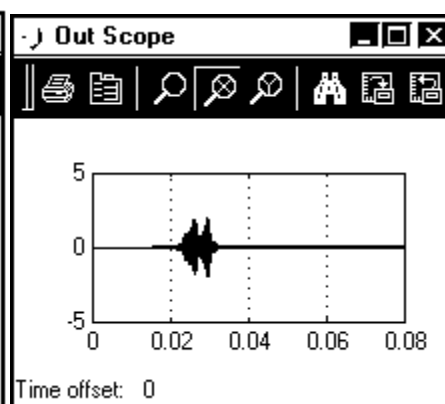


fig. 7b):-Thesignal at the output on the filter.

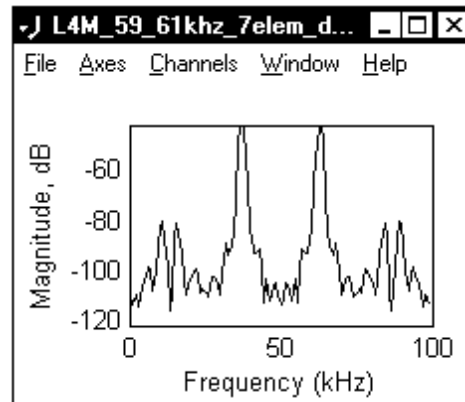


fig. 7 c):- The signal's spectrum at the output on the filter.

Conclusion:-

The following conclusions have been drawn from the research of the suppression degree of the chirp filter jammed by chirp signal:

1. The filter, matched to the radar's linear frequency modulated signal does not suppress the input jamming chirp signal but also accumulates it. The degree of accumulation is proportional to the coincidence of the deviation of the jamming signal with the complex amplitude-frequency characteristic of the filter;
2. The output signal of the chirp filter is accumulated from 1.6 to 5.6 times ($4 \div 15$ dB), which exceeds the threshold of the automatic detector several times. The amplitude of the output signal depends on the deviation value of the jamming signal;
3. Jamming signal with frequency deviation three times smaller than the bandwidth of the receiver's chirp filter causes 1.125 times higher level of its output compared to jamming signal with frequency deviation two times larger than the frequency band of the filter;
4. Counteraction by jamming chirp signals is more effective than counteraction by noise signals from an energy point of view. This is a result of the longer time for matching the spectra and phase ratios of jamming chirp signals with the frequency band of the optimal filter of the receiver and depends on the structure of the jamming signal and the complex characteristic of the filter.

The obtained results could be used to design technical devices to improve the jamming against military surveillance radars operating with chirp signals. These devices could degrade the performance of the radar, which would significantly affect its jamming immunity.

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