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RESEARCH ARTICLE

JAMMING IMMUNITY RESEARCH OF A RADAR OPERATING WITH BARKER CODED PHASE MODULATED SIGNAL

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Abstract

The matched filter is one of the most important elements in the pulse compression technique. Pulse compressed signal enhances the interference immunity of a radar operating with such a signal. A model of the matched filter for a Barker coded phase modulated 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 radars operating with Barker coded phase modulated signal.

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Introduction:-

Radars operating with Barker coded phase modulated signal could be susceptible to jamming signals which possess a high cross-correlation function with radar's transmitted signal. The correlation properties of Barker coded phase modulated signals are analyzed by (Skolnik1970), (Richards2014) and (Nenging1984). 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 low efficiency of a noise-like signal on a chirp filter is proved by (Spassov2005), even at very high values of the power spectral density.

Barker coded phase-modulated signals were used to simulate jamming signals. The receiver 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 jamming Barker coded phase-modulated signals.

The simulation uses a matched filter to a Barker coded phase modulated signal as a part of the radar's receiver. The matched filter is a functional element of the receiver of the radar that uses compressed signal (Barker coded phase modulated signal). Some of the radar's parameters are implemented in the simulation of the matched filter's operation.

Simulation setup:

A simulation of a matched filter's reaction to Barker coded phase-modulated jamming signals was made using the Matlab software. The Simulink tool of the Matlab software was used to create a model of matched filter to a Barker coded phase modulated signal, according to (Spassov20052006) and similar to a real matched filter of a typical military air defense radar. Barker coded phase-modulated signals were synthesized as jamming signals. These

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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 research of the radar matched filter's jamming immunity to Barker coded phase-modulated jamming signals was done in the following order:

1. A model of a filter matched to the radar's Barker coded phase modulated signal was synthesized, and the parameters of the signals at the radar receiver were determined;
2. Barker coded phase-modulated jamming signals were selected and the limits of their changes were determined;
3. Barker coded phase-modulated jamming signals were feed to the input of the matched filter and output signals were measured;
4. The obtained results were evaluated and conclusions were made.

The diagram of the simulation model of the process is shown in Fig. 1. A model of a filter matched to the radar's Barker coded phase modulated signal was synthesized according to the block diagram shown in Fig. 2. The filter parameters are selected by the real filter's parameters of typical radar, operated with Barker coded phase modulated signal.

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 in the model, the threshold level is 100 mV (for the input power $2 \cdot 10^{-4}$ W of the tested filters accepted in the experiments - normalized amplitude 0.1V on a load of 50 Ω). The amplitude of the Barker coded phase-modulated jamming signals at the filter's input is normalized to 0.1V at all of the experiments. The automatic detector's threshold amplitude is equal to 0.1V at all of the experiments;
2. At 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). A scale of 1000:1 between the real system and the model has been chosen, due to a limitation in the speed of the software product. The ratio between the values of the parameters and their tolerances in the radar and the model is strictly preserved. The modeling was made at the ratio of the parameters between the real radar and the model by Table 1.

Results and Discussions:-

A model of a 7-element filter matched to the radar's Barker coded phase modulated signal was synthesized. All parameters at each unit are selected, optimized, and adjusted according to the theoretical requirements defined in (Barton2004) and (Skolnik1970). The 7-element filter is matched to a central frequency of 60 kHz of the radar's Barker coded phase modulated signal at all simulated experiments.

The results obtained from simulation experiments are shown in the figures. The oscillograms and spectrograms of the research are shown from Fig. 2 to Fig. 6. In each figure a) represents the input jamming chirp signal and b) represents the response of the filter at the time domain.

A 13-element Barker coded phase-modulated jamming signal was applied to the filter input. Figure 2 a) shows the input Barker coded jamming signal and Figure 2 b) shows the output signal of the filter. The level of the output signal is 0,5 V. The output signal exceeds the detector threshold 5 times (14 dBU). The filter accumulates 5 times the jamming chirp signal instead of suppressing it.

A second experiment was made. A 7-element Inverse Barker coded phase-modulated jamming signal was applied to the filter input. Figure 3 a) shows the input 7-element Inverse Barker coded jamming signal and Figure 3 b) shows the output signal of the filter. Many peaks are exceeding the threshold of 0,1 V (one scale division). The maximum level of peaks of the output signal is 0,35V. The maximum output signal exceeds the detector threshold 3,5 times (10,9 dBU). The filter accumulates 1,5÷3,5 times jamming chirp signal instead of suppressing it.

A 7-element Barker coded phase-modulated jamming signals were applied to the filter input. The jamming signals have different discrete code times. The discrete's time of the code was short, equal, and longer than the elementary discrete of the filter. The numbers of peaks exceeding the output threshold of the filter (0,1 V) for standard and Inverse Barker coded phase-modulated jamming signal were calculated. The results are shown in Table 2. There are

different numbers of peaks exceeding the output threshold of the filter, but they are more at the case of the Inverse Barker coded phase-modulated jamming signal.

The third experiment included a random coded phase-modulated jamming signal, with a different discrete code time. The discrete's time of the random code was short, equal, and longer than the elementary discrete of the filter. Figure 4 a) shows the random coded phase-modulated jamming signal, with an elementary discrete's time $\tau=100 \mu\text{s}$, which is twice short than the elementary discrete's time of the filter. Figure 4 b) shows the output signal of the filter. Many peaks are exceeding the threshold of 0,1 V (one scale division). The maximum level of peaks of the output signal is 0,5 V. The maximum output signal exceeds the detector threshold 5 times (14 dBu). The filter accumulates 2÷5 times jamming chirp signal instead of suppressing it.

Figure 5 a) shows the random coded phase-modulated jamming signal, with an elementary discrete's time $\tau=200 \mu\text{s}$, which is the same as the elementary discrete's time of the filter. Figure 5 b) shows the output signal of the filter. Many peaks are exceeding the threshold of 0,1 V (one scale division). The maximum level of peaks of the output signal is 0,7 V. The maximum output signal exceeds the detector threshold 7 times (16,9 dBu). The filter accumulates 1÷7 times jamming chirp signal instead of suppressing it.

Figure 6 a) shows the random coded phase-modulated jamming signal with an elementary discrete's time $\tau=400 \mu\text{s}$, which is twice longer than the elementary discrete's time of the filter. Figure 6 b) shows the output signal of the filter. Many peaks are exceeding the threshold of 0,1 V (one scale division). The maximum level of peaks of the output signal is 0,6V. The maximum output signal exceeds the detector threshold 6 times (15,5 dBu). The filter accumulates 1,5÷6 times jamming chirp signal instead of suppressing it.

Table 1:- TheParameters ratio between the real radar and the model.

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

Table 2:- Thenumbers of peaks exceeding the output threshold of the filter for standard and inverse Barker coded phase-modulated jamming signal.

Barker code signal type	Discrete time length of the Barker code jamming signal [μs]				
	100	150	200	250	300
Standard Out signal numbers above the 0,1 V threshold	2	3	1	4	5
Inverse Out signal numbers above the 0,1 V threshold	4	5	7	6	6

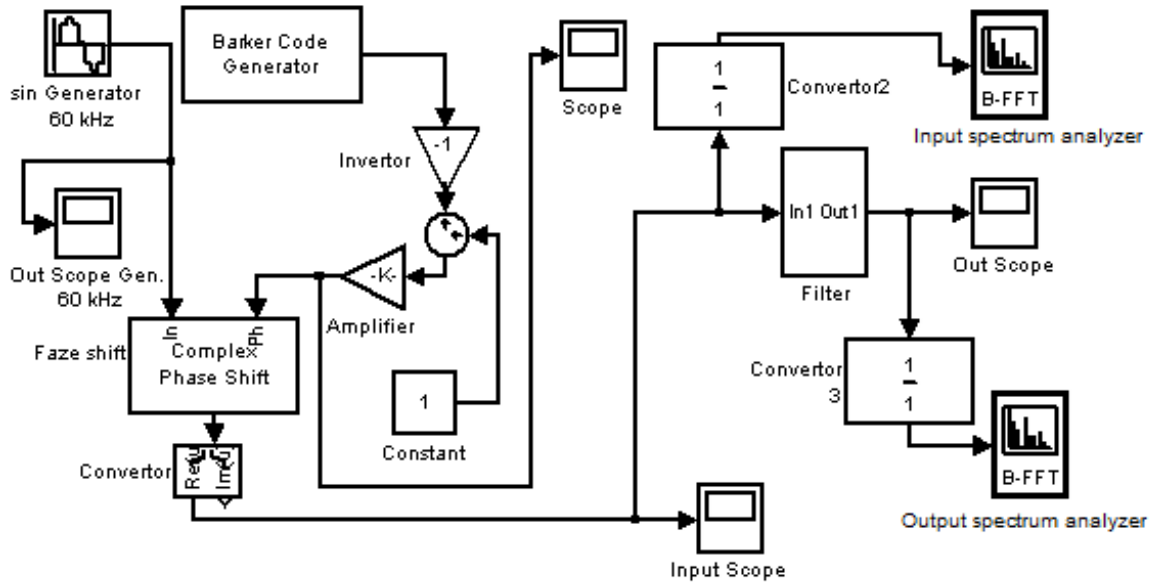


Fig. 1:- Thefunctional diagram of the imitation modeling of the process.

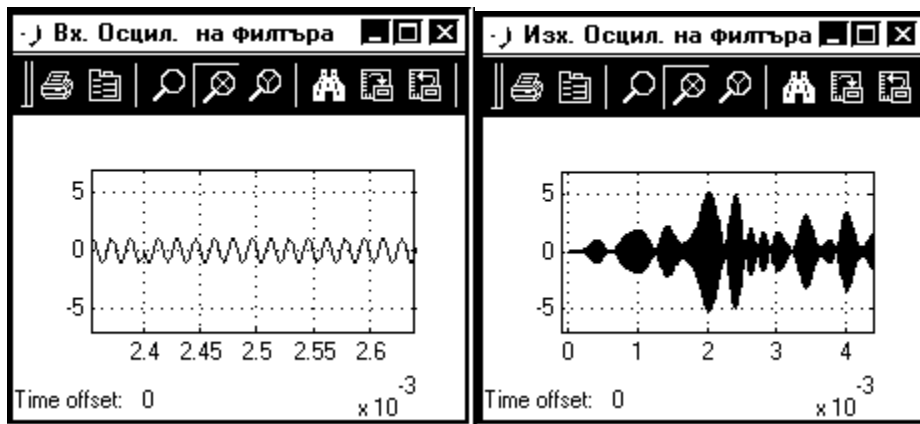


Fig. 2 a):-Theinput 13-element Barker signal.

Fig. 2 b):-Theoutput signal of the filter.

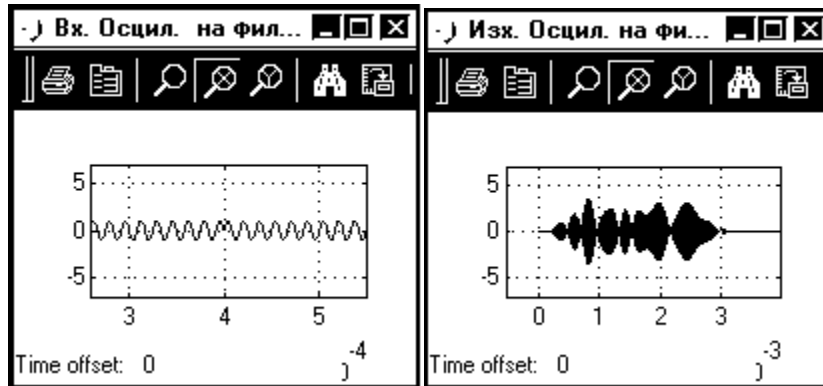


Fig. 3 a):-Theinput 7-element inversed code signal.

Fig. 3 b):-Theoutput signal of the filter.

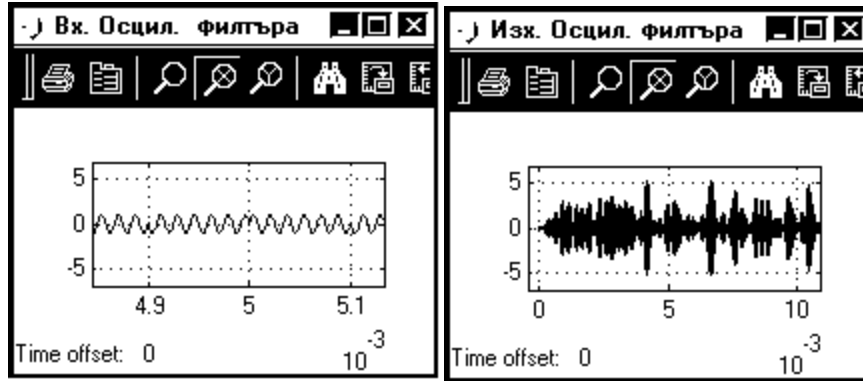


Fig. 4 a):-Theinput random coded jamming signal ($\tau = 100 \mu s$).Fig. 4b):-Theoutput signal of the filter.

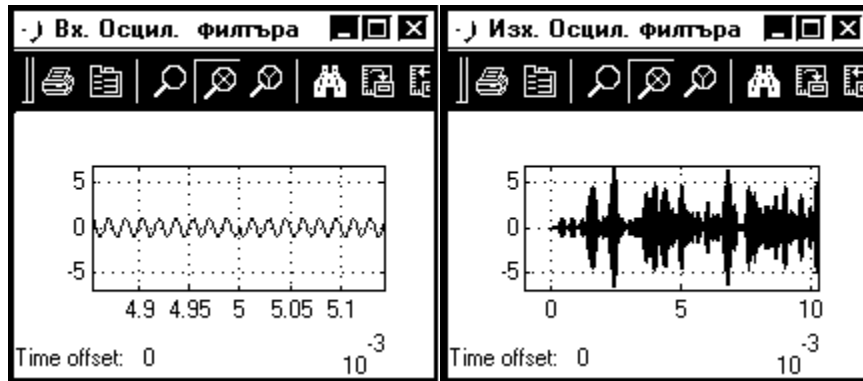


Fig. 5 a):-Theinput random coded jamming signal ($\tau = 200 \mu s$).Fig. 5b):-Theoutput signal of the filter.

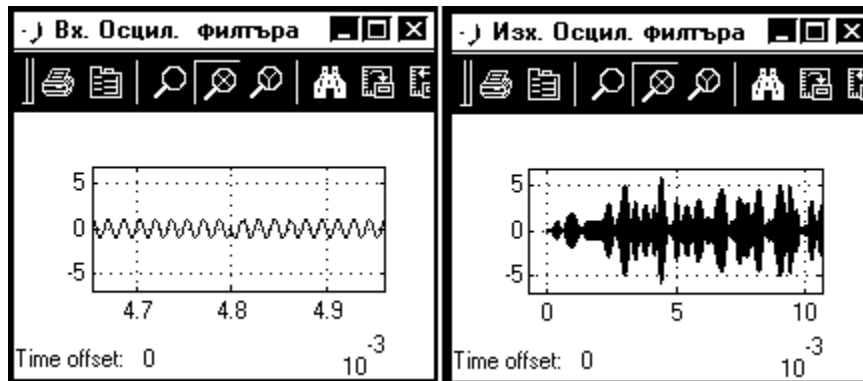


Fig. 6 a):-Theinput random coded jamming signal ($\tau = 400 \mu s$).Fig. 6b):-Theoutput signal of the filter.

Conclusion:-

The model of a 7-element filter matched to the radar’s Barker coded phase modulated signal not only does not suppress the input Barker coded jamming signal, but also accumulates it.

The matched filter’s degree of accumulation of the jamming signal depends on the time length and elementary discrete's time of the jamming signal code. The maximum numbers of out signal’s peaks exceeding the output threshold of the filter were measured when discrete's time of the jamming code was equal to the elementary discrete of the filter.

Jamming by Barker coded phase modulated signal is more effective than jamming 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 Barker coded jamming

signals with the frequency band of the optimal filter of the receiver (Spasov2006). It also depends on the structure of the jamming signal and the complex characteristic of the filter.

The obtained results can be used to implement technical devices to improve the jamming against military surveillance radars operating with Barker coded phase modulated signal. These devices could degrade the radar's performance, which would significantly affect its jamming immunity (Velkov2003).

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