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INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/12216
DOI URL: http://dx.doi.org/10.21474/IJAR01/12216

RESEARCH ARTICLE

SIMULATION MODELING OF THE INTERFERENCE IMMUNITY OF THE RADARS OPERATING WITH COMPRESSED SIGNAL

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Manuscript Info

Manuscript History
Received: 25 October 2020
Final Accepted: 28 November 2020
Published: December 2020

Key words:-
Radar, Pulse Compression, Linear Frequency Modulation, Matlab, Interference Signals

Abstract

The immunity to the interference of a radar operating with a pulse compression signal is an important feature. The matched filter is one of the elements of the radar, providing resistance to interference. A model of a matched filter to chirp signal has synthesized using the Simulink tool of the Matlab software. Two types of interference signals have fed to the matched filter input, and the output signals are measured. The matched filter's degree of suppression against these two interference signals has been assessed. Inferences about the interference immunity of the radars operating with compressed signals have been made.

Introduction:-

Different sensor types use various physical principles to select their signal type at the interference environment (Slavov2019), (Velkov2003). Radar sensor uses time, frequency, and space domain to acquire an echo signal (Velkov2008), (DimovVelkov1978), (Velkov2005). A model of a filter matched to linear frequency modulated signal (Spassov2005) has been created, after which the suppression degree of this filter for two types of interferences has been evaluated. Some of the modern military radars use such matchedfilters in their receivers.The assessment of the suppression degree of the matched filter has been made in two stages:

First - measurements and assessments of the suppression degree of a matched filter to linear frequency modulated signal against active pulse interference were made.

Second - measurements and assessments of the suppression degree of a matched filter to linear frequency modulated signal against active noise interference were made.

The following indicators are introduced to evaluate the results obtained in the experimental modeling:
1. In terms of energy –the level (amplitude) of the signals;
2. In terms of information – the number of signals exceeding this level and possessing duration equal to the chirp signal's shrunken pulse.

This level at the output of the receiving system or the input of the ADC is about 20 ÷ 30 mV for radars operating with a compressed signal (TBP = B.τ>> 1), with bandwidth at an intermediate frequency B ≈ (8 ÷ 10) MHz and with a noise factor of the input stages of the order of 3 ÷ 6 dB (Traveling Wave Tubes, parametric amplifiers, solid-state microwave receivers).

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Taking into account the signal-to-noise ratio 3:1 of the threshold automatic detector, a level of 60 ÷ 90 mV is obtained and therefore the threshold for comparison and evaluation is fixed at 100 mV.

The evaluation rate in the time domain is τ = 200 ± 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).

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

1. In terms of energy - the threshold level in the model is 100 mV (the input power of the tested filtersin the experiments is 2.10^{-4}W - normalized amplitude 0.1V on a load of 50 Ω);
2. At the time domain–a scale of 1000: 1 was chosen between the real system and the model due to the software product's limitation speed.

The specific values of the parameters are given in the description of the results for each measurement. The ratio between the parameters values and their tolerances in the radar and the model is strictly preserved. The modeling is performed at the ratio of the parameters between the real radar and the model by Table 1.

The block diagram of the simulation model of the process is shown in fig. 1. A 7-unit matched filter for a linear frequency modulated signal is synthesized according to the block diagram shown in Fig. 2 and with parameters given in Table 2.

The process and matched filter models are synthesized using the Simulink tool of Matlab software.

Results and Discussions:-

Chirp filter's suppression degree to jamming series of pulses:
The response of a 7-unit matched filter for a chirp signal to jamming series of pulses has been researched. The research is made according to the structural scheme of the simulation model of the process, shown in Fig. 1, and the series of pulses have a carrier frequency equal to the average frequency of the filter. A continuous pulse series generator with a pulse duration t = 0,2 ms, a carrier frequency of 60 kHz, a repetition frequency of 100 Hz, and an amplitude equal to 0.1V is used as the input signal source. This amplitude is normalized, and it is equal to one division of the scale of the oscilloscope/spectrum analyzer in all experiments. The maximum amplitude is 0.7V, which corresponds to 7 divisions on the scale of the oscilloscope/spectrum analyzer.

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. They are given in Table 2, and the theoretical requirements are defined by (Levanon2004). 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 filter parameters are selected by the filter parameters of a typical radar with a chirp signal.

Figures 3 a) and b) show the input pulse sequence and the output signal of a 7-element filter matched to a linear frequency modulated signal. The amplitude of the pulses at the input of the filter is normalized to 0.1V. The level of the output signal is about 0.014V. The output signal will not exceed the detector threshold of 0.1V, and the filter has a suppression factor of 7 times (16.9 dB) for this pulse sequence.

Similar experiments were performed with the same matched filter to a linear frequency modulated signal, but for a pulse sequence with a pulse duration longer than the shrunk pulse duration (τ = 0.3 and 0.4 ms) and with the same input pulse sequence parameters, as in Fig. 3. The results compared with the experiment of Fig. 3 are shown in table 3. A comparison of the results shows that the chirp filter better suppresses (17 dBU) pulse interference with a duration comparable to that of the shrunken pulse (τ = 0.2 ms). Pulse disturbances with a duration of 1.5 and 2 times longer than that of the compressed pulse (τ = 0.3 and 0.4 ms) are suppressed slightly less (14.9 dBU and 14 dBU), but cannot exceed the threshold of 0.1 V.

Chirp filter's suppression degree to a noise jamming:
Simulation modeling has been made. The matched chirp-filter resistance to jamming signals (white noise) is researched. The functional scheme of the simulation model of the process is similar to the one shown in Fig. 1. The differences include a switch and generators of sinusoidal and pulse signals, which are connected to a generator of "white" noise. The input signal is "white" noise with power 20.10^{-4} W (normalized amplitude 0.1V on a load of 50 Ω). The dispersion chirp filter has a lower cutoff frequency of 57 kHz and an upper cutoff frequency of 63 kHz. The filter has the same functional scheme and characteristics as these, shown in Fig. 2, and its parameters are the same as those shown in Table 2.

The oscillogram of the input signal in Fig. 4 a) and respectively the filter's reaction - the oscillogram of the output signal (Fig. 4 b) are shown. While the average amplitude of the input "white" noise is equal to 0.1V, the output signal is 0.015V, which is equal to the suppression of 6.6 times (16.5 dB).

Evaluation of the simulation modeling results:
Table 4 shows the results of the measured degree of filter suppression under the influence of impulse and noise interference. The results of the research show that the matched filter to a linear frequency modulated signal has a suppression factor of 14 ÷ 17 dBU of the pulse and 15.5 dBU of the noise interference. Measurements show that the filter suppression factor of a pulse interference is highest (17 dBU) at a pulse duration equal to the shrunk filter pulse (t = 0.2 ms).

The matched filter to a linear frequency modulated signal has a slightly lower suppression factor (15.5 dBU) of the noise interference, compared to the suppression factor (17 dBU) of a pulse interference.

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

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:- The specifications of the7-element matched filter to the 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

Table 3:- The Chirp matched filter suppression factor against pulse interference at different pulse duration.

Input pulse duration T_{in} [ms]	0.2	0.3	0.4
Average Output amplitude U_{out} [V]	0.014	0.018	0.020
Average value of the suppression factor[dBU]	17	14.9	14

Table 4:- The Chirp matched filter suppression factor against pulse interference and white noise interference.

Average value of the suppression factor [dBU]	
Pulse interference	White noise
14 ÷ 17	15.5

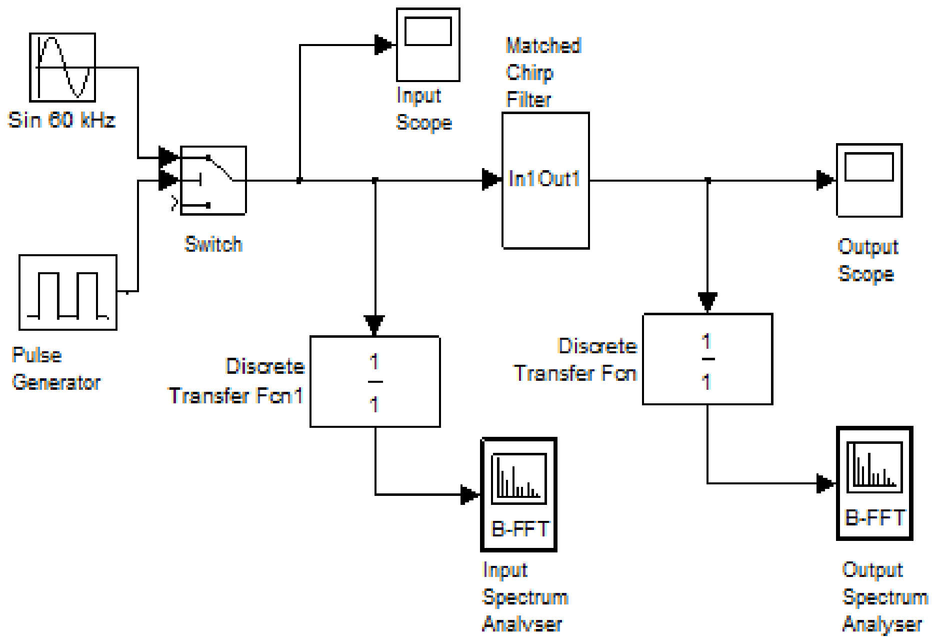

Fig. 1:-Thefunctional diagram of the imitation modeling of thejamming process.

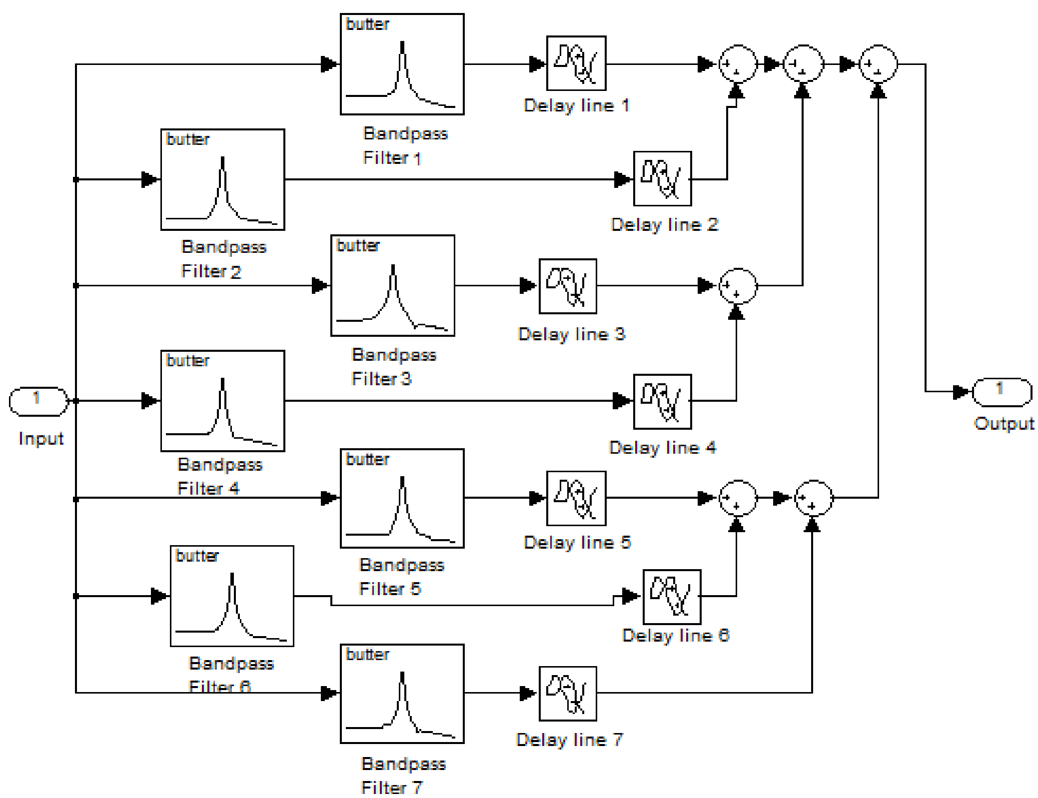

Fig. 2:- TheChirp matched filter Structural diagram.

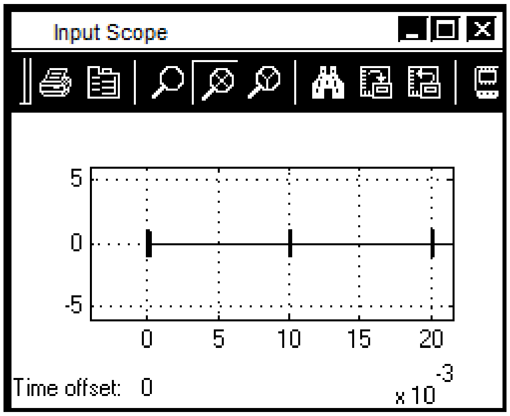

Fig. 3 a):-Thepulse jamming at the input of the chirp filter,

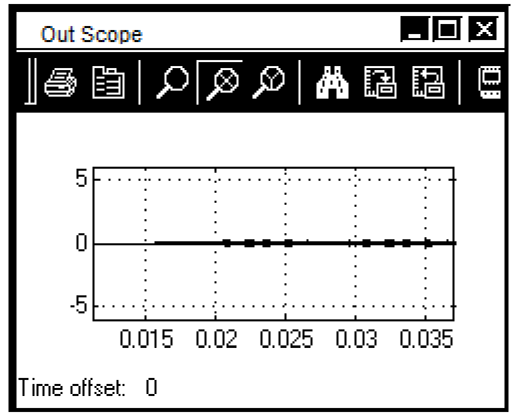

Fig. 3 b):-Thesignal at the output on the filter.

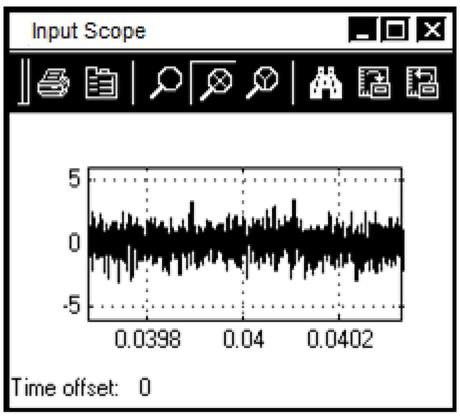

Fig. 4 a):-The “white” noise at the Input on chirp filter.

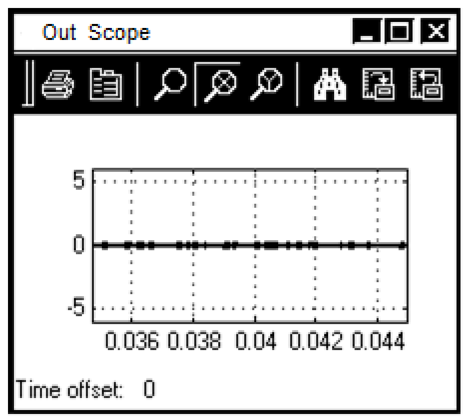

Fig. 4:b):-Thesignal at the output on the filter.

Conclusion:-

The following conclusions can be drawn from the research of the simulation modeling of the matched filter for linear frequency modulated signal:

1. Modern military radars have adaptive modes of operation, use a compressed signal with a big Time-Bandpass Product (TBP = B.τ>> 1) and matched filter to it. They have high noise resistance to active wideband interference and to impulse interference and therefore require significant jamming power to be suppressed.
2. Higher jamming signal power (14 ÷ 17 dB) is required against radars operating with a chirp signal compared to radars using a standard (not compressed) signal to achieve equal jamming efficiency. This value is proportional to the compression ratio of the pulse.
3. This class radars could be effectively jammed by signals that have high correlation between their spectrum and the complex frequency response of the optimal filter of the radar. Jamming signals may be lower in power than active pulse interference.

The obtained results can be used to detect methods and technical means to improve the jamming against military surveillance radars operating with chirp signals. These methods must degrade the performance, which significantly affects the noise immunity of the radar. In the case of active jamming by (Korobko2003), (Nenging1984), (Velkov2003) these devices could be CFAR (Constant False Alarm Rate), repetition frequency-changing, and transmitting frequency change modes.

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