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Study of the frequency range measurement method using train chirp signal

The paper proposes a method for measuring range in the track-while-scan mode. The dependence of the measurement error for different deviation frequencies is studied by the method of mathematical modelling in *MATLAB*.

Keywords: secondary processing, range measurement, train chirp signal, deviation, *MATLAB*

By means of the track-while-scan (TWS) mode it is possible to manage multi-target tracking within the scan zone, with the number of targets up to 100. However, in the mode of quasi-continuous radiation of scanning pulses, ambiguousness by Doppler frequency occurs, when Doppler frequency shift of a signal reflected from an object exceeds pulse repetition frequency. There is ambiguousness by range as well, which occurs because the repetition frequency of scanning pulses is less than the real delay of the received signal.

As a result, for measurement of the coordinates, simultaneous radiation of several signal trains takes place, each train having different values of the repetition frequency. By applying correlation processing as per ambiguous coordinates measured at arrival of each train, unambiguous target coordinates, i. e., range and speed, are calculated. This method requires 8 to 10 radiations in one angular position on different repetition frequencies.

In the TWS mode it is possible to reduce the time of unambiguous range measurement. For that purpose it is necessary to perform signal radiation and processing in two successive scan clock cycles with a train chirp signal.

The use of frequency modulation in a train of coherently radiated pulses enables to apply Doppler processing of reflected signals with Doppler frequency measurement [1]. Deviation change from train to train makes it possible to measure Doppler frequency dependence on the value of deviation and range to target. The frequency method allows to obtain an unambiguous range measurement within a short period of time [2–4].

This paper is a study, carried out using the method of mathematical modelling, of the dependence of target range measurement accuracy on:

- the passband and Doppler filters arrangement;
- frequency deviation;
- noise factor (F) in Doppler frequency measurement.

Range finder block diagram is given in Fig. 1.

A transmitter consisting of a frequency modulator and an HF generator generates oscilla-

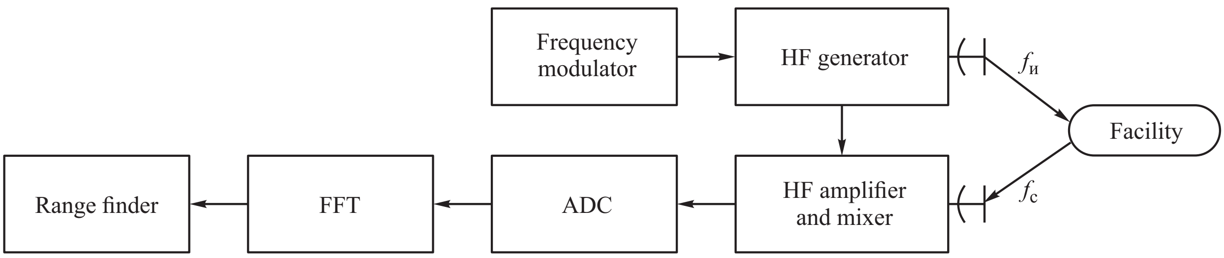

Fig. 1. Range finder block diagram:
FFT – fast Fourier transform; ADC – analogue-to-digital converter

tions whose frequency changes according to the sawtooth periodic law. An analytical notation of a chirp signal has the following view:

$$S(t) = U_0 \cos(2\pi f_0 t + \pi k t^2), \qquad (1)$$

where U_0 – amplitude;

f_0 – carrier frequency;

t – time varying within a range of $0\ldots T_{signal}$, with sampling period Δt;

T_{signal} – duration of scan clock cycles;

k – frequency deviation.

In this way, instantaneous frequency in a signal changes according to the linear law:

$$f_и = f_0 + kt. \qquad (2)$$

In case of a reflected signal, instantaneous frequency will look as follows:

$$f_с = f_0 + k(t - \tau_D), \qquad (3)$$

where $\tau_D = \frac{2D}{c}$ – delay time;

D – range;

c – speed of light.

Taking into account the Doppler effect, we have:

$$f_с = f_0\left(1 + \frac{2V_{radial}}{c}\right) + k(t - \tau_D). \qquad (4)$$

Here, V_{radial} – target’s radial velocity.

Having measured the frequency difference of the radiated and received oscillations, we obtain Doppler frequency value:

$$f_Д = f_и - f_с = k\tau_D + \frac{2 f_0 V_{radial}}{c}. \qquad (5)$$

With the signal radiated in two successive scan clock cycles on one carrier frequency but with different frequency deviations k_1 and k_2, we calculate the difference between Doppler frequency values:

$$f_{Д1} - f_{Д1} = k_1\tau_D - k_2\tau_D(k_1 - k_2). \qquad (6)$$

Then, having measured the values of Doppler frequencies of signal in two scan clock cycles, we can obtain the target range. Moreover, the measurement accuracy will depend not on the target speed but on the difference of Doppler frequencies.

Knowing the radiated signal at zero-range, we can calculate dependence of the autocorrelation function shift on the current range. For a reflected signal with time delay, a cross-correlation function is built from the radiated and received signals [5, 6].

Based on the maximum values of the functions and knowing the difference on the frequency axis, we can determine Doppler frequencies $f_{Д1}$ and $f_{Д2}$ for two deviation values.

Hence, the target range is calculated by the formulas:

$$\tau_{Dизм} = \left|\frac{f_{Д1} - f_{Д2}}{k_1 - k_2}\right|; \qquad (7)$$

$$D_{изм} = \frac{c\tau_{Dизм}}{2}. \qquad (8)$$

For model building, software package *MATLAB* with extension *Simulink* was used. As an input action, a pinpoint target movement trajectory in the rectangular coordinate system was simulated. Values of target range $D = 1\ldots220$ km with 500 m increment were selected on the trajectory.

At the first modelling stage, dependence of root-mean-square deviation (RMSD) on the value of noise dispersion for the next deviation values for the first and second scan clock cycles, respectively, was studied:

- $k_1 = 40$ kHz, $k_2 = 60$ kHz;
- $k_1 = 300$ kHz, $k_2 = 500$ kHz;
- $k_1 = 3$ MHz, $k_2 = 5$ MHz.

For a train with duration $T_{signal} = 10$ ms, the spacing of Doppler filters arrangement is $1/T_{signal}$, i. e., 100 Hz. Range measurement errors for different deviation values were obtained. At each target position with 500 m increment, a series of numerical experiments on ranges within 1…220 km was successively performed. There were 440 experiments in total. Statistical processing of the numerical experiments yielded the following range measurement errors:

- for deviations of 40 and 60 kHz – 1500 m;
- for deviations of 300 and 500 kHz – 100 m;
- for deviations of 3 and 5 MHz – 10 m.

The radar measurements are accompanied by a fluctuation component. In the mathematical model, a random number generator with Gaussian distribution was used as a noise source.

The RMSD of random number σ was selected within the range with 5 Hz increment. For each noise dispersion value a series of numerical experiments on ranges within 1…220 km, with 500 m increment, was successively performed. The total number of samples at each noise dispersion value amounted to 4400 numerical experiments.

Proceeding from the results of range measurement statistical processing, the RMSD was calculated. Shown in Fig. 2 are the dependences of range measurement RMSD on noise dispersion for different values of selected frequency deviations.

Based on the obtained results, a conclusion can be drawn that an increase of frequency deviation leads to a decrease of range measurement error.

At the second modelling stage, Doppler filter arrangement spacing was reduced from 100 to 20 Hz. The following values of deviation *k* were selected: 40 kHz for the first and 60 kHz for the second scan clock cycles.

In a similar way, a series of numerical experiments on ranges within 1…220 km, with 500 m increment, was successively performed. In the absence of noise factor, error in the 440 range measurements obtained decreased from 1500 to 400 m.

The RMSD of random number σ was selected within the range of 0...100 Hz with 1 Hz increment. For each noise dispersion value a series of numerical experiments on ranges within 1…220 km, with 500 m increment, was successively performed.

Given in Fig. 3 are the results of range measurement statistical processing depending on the noise dispersion. The total number of samples at each noise dispersion value amounted to 4400 numerical experiments.

Figs. 2 and 3 demonstrate that measurement accuracy can be improved not only by increasing frequency deviation, but also by reducing spacing of Doppler filters arrangement.

In this paper, numerical modelling of range measurement by the frequency method using train chirp signal has been performed. It was established that target range measurement error can be reduced by increasing deviation and decreasing spacing of Doppler filters arrangement.

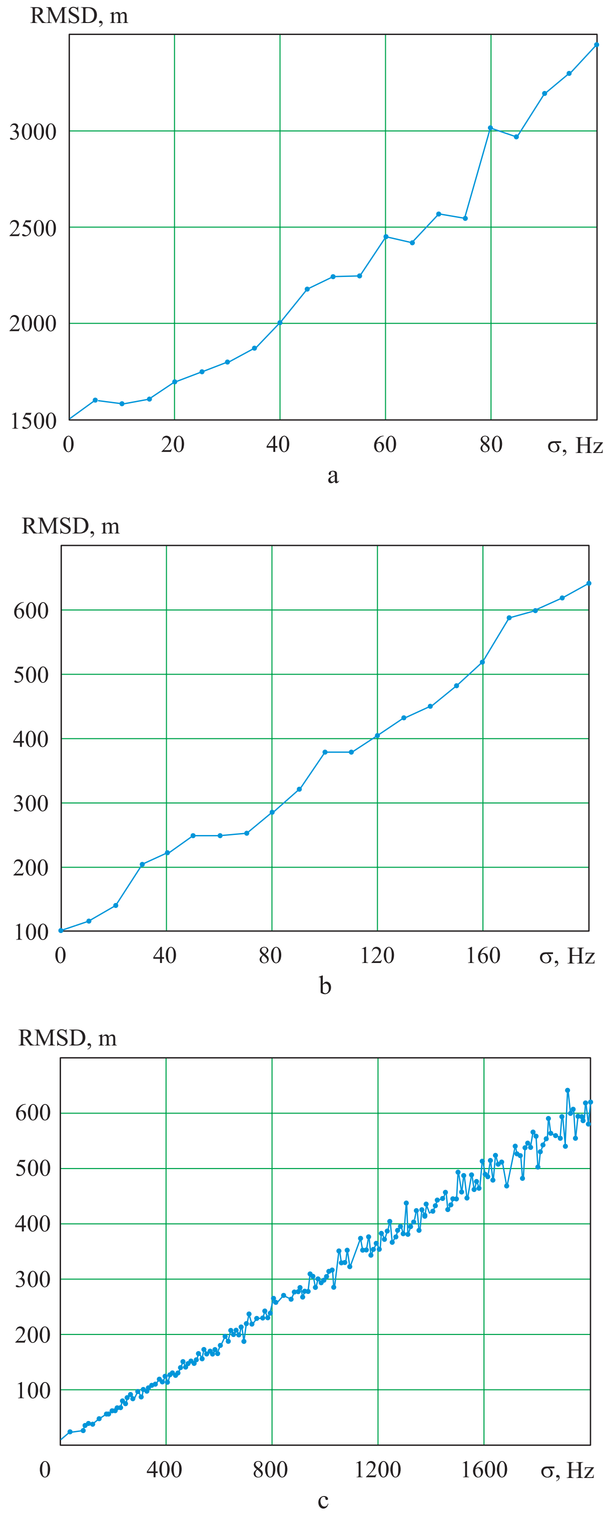

Fig. 2. RMSD dependences: on noise dispersion value a – deviations 40/60 kHz; b – deviations 300/500 kHz; c – deviations 3/5 MHz

For implementation of this range measurement method, subject to its engineering feasibility within radars, the optimal deviation values proved to be frequencies of the order of 40 and 60 Hz.

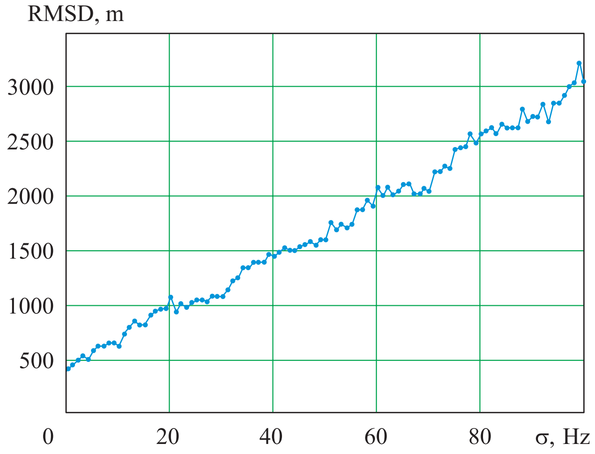

Fig. 3. RMSD dependence on noise dispersion value with reduced spacing of Doppler filters arrangement (deviations 40/60 kHz)

In the absence of noise factor, range measurement error is determined by the Doppler frequency resolution capability.

For deviation frequencies of 40 and 60 Hz, with signal accumulation time of 10 ms, range measurement error equals to 1500 m.

For typical values of F ≥ 15…20 dB in the TWS mode, Doppler noise dispersion is below 30 HZ, and the range measurement RMSD will amount to max. 1700 m.

With the deviation value exceeding pulse repetition frequency in a train, ambiguousness by Doppler frequency occurs, which should be taken into account when selecting frequencies.

The unambiguous values of target coordinates obtained through this method allow to run a procedure of correlating the values of newly measured coordinates with those of already tracked targets in the TWS mode, whereby the time of unambiguous range measurement is reduced. During operation of radars in the automatic mode this is the only method to manage scanning of the assigned sector of responsibility with generation of multiple-target tracks.

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Исследование частотного метода измерения дальности с использованием пачечного ЛЧМ-сигнала

Предложен способ измерения дальности в режиме «Сопровождение на проходе». Исследована зависимость погрешности измерения для разных частот девиации методом математического моделирования в среде *MATLAB*.

Ключевые слова: вторичная обработка, измерение дальности, пачечный линейно-частотно-модулированный сигнал, девиация, *MATLAB*.

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