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The Use of Fast Convolution and Correlation Analysis to Increase the Resistance of Digital Location

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The method of analog location with the use of devices with SAW that is now being used in our country is fast, however it is not accurate enough and has insufficient resistance to both natural and artificial noise. In the paper is proposed to increase the resistance of the digital location system by means of using a location system manipulated with noise-like code, and additional signal compression, filtration based on fast convolution and correlation analysis to isolate noise-like codes. The system proposed here easily adjusts to the changes in the code of the signal generated by the radar, and it also works in real time.

1. Introduction

Signals generation and compression for location purposes is carried out by means of the technique based on surface acoustic waves (SAW) – dispersive delay lines with SAW , and since recently with the use of digital technique. The method of analog location with the use of devices with SAW that is now being used in our country is fast, however it is not accurate enough and has insufficient resistance to both natural and artificial noise; there is a possibility that unexpected similar signals generated by other sources can be received instead of the signal reflected from the aim.

Technological development in fast specialised processors and digital devices resulted in the subsequent studies on the possibilities to use digital technology for location purposes [3, 4]. Contrary to analog location, digital location systems are more accurate, reliable (especially when using digital manipulation), ensure sufficient resistance to noise and are protected against unwanted signals from other sources.

If we have special processors for Fast Fourier's Transformation (FFT) of large capacity, then we can successfully apply digital filtration in frequencies in order to receive even highly disturbed location signals. Such a filtration allows to decrease to a high degree the minor lobe of the compressed impulse and at the same time to reduce the transitional process in comparison with digital filtration in digital domain. In such case radar signals have a form of radio impulses with modulated frequency and amplitude, and they are modulated linearly or non-linearly.

The basic structure of such system includes the FFT processor of the input signal, the system of fast multiplication of FFT's results in the appropriate elements of the frequency responses characteristics of the matched filter (MF), and the processor for the calculation of amplitude spectrum and inverse FFT (IFFT) in order to obtain compressed impulse in time domain [3]. However, such system does not ensure sufficient resistance to natural noise and artificial signals generated by other sources.

The aim of this paper is to increase the resistance of the studied digital location system by means of using a location system manipulated with noise-like code, and additional signal compression, filtration based on fast convolution and correlation analysis to isolate noise-like codes.

2. Signals

Signals with linear modulation of frequency, as it is shown in Fig.1a (with impulse compression) used in analog location usually have rectangular (Fig. 1b) or belling (Fig. 1c) envelope shape.

The frequency of such signals $f(t)$ increases lineary during transmission of a radio impulse length τ_i

$$f(t) = f_0 + (\Delta f \cdot t/\tau_i)\,\left[H^{(1)}(t) - H^{(1)}(t-\tau_i)\right], \qquad (1)$$

which reflects the inequality $t \le \tau_i$. W (1) f_0 - initial frequency, Δf - width of various frequency band, $H^{(1)}(t)$ – Hewisajd's function.

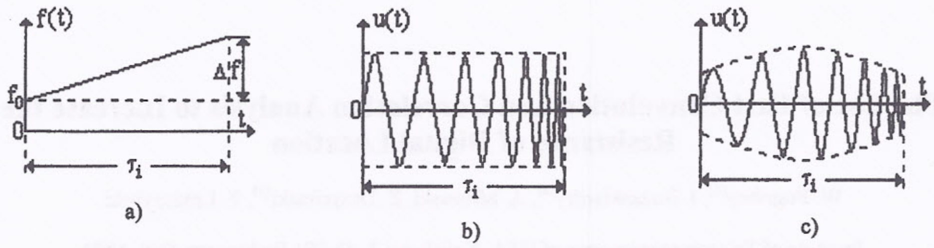

Fig.1. Signals with linear modulation of frequency.

We shall now use the signal response of periodical rectangular [1] (Fig.2) for which generally

$$x(t) = \sum_{m=0}^{\infty}\left[H^{(1)}(t - m(\tau_i + \tau_p)) - \right. \qquad (2)$$
$$\left. - H^{(1)}(t - m(\tau_i + \tau_p) - \tau_i)\right]$$

where $\forall H^{(1)}(r) = 0,\ r < 0;\ H^{(1)}(r) = 1,\ r \ge 0.$

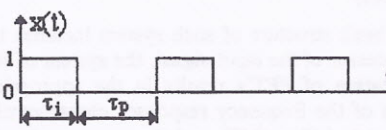

Fig.2. Periodical rectangular signal.

The series of periodical rectangular radio impulses length τ_i and pauses between ones τ_p can be represented in an analytical form using the operation [2] and when representing (2) in (1):

$$f(t) = \sum_{m=0}^{\infty}\left(f_0 + \frac{\Delta f}{\tau_i}\left(t - m(\tau_i + \tau_p)\right)\right) \times \qquad (3)$$
$$\times\left[H^{(1)}(t - m(\tau_i + \tau_p)) - H^{(1)}(t - m(\tau_i + \tau_p) - \tau_i)\right]$$

Fig.3 illustrates the generation of radio impulses with frequency linear modulation.

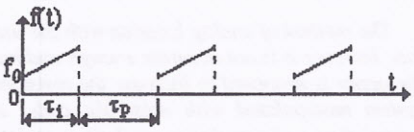

Fig.3. Radio impulses with frequency linear modulation

Radio impulse of rectangular shape is the basic one. Based on it we can obtain belling impulse in two ways:

- using amplitude modulation;
- shaping the appropriate frequency responses of the receiver.

Within one radio impulse length τ_i the phase becomes a non-linear function of time

$$\varphi(t) = 2\pi\int_0^t f(t)dt = 2\pi f_0 t + bt^2\ , \qquad (4)$$

where $b = \pi\ \Delta f / \tau_i$ - parameter of signal modulation.

Usually, in order to improve the signal to noise ratio (SNR), apart from linear modulation of frequency, also modulation of line segment frequency is used [4]. Such a deformation of the modulator's characteristics gives similar results to those which are obtained by means of smoothing window of a receiver's filter.

2.Methods and structures of increasing the location system resistance

Location systems with increased resolution are based on matched filtering with fast convolutions. Function of convolution is the base for non-recursive filtering in time domain

$$y_n = \sum_{m=0}^{M-1} x_{n-m} h_m , \tag{5}$$

where $\{y_n\}$ – filtration result; $\{x_n\}$ – input signal reading; $\{h_n\}$ – weight factors of impulse response, M – number of signal input samples.

Algorithm (5) requires a large number of mathematical operations and it does not ensure high accuracy with short signals. The product below relates to convolution (5) in frequency domain

$$\dot{Y}(k) = X(k) \cdot H(k), \tag{6}$$

where $Y(k)$ – Fourier's picture of output signal of the filter; $X(k)$ - Fourier's picture of input signal; $H(k)$ – frequency filter responses factors.

After obtaining the products (6) and amplitude spectrum, this spectrum should be processed to the time domain on the basis of IFFT. With the use of matched filter in location system a significant signal compression in time domain takes place.

It should be noted that the impulse characteristics of matched filter is a mirror reflection of the expected signal. Frequency responses of such filter is irregular, while the phase-frequency characteristics is non-linear. This does not reproduce the signal, but only isolates its peak on the background of the disturbance or noise. Phase and frequency characteristics of MF compensates mutual phase shifts of the signal harmonics. Output signal MF depends only on the amplitude spectrum of the signal and not on its phase spectrum. In the moment $t = t_0$, t_0 - some delays, $t_0 \geq \tau_i$ harmonics of various frequencies add up with the same phase, which creates signal peak on the output of MF.

Signal compression with frequency modulation is carried out on the basis of group delay t_{gr} (Fig. 4) which depends on frequency.

Groups of vibrations of high frequencies start to operate later, but they stop simultaneously with groups of lower frequencies. This ensures the joining of vibrations of all frequency groups. When these groups overlap, short compressed impulse is realised.

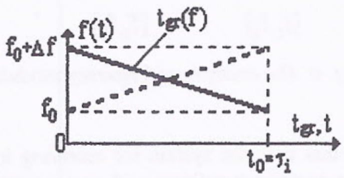

Fig. 4. Group delay.

The example of such MFs are surface acoustic wave (SAW) dispersive delay lines which were worked out a long time ago. Digital matched filtration is realised by means of a scheme shown in Fig. 5.

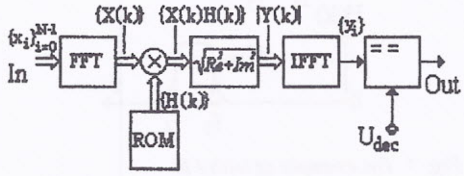

Fig. 5. The structure with use of fast convolution.

In location systems also correlation analysis (CA) of noise-like signals (Barker's, Nejman-Hoffman's and others) is used [2]. In this case the correlator works as a matched filter. On its output a narrow impulse is generated as a result of filtration, and its amplitude exceeds side leafs many times. With filtration of distorted noise-like signals time location of the compressed impulse does not change, but its height and position to side leafs is worse. However, usually the parameters of this impulse are good enough to read the impulse.

To characterise the impulse MF the same noise-like code is used which is written in a reverse order. [1]

In order to increase SNR of the compressed impulse it is suggested in the location systems to use together with the filtration on fast convolutions also AC noise-like codes. In order to do this the system is to generate and receive signals which are modulated in two different frequency intervals $[f_1, f_2]$ i $[f_3, f_4]$. Radio impulse in interval $[f_1, f_2]$ corresponds to „1" and in interval $[f_3, f_4]$ – „0" of the noise-like code. For instance, the radio impulses sequence shown in Fig. 6 correspond to the 101100 code sequence.

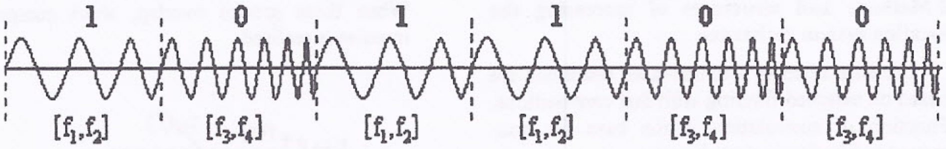

Fig. 6. The example of frequency modulation and code manipulation signal.

In that case the system for receiving location signals contains two filters with various capacities which correspond to frequency intervals $[f_1, f_2]$ i $[f_3, f_4]$. Fig. 7 illustrates as an example such frequency responses (FR) of two filters.

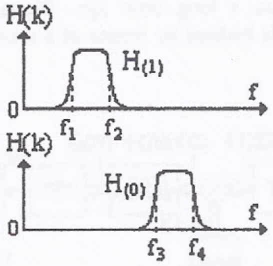

Fig. 7. The example of both FR.

The structure of the location system which is resistant to unwanted natural and artificial disturbances are shown in Fig. 8.

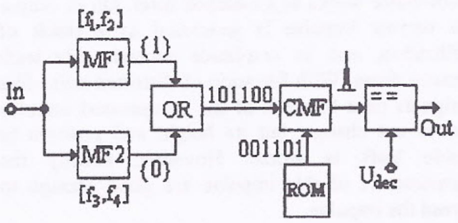

Fig. 8. The structure of the location system.

Such a structure is comprised of two identical channels with exactly evened delays which depend on periodical processes in those channels. It is obvious that these intervals between code symbols cannot be smaller than τ_i. The upper channel with capacity band $[f_1, f_2]$ picks up 1s, while the lower channel with capacity band $[f_3, f_4]$ picks zeros of the noise-like code. Zeros and ones in proper order join together in OR system and then overlap on the correlator input. The same code overlaps the second input of the correlator as a matched filter (CMF), but in reverse direction. The decision system threshold is chosen a'priori on the basis of the information on location signals.

3. Conclusion

According to the literature [4] location with the use of fast convolutions depends on the present development of the processor technology. Such a location ensures SNR of 70 dB. Additional use of correlation analysis with code manipulation and noise-like codes in such systems will allow to significantly increase such SNR, and at the same time to increase the resistance on natural disturbances and artificial noise generated by other sources.

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