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Study of pulse-width and amplitude-phase modulation influence on the M-sequences correlation characteristics

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***Abstract* — This paper considers the use of pulse-width modulation in modern small-size airborne radar systems to increase the resolution of images of the Earth's surface and improve the quality of radar surveillance. The use of complex signals with a wide spectrum allows to significantly increase the accuracy of object coordinates determination and improve radar images. The influence of pulse-width modulation parameters, such as pulse width and fill factor, on the characteristics of autocorrelation functions and the systems' ability to detect different types of objects under different conditions is investigated. Conventional M-sequences were used in the analysis, varying according to the use of different fill factors. The results showed that reducing the peak width of the normalized autocorrelation function improves the detection accuracy of radar signals**

Keywords — pulse width modulation; amplitude phase modulation; autocorrelation function; M-sequence; small-sized airborne radar system; object detection.

I. Introduction

In modern small-sized airborne radar systems (MSARS), it is important to ensure high resolution to obtain detailed images of the earth's surface [1-11]. To achieve this goal, complex signals with a wide spectrum are used, which significantly increases the accuracy of determining the coordinates of objects and improves the quality of the radar image.

The choice of signal modulation and its spectral characteristics affects the resolution and detection of ground objects. Currently, attention is paid to pulse-width modulation (PWM) [12-14], which ensures efficient signal processing and helps to reduce the width of the main peak - the lobe of the autocorrelation function (ACF) at a level of 3 dB. This leads to improved characteristics of radar systems [15-20], namely, it increases the accuracy of determining the distance to objects, allowing the system to more effectively resolve physical ground objects (PGO) under various monitoring conditions. Thus, the width of the main lobe of the ACF should be taken into account at the design stage of small-sized airborne radar systems [21-28] to ensure reliable and highly accurate measurement results.

II. Pulse-width modulation of M-sequence

PWM signals can be used in the MSARS for monitoring the earth's surface zones. This approach allows for effective adaptation of the signal parameters to the system's operating conditions and ensures high sensitivity when detecting objects. The use of PWM signals allows for control of the pulse width, which in turn allows for changing the average power and spectral characteristics of the radiation, making it more resistant to internal noise and ensuring better accuracy and reliability when determining distances to the PGO.

The use of PWM signals in MSARS also helps improve the systems' ability to recognize various types of objects on the ground, including vehicles and buildings. The change in signal parameters during modulation makes PWM signals important for improving the efficiency of real-time situation monitoring and analysis.

As is known, PWM depends on the values of the pulse duty cycle S or on its inverse duty cycle D. In this article, we will consider changes in canonical M-sequences depending on the duty cycle, characterized by expression (1):

$$D = \frac{\tau}{T} = \frac{1}{S}, \tag{1}$$

where T is the pulse period, τ is the pulse duration.

Several M-sequences of length N = 7, 15, 31 are considered, the generating polynomials and initial registers of which are presented in Table I. Table II presents the generated M-sequence.

TABLE I. GENERATING POLYNOMIALS AND INITIAL REGISTERS FOR M-SEQUENCES

Length N	**Generating polynomial**	**Initial register**
7	x^3+x+1	[1 0 1]
15	x^4+x^3+1	[1 0 1 1]
31	x^5+x^2+1	[1 0 1 0 0]

TABLE II. M-SEQUENCES

Length N	**M-sequence**
7	1 −1 1 1 1 –1 –1
15	1 1 –1 1 –1 1 1 –1 –1 1 –1 –1 –1 1 1
31	–1 –1 1 –1 1 1 –1 –1 1 1 1 1 1 –1 –1 –1 1 1 –1 1 1 1 –1 1 –1 1 –1 –1 –1 –1 1

Fig. 1 shows the normalized ACF (NACF) of the M-sequence data.

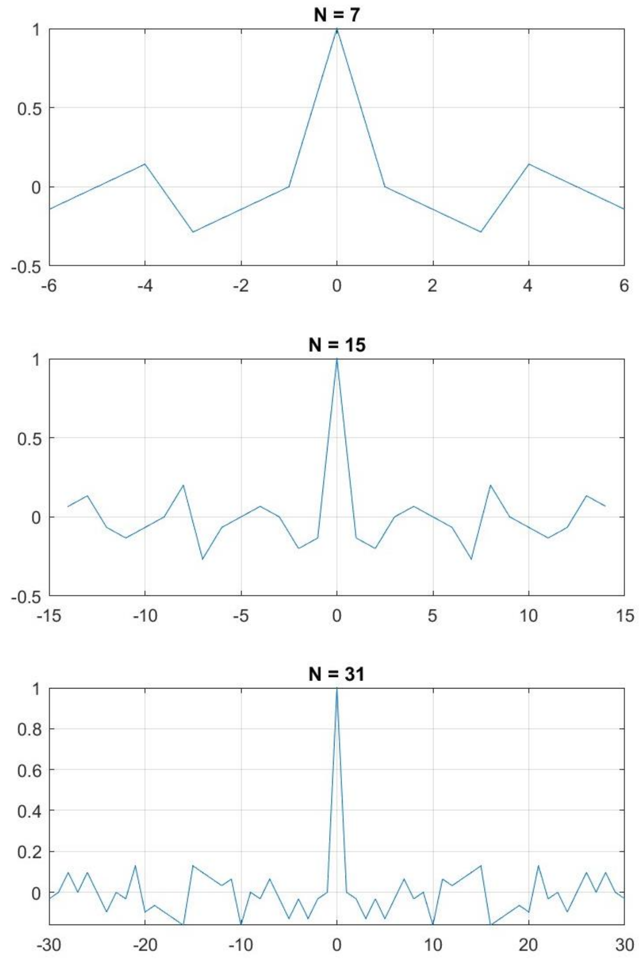

Fig. 1. NACF M-sequences of length N = 7, 15, 31

Below we will consider several variants of pulse sequences with different duty cycles D: 100%, 50% and 25% (1, 0.5 and 0.25 respectively). The duty cycle determines the ratio of the time during which the signal is active to the total pulse time. This parameter plays a key role in the formation of the signal, as it affects its amplitude and spectral characteristics. With a duty cycle of 100%, the signal is active throughout the entire pulse time, which ensures the maximum power of the transmitted signal. When the duty cycle is reduced to 50% and then to 25%, the length of the elementary pulse decreases, which leads to a change in the width of the elementary pulse of the M-sequence. These changes are shown in Fig. 2, demonstrating how a change in the duty cycles D affects elementary pulses in M-sequences.

As can be seen from the graphs, with a decrease in the duty cycle, the duration of an elementary pulse decreases in direct proportion, which leads to shorter but more frequently repeating signals. This is important for processing modulated signals, since it can significantly affect the resolution of images formed in MSARS by the method of synthesizing the antenna aperture.

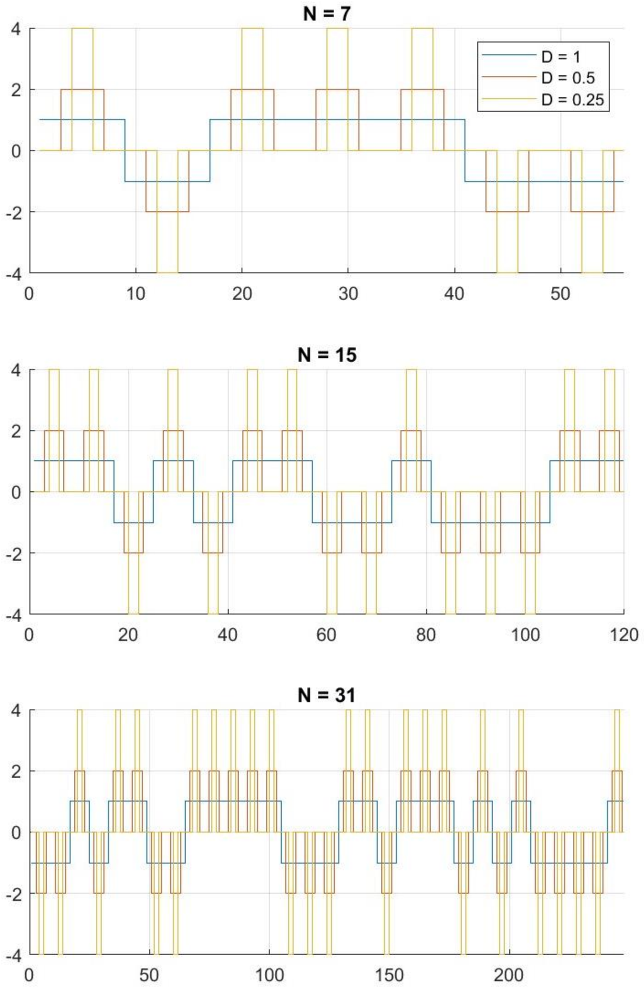

Fig. 2. The shape of pulse sequences depending on D

It is important to note that such changes reflected in the NACF affect the ability of the system to detect objects against the background of internal noise, which makes the analysis of these sequences a necessary step in the design of airborne radar monitoring systems. Fig. 3 shows the NACF of pulse sequences, where the presented graphs illustrate how changes in duty cycles affect the width of the main peak, as well as the side lobes.

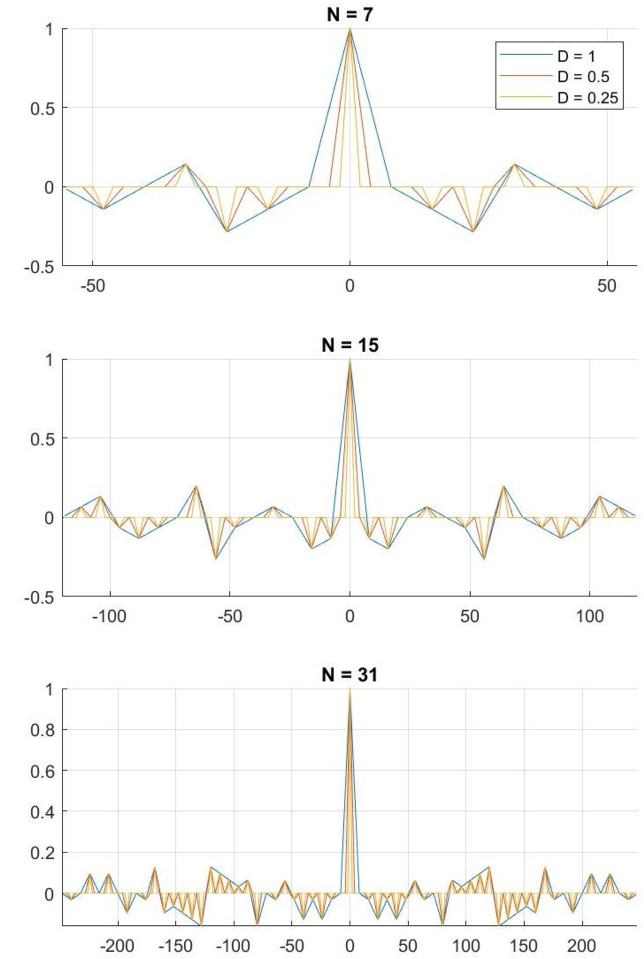

Fig. 3. NACF of *D*-dependent pulse sequences

Thus, in the course of the study, pulse-width modulation of canonical M-sequences was successfully implemented, which made it possible to analyze the influence of the duty cycle *D* on the characteristics of compressed signals. The results of computer experiments show that with a decrease in the parameter *D*, the width of the main peak of the NACF decreases significantly. A decrease in the width of this peak is a key indicator of an increase in the resolution of the system, since it indicates a more accurate separation of signals in the time domain

III. Amplitude-Phase Modulation of a Signal by M-Sequences

Further, to form the signal, amplitude-phase modulation (APM) [29] of the carrier signal by the formed M-sequences will be used. Fig. 4 shows APM pulses constructed on the basis of M-sequences with different widths of elementary pulses.

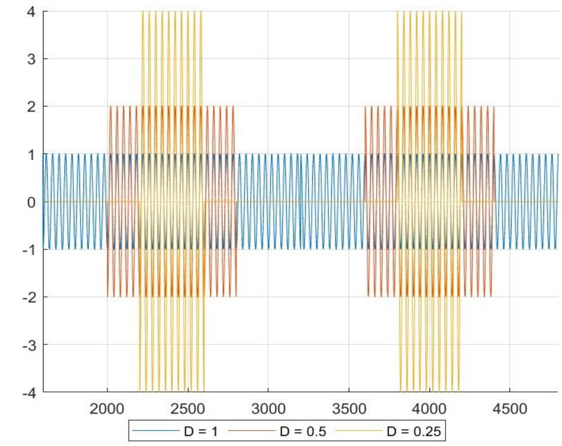

Fig. 4. APM pulses

Fig. 4 shows 2 elementary pulses from the considered sequences – positive and negative. As can be seen, for the positive elementary pulse the initial phase equal to 0° is used, while for the negative one – the initial phase equal to 180°. Fig. 5 shows the NACF of signals modulated by M-sequences both in phase and in width with amplitude.

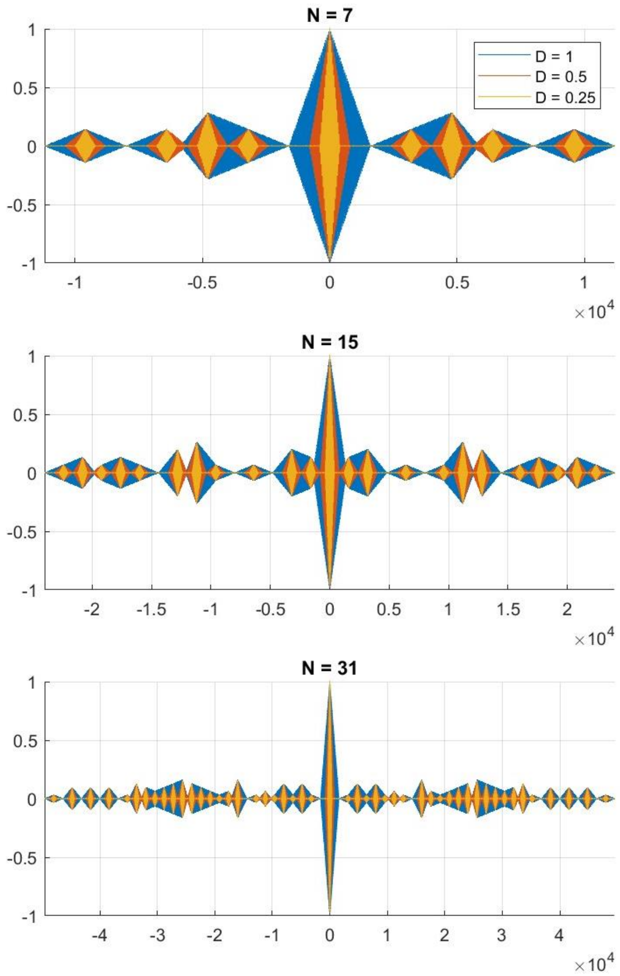

Fig. 5. NACF of modulated signals

In addition, the narrower main peak of the NACF contributes to a clearer separation of individual signals from background noise, which is necessary when working in difficult radar conditions. Thus, high signal detection accuracy combined with reduced sensitivity to internal noise allows systems to more effectively identify and classify PGO, opening up new possibilities for the application of radar technologies in various fields, such as monitoring in emergency zones and environmental monitoring

IV. Conclusion

Thus, the use of PWM and APM in MSARS significantly increases both the accuracy and sensitivity of these systems. Adaptation of signal parameters in accordance with operating conditions allows for highly accurate determination of the range to PGO, as well as complex structures such as vehicles and buildings.

The obtained results highlight the importance of choosing the modulation method at the design stage of small-sized radar systems, which ensures successful operation even in difficult conditions of limited visibility. Further research in this area opens up new opportunities for improving on-board monitoring and real-time analysis technologies, which can significantly improve the efficiency of radar observations and expand the possibilities of MSARS application in various fields.

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