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Methods beamforming adaptive digital array and their study using a computer model

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Abstract. The article describes the computer model of an adaptive digital antenna array. We considered in detail its features and specifications. The results of experimental research methods beamforming digital adaptive antenna array using a computer model. We studied four methods of providing independent beams forming the directivity pattern, calibration of the receiving channels, interference suppression and measurement navigation parameters.

1. Introduction

At present, modern radio electronic devices are increasingly equipped with adaptive antenna arrays with digital control. Adaptive digital antenna arrays are difficult to manufacture and have the worst mass and size characteristics. But they have the ability to control the shape of the radiation pattern. This is especially important in modern special radio-electronic equipment – radar equipment, professional radio navigation receivers, communication equipment. Development of command and measurement systems of the ground control complex is also possible with the use of adaptive digital antenna arrays. This will improve the efficiency of managing the exchange of information with spacecraft and the productivity of technological operations, reduce the time interval for carrying out the technological control cycle.

Adaptive antenna arrays with digital beamforming make it possible to realize special types of amplitude-phase distribution in the aperture and to apply various methods for processing signals received by individual antenna elements [1]. It is possible to obtain low levels of sidelobes of the antenna pattern, to use adaptive algorithms for optimal spatio-temporal filtering of signals against background noise [2, 3], to create multi-beam directional patterns for simultaneous tracking of several sources of useful signals [4, 5].

Some features of the use of adaptive digital antenna arrays for control and measurement systems of the ground control complex have already been sufficiently developed. For example, in [6] developed an adaptive algorithm for the radiation pattern control. This method allows to form several beams for simultaneous tracking of space vehicles. In [7] synthesized by the adaptation algorithm a phased array antenna to noise conditions. On the basis of this algorithm, an adaptive diagram-forming system is proposed. The use of adaptive frequency response correctors for receiving channels to equalize the group delay time of signals and improve the quality of interference suppression are discussed in [8].

However, the above sources did not carry out comprehensive studies of the developed methods of beamforming. At present, the methods of mathematical modeling are gaining popularity in conducting experimental research. The main advantage of these methods is a significant reduction in the financial, time, labor costs for conducting experiments.

In this paper, we consider a computer model of an adaptive digital antenna array and the results of a study of the methods of forming a radiation pattern with its help.

2. Features of the computer model

The computer model of the adaptive digital antenna array [9] is designed:

- investigation for beamforming methods for simultaneous reception of signals from at least four sources;
- spatial filtering of interference;
- measurement of navigation parameters (pseudorange and pseudo-speed);
- the influence of the distortion of the group delay time on the accuracy of the estimation of navigation parameters.

The computer model simulates the operation of an adaptive digital antenna array and allows:

- conduct spatial filtering of received useful signals from interference;
- to investigate the influence of the amplitude-frequency and phase-frequency characteristics of the receiving paths on the quality of the received signals;
- assess the accuracy of measuring navigation parameters.

The program allows you to conduct research and analysis:

- the level of the side lobes of the antenna pattern for different types of amplitude-phase distributions;
- the depth of the formation of dips in the antenna pattern for spatial filtering of interference;
- influence of heterogeneity of the group delay time in the measurement accuracy of navigation parameters and the level of noise reduction;
- the influence of the ratio of the power of useful signals to the power of interference and internal noise on the accuracy of measuring navigation parameters;
- the accuracy of measuring navigation parameters depending on the direction of reception of useful signals under interference conditions;
- the amount of error introduced by the delay tracking circuit.

Technical characteristics of computer model of adaptive digital antenna array:

- nine simulated antenna elements;
- four simulated moving sources of useful signals;
- the level of signals generated - from minus 145 to minus 165 dBW;
- the level of generated interference is from minus 80 to minus 145 dBW.

The computer model of the adaptive digital antenna array is developed using the Matlab R2016b complex, VisualStudio 2013, the development languages are Simulink (S-code), Matlab (M-code), C / C ++ (figure 1).

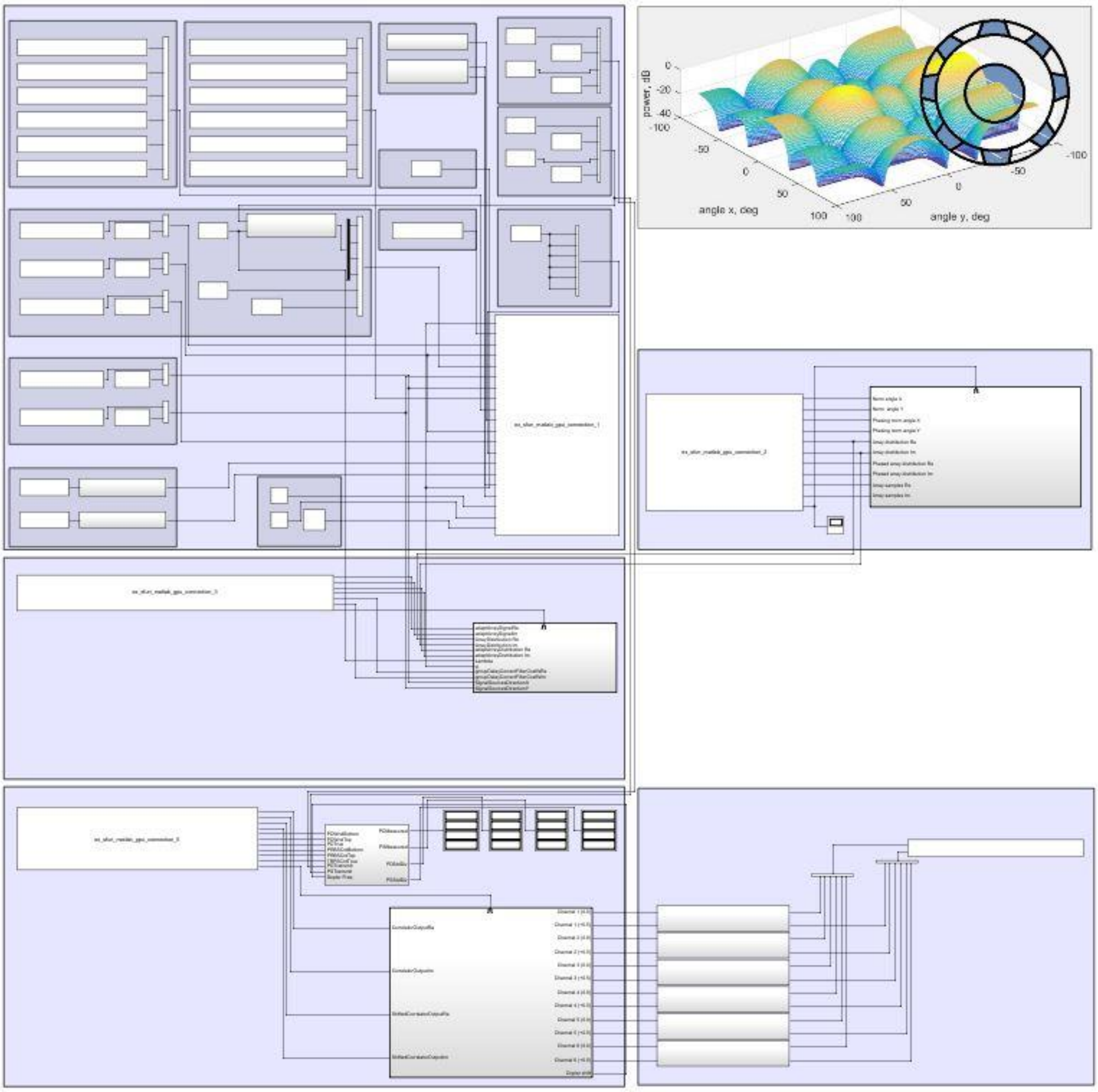

Figure 1. Computer model of adaptive digital antenna array in Matlab Simulink software environment, general view.

The computer model of the adaptive digital antenna array allows you to control:
- amplitude and phase distribution (figure 2);
- the size of the flat lattice pitch (figure 3).
- parameters of the distortion of the receiving channels (figure 4);
- the wavelength of the useful signals (figure 5);
- the direction of the signal sources and interference (figure 6).

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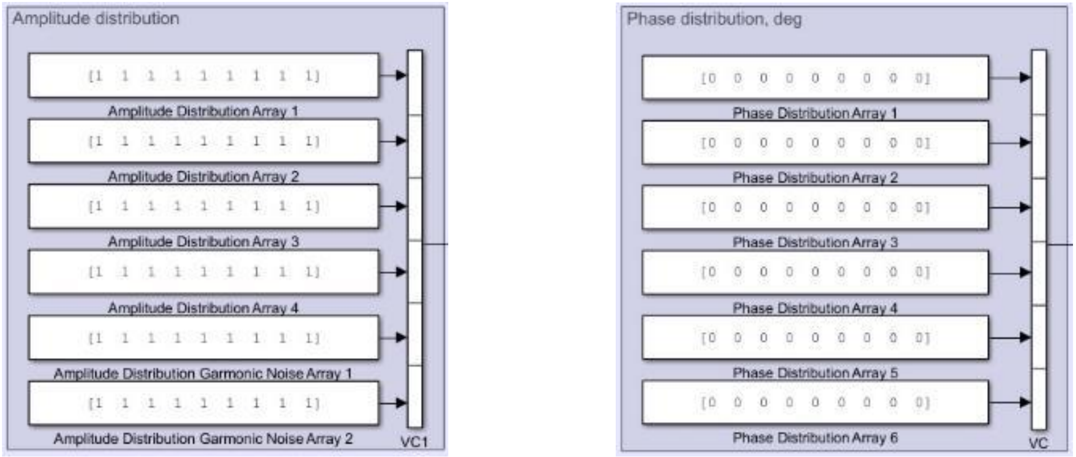

Figure 2. Amplitude and phase distribution.

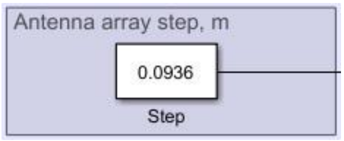

Figure 3. The pitch of the antenna array.

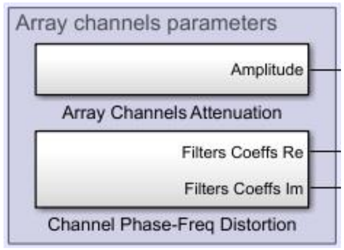

Figure 4. Parameters receiving channels distortions.

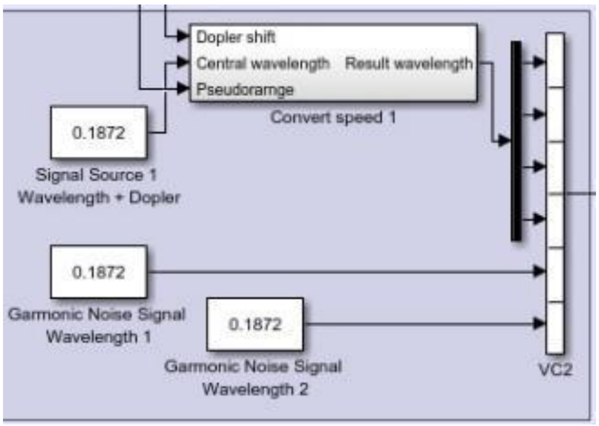

Figure 5. Wavelengths of signals.

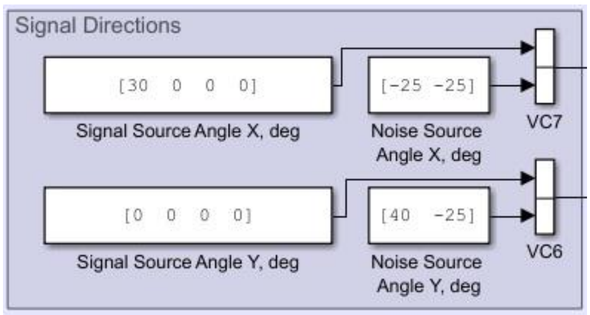

Figure 6. Sources of signals and interference.

3. Experimental studies of the computer model

Experimental studies were performed to evaluate the methods developed beamforming digital adaptive array antenna. The following evaluation was carried out:

- beamforming with simultaneous reception of signals from at least four sources;
- calibration of receiving channels, providing equalization of group delay time of signals and determination of mutual position of its elements;
- suppression of interference while maintaining the maximum of the radiation pattern on the source of the useful signal and the phase relationships between the signals received by the individual elements of the antenna array;

- measurements of navigation parameters (pseudorange and pseudo-speed) based on the received useful signal for ephemeris support.

In the course of the experiment, it was found that in the computer model of the adaptive digital antenna array forms a four-beam pattern. The beams are spaced at a solid angle of 120 degrees and follow the moving source of the useful signal. The required directivity pattern is formed both with the original uniform amplitude distribution and with the Dolph-Chebyshev distribution. Figures 7 and 8 show examples of the formed beam pattern of the first ray, which is deflected by 60º from the normal.

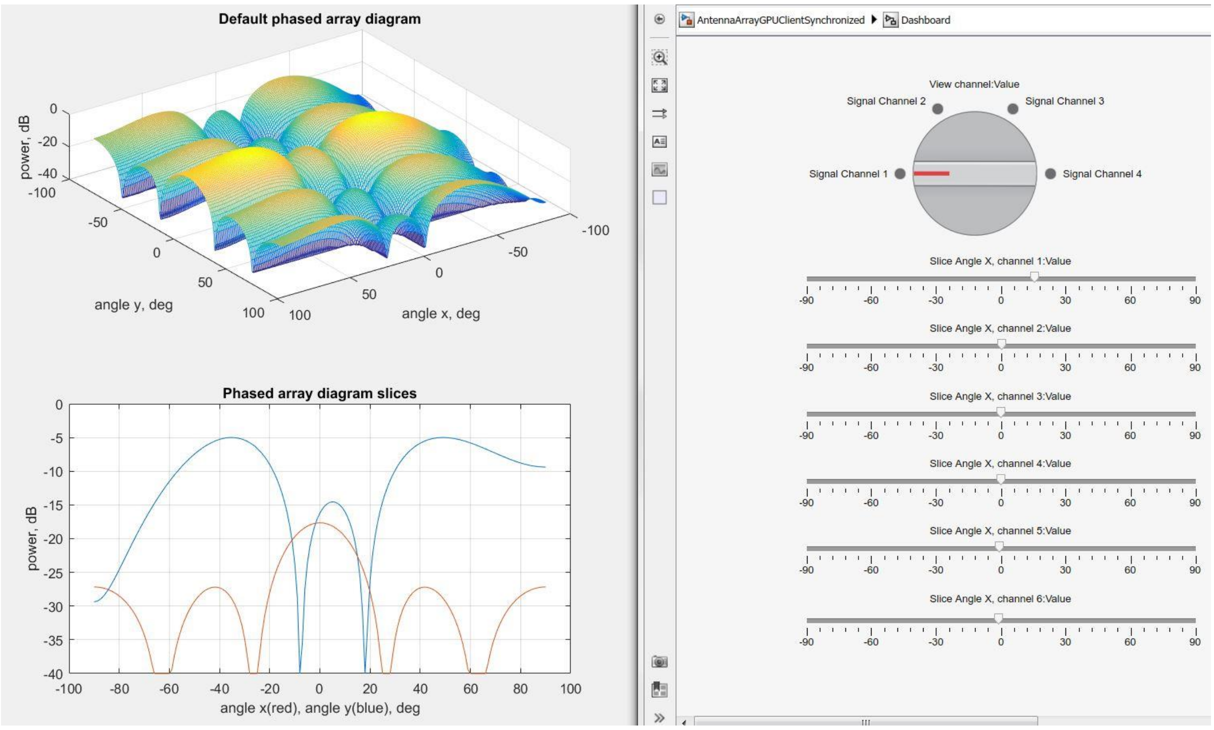

Figure 7. The beam pattern of the first ray with uniform amplitude distribution.

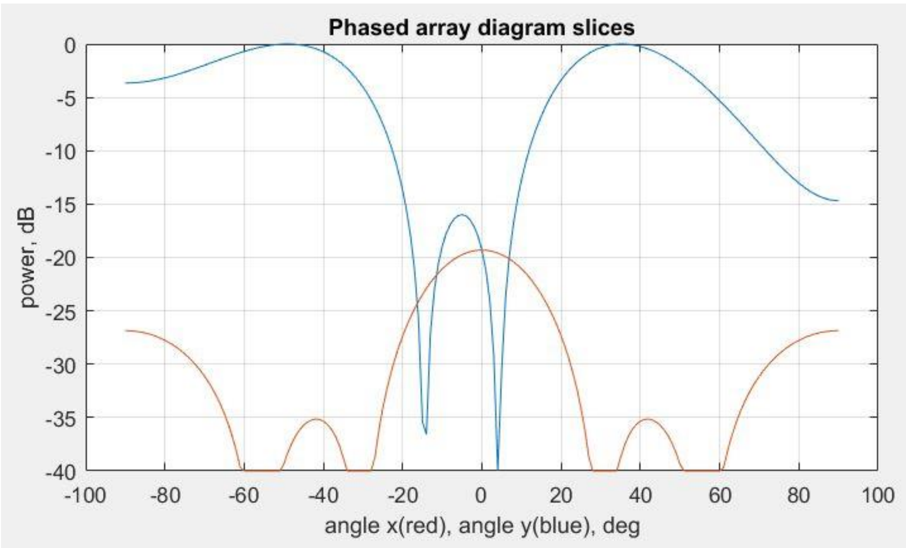

Figure 8. The beam pattern of the first ray with the distribution of Dolph-Chebyshev.

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The computer model makes equalization of the amplitude-frequency characteristics of the receiving channels. Their phase-frequency characteristic becomes linear after introduction of preliminary distortion, the coordinates of the antenna elements are determined relative to the central one. The change in the magnitude and type of distortions introduced, as well as the magnitude of the antenna array pitch, does not affect the results. The results of the experimental studies are shown in figures 9 and 10.

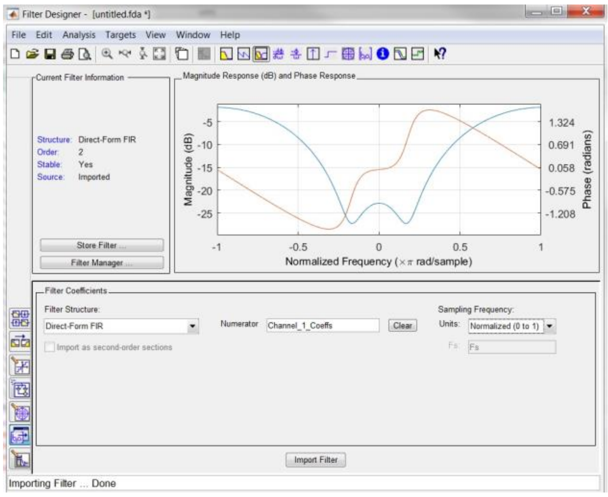

Figure 9. Introduction of preliminary distortions of the amplitude-frequency and phase-frequency characteristics of the receiving channel.

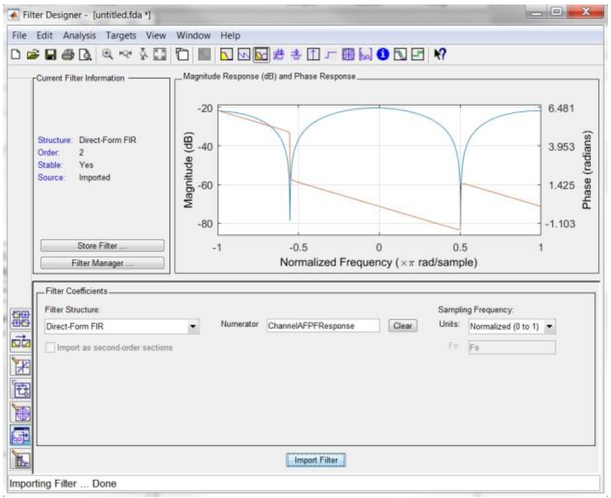

Figure 10. Amplitude-frequency and phase-frequency characteristics of the receiving channel after calibration.

The computer model suppresses interference from two sources with the formation of antenna polarity dips to a depth of 40 dB. When adapting, the direction of the main lobe of the radiation pattern and the phase relationships between the signals received by the individual elements of the antenna array remain unchanged. The change in the directions of the influence of sources of interference and their power on the results does not affect. The results of the experimental studies are shown in figure 11.

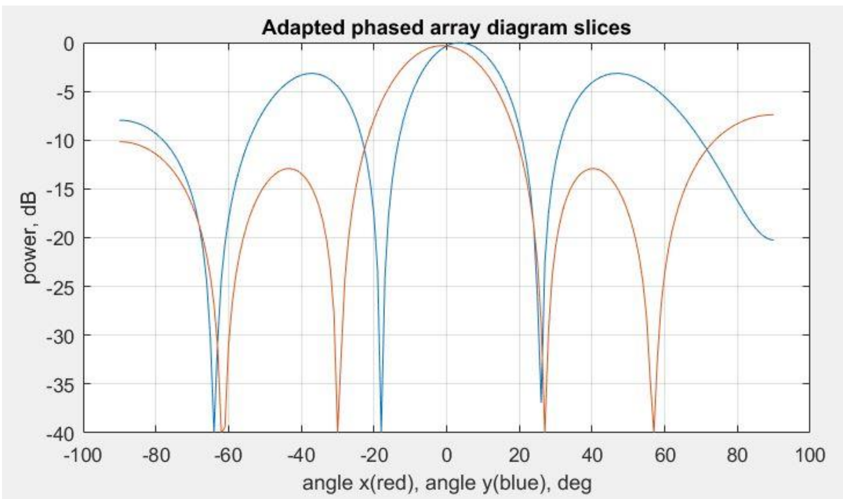

Figure 11. Suppression of interference from directions -30, 0 and 0, -50.

In the computer model, the navigation parameters (pseudorange and pseudo-speed) are measured by the received useful signal with a maximum pseudorange error of 4.8 m, pseudo-speed is 0.43 m / s.

When adapting the direction of the main lobe of the radiation pattern and the phase relationships between the signals received by the individual elements of the antenna array remain unchanged. The change in the set value of pseudo-range and pseudo-speed does not affect the results. The results of the experimental studies are shown in Figure 12.

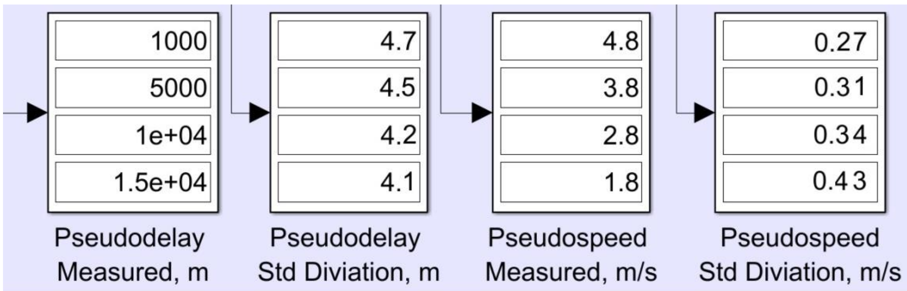

Figure 12. The measured values of pseudorange and pseudo-speed.

4. Conclusion

Thus, the developed computer model makes it possible to study the methods of beamforming in adaptive digital antenna arrays. In the course of the research it was obtained that the developed methods provide:

- the formation of a multi-beam radiation pattern providing simultaneous independent reception of signals from at least four sources spaced to a solid angle of up to 120 degrees, as well as automatic search, capture and tracking of sources moving at a speed of up to 1 degree / s for stable and guaranteed information reception;
- formation of dips in the radiation pattern with a depth of up to 40 dB relative to the main lobe in the direction of no less than two sources of interference;
- calibration of receiving channels, including linearization of the phase-frequency characteristic and alignment of the group delay time;
- measurement of current navigation parameters according to the received useful signal with pseudorange measurement error - no more than 5 m, pseudo-speed measurements - no more than 1 m/s.

Acknowledgements

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