Radar complex for unmanned aerial vehicles

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Abstract. The paper considers the problem of creating a radar complex designed to detect air, sea and ground objects as well as to determine their range, speed, geometric parameters, and promptly present the results of automated processing to the operator. The goal of the work is to create a side-scan airborne radar complex with a synthetic aperture installed on an unmanned aerial vehicle. The design of the airborne radar complex has been determined. The main characteristics of the developed complex are given. The main operating modes of the combined complex as part of an aircraft are considered and described: lateral sighting and sighting in the front hemisphere. The structural and functional diagram of the X-band side-view of airborne radar equipment, consisting of an antenna, a transceiver unit, a container with a digital core and a micronavigation system, is described. In high-resolution mode, the radio hologram generated on board is sent via a communication channel to the control and processing station. Radar image formation and secondary processing are performed at a ground station in automatic mode.

1 Introduction

This paper discusses the creation of an airborne side-scan radar complex (SAR) with a synthetic aperture installed on an unmanned aerial vehicle (UAV), as well as automated processing of the received information on a ground-based complex. The possibility of installing such a radar control system on a UAV makes it possible to realize the following characteristics of targets of interest to potential consumers when conducting radar surveillance:

- to provide the ability to detect and recognize around the clock, in any weather conditions, both moving and stationary ground and surface targets at a range of up to 100 km with high resolution (up to 0.3 m), while ensuring a wide acquisition band (up to 40 km);
- to generate radar images both on board the UAV (with a resolution of several meters) and at the ground processing station;
- to ensure the transfer of information about the parameters of detected targets to the associated systems of on-board radio electronic equipment (avionics) of the UAV or a ground information processing point.

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2 Design and main characteristics of the radar system

The radar system consists of the following elements:

1. On-board radar equipment, which includes the following elements:
   - antenna system;
   - transceiver device;
   - signal generation and processing equipment;
   - computing complex.
2. Ground-based automated information processing and analysis point, which can be integrated into a ground-based mobile control center consisting of:
   - hardware and general software;
   - software components for primary information processing;
   - software components for secondary information processing;
   - means of dispatching and controlling technological processes of information processing and analysis.
3. High-speed radio link (HSR) with an information transfer rate of 1.2 Gbit/s.

The main technical characteristics of the on-board equipment under consideration are given in Table 1.

Table 1. The main characteristics of the RLC as part of the UAV.

Parameter	**Value**
Pulse power	1440 W
Operating frequency	9600 MHz
Frequency band	600 MHz
Maximum operating range	up to 100 km
Capture strip	40 km
Maximum spatial resolution in azimuth	0.3 m
Maximum spatial resolution in range	0.3 m
The probability of detecting an object is no worse	0.96
Overall dimensions of AFAR	500x250x100 mm
Overall dimensions of transceiver and computing equipment	350x400x120 mm
Energy consumption	no more than 1500 W
Weight (depending on configuration)	35-80 kg

When the radar is operating, it is possible to generate radar radiation (RL) in real time on board the UAV and reset the radar via UAV communication channels to the information processing and analysis point, where it is subjected to various stages of automated processing and analysis in accordance with the established technological processes. During the processing process, objects of interest to the consumer are detected and recognized. Based on the obtained processing results, the operator decides on the generation and issuance of target designations or additional monitoring in high-resolution mode [1].

In high-resolution mode the radio hologram (information) generated on board is dropped via the UAV communication channel to the information processing and analysis point. The formation of radar images and automated processing and analysis are carried out using other technological processes for processing and analyzing information.

3 Operating modes of the SAR

The onboard equipment of the combined radar for UAVs provides two operating modes:

1. Lateral sighting;
2. Sighting in the front hemisphere.

Lateral sighting is shooting with a synthetic aperture radar (SAR), which provides a two-dimensional brightness radar image of the area to control the location of an object and correct its coordinates according to the radar map of the selected area.

With side-sighting, the radar photographs the surface with high spatial resolution, close to optical means. Some characteristics of the radar image depend significantly on the shooting altitude [2]. In particular, the equipment under consideration ensures obtaining an image frame measuring 0.8 km x 0.8 km - at a UAV altitude of 100 m, up to 7 km x 7 km - at a UAV altitude of 500 m [3,4], when using an antenna with a cosecant radiation pattern in a vertical plane.

The spatial expansion of SAR, set by software, ranges from 0.4 m to several meters with a possible additional increase (enlargement) of resolution elements.

The energy indicators of SAR in the operating range are quite high, so the radiometric sensitivity is about -17 dB with good resolution.

Sighting in the forward hemisphere is a pulse-Doppler mode (PDR) of a radar with scanning of the antenna beam, providing information about the surface and objects located on it.

In the pulse-Doppler mode of the radar, the surface is photographed along the UAV's course of movement, for which electronic scanning of the antenna beam is carried out in two planes [5]. A two-dimensional active phased array antenna (AFAR) is used as an antenna device. The antenna aperture diameter is 250 mm, the gain of the radiating system is 26 dB, and the radiation pattern width in each plane is about 5°.

The range acquisition band in the radar operating altitude range is 3-14 km. The magnitude of the azimuth trace of the radiation pattern at a distance of 5 km is about 600 m. The spatial resolution of the radar along the slant range is more than 0.25 m (set by software).

4 Technical appearance of the SAR side-view

It is proposed to use a mirror antenna with a sectoral horn as a feed [6,7], which has a cosecant radiation pattern in the vertical plane.

Characteristics of the mirror antenna:

- Bandwidth: 9.3 - 10.3 GHz;
- E-plane (vertical) beamwidth: 49° at 8 dB;
- Beam width in H-plane (horizontal): 7.0-8.4° dB;
- UBL in both planes: minus 22 dB.
- antenna weight: no more than 2.5 kg.

The transceiver unit combines the main analog components of radar equipment:

- amplifier;
- transceiver module.

Probing signal power amplifier at the output of which a powerful signal is generated at the carrier frequency, which is transmitted via a feeder path to a mirror antenna placed on the side of the UAV. The power amplifier also includes a circulator.

The transceiver module (low-power part of the transceiver), which functionally and structurally includes the following devices:

- pre-power amplifier (PPA);
- receiver together with a receiver gain control device. Receiver gain control allows you to match the dynamic range of the ADC to the input signal level;
- a multifunctional high-frequency generator designed to generate a grid of coherent signals necessary to transfer the probing signal to a high frequency and back.

The main characteristics of the X-band transceiver unit are presented in Table 2.

Table 2. Main characteristics of the X-band receiving and transmitting unit.

Parameter	Value
Central part of the signal	9800 MHz
The gain of the mirror antenna at the maximum of the radiation pattern	20 dB
Maximum spectral width of the probing chirp signal	600 MHz
Transmitter pulse power	not less than 320 W
Type of signal modulation	Chirp
Duty factor	at least 16
Pulse duration	5 - 60 µs
Receiving channel noise factor	no more than 4.5 dB
Network consumption 27 V	no more than 70 W
Weight	10 - 14 kg

The container with the digital core combines all the digital components of the PDR:

- special computer - a control computer that implements an algorithm for automatically controlling the shooting of specified objects. The software of this computer allows you to control the radar in all operating modes;
- digital signal generation module, multifunctional probe signal shaper, which implements the formation of a probe signal packet in accordance with the task received from the control computer;
- analog-to-digital signal processor with mezzanine DAC and ADC modules, which digitizes the analog signal coming from the radar transceiver, buffers and initially processes the signal. The carrier module contains a processor that processes radar information [8] in real time.

5 Description of automated processing and analysis of information

At the ground point, to automate the process of processing and analyzing information from the SAR, it is proposed to use various software components for processing radar images in conjunction with special customizable (adaptable) software for automating technological processes of processing and analyzing information. For each information processing mode, a separate technological process must be built [9]. Depending on the received initial data and the required presentation of the results of information processing, special software automatically applies the built-in information processing scenario. The use of special software for automating technological processes of information processing and analysis at the SAR ground station will allow solving the following tasks:

- increasing the automation of technological processes for processing and analyzing SAR information at a ground point and reducing the likelihood of operator error;
- reducing the processing time of SAR information at the ground point;
- automation of emergency processes for processing SAR information at a ground point;
- reduction in the number of personnel involved in processing information at the SAR ground station.

6 Conclusion

Based on the research results, proposals have been developed for the composition and design of the radar control system for UAVs, including those that provide the ability to obtain radar images in real time on board the carrier.

The possibility of installing the considered SAR on a UAV together with an automated information processing and analysis point makes it possible to realize the following characteristics of targets of interest to potential consumers when conducting radar surveillance:

- to provide the ability to detect and recognize around the clock, in any weather conditions, both moving and stationary ground and surface targets at a range of up to 100 km with high resolution (up to 0.3 m), while providing a capture swath of up to 40 km;
- to generate radar images both on board the UAV (with a resolution of several meters) and at a ground-based automated information processing and analysis station;
- to ensure the transfer of information about the parameters of detected targets to the associated systems of on-board electronic equipment of the UAV or a ground-based automated information processing and analysis point.

References

1. S.A. Vorontsova, Radio engineering and telecommunication systems **1(25),** 24-30 (2017)
2. Y. Wang, W. Yang, J. Chen, H. Kuang, W. Liu, C. Li, Sensors **19(12),** 2764 (2019)
3. J.V. Fayne, L.C. Smith, MDPI Remote Sensing **15,** 3361 (2023).
4. V.A. Dobrikov, V.A. Avdeev, D.A. Gavrilov, Instrumentation **1(52),** 10-14 (2009)
5. K.K. Venkata, V. Kumar, International Journal of RF and Microwave Computer-Aided Engineering **31(6),** e22625 (2021)
6. V.A. Kuznetsov, S.A. Goncharov, Control, communication and security systems **3,** 28-72 (2017)
7. V.P. Berdyshev, A.M. Mironov, O.N. Pomazuev, A.N. Savelyev, V.A. Kopylov, V.V. Loy, Journal of the Siberian Federal University. Technics and techology **7(11),** 764-774 (2018)
8. X. Wang, W. Hong, Y. Liu, D. Hu, P. Xin, Applied Sciences **13(18),** 10023 (2023)
9. N.A. Correa-Muñoz, C.A. Murillo-Feo, Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS **42,** 177-184 (2018)