Features of Through-Wall Radars Development for Detecting of Moving Objects behind Optically Opaque Barriers

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Abstract. Detecting people behind optically opaque barriers is an urgent task of the modern world. It allows to solve problems in the following areas: conducting anti-terrorist operations, searching people under rubble and avalanches, security measures. This article describes the device features developed on the basis of the radio wave methods usage, which makes it possible to detect moving objects behind optically opaque obstacles. The performance of the instrument is improved over the prototype broadband radar for detecting people behind optically opaque obstacles "Dannik-5", developed at the Federal State Unitary Enterprise SDB IRE RAS. Unique ultra-wideband small-sized printed antennas have been developed for the device. Thanks to them, its directional diagram has been improved, a clearer restructuring in the field of view and a more accurate determination of the location of a moving object are provided. The use of small-sized printed antennas and an optimized internal layout of the device made it possible to improve the shielding of the device, which eliminated its susceptibility to objects moving on the side and behind the radar, and also made it possible to significantly improve its mass-dimensional characteristics. Comparative characteristics in relation to domestic devices and foreign analogs are given. The device is competitive with world analogues.

1. Introduction
Currently, non-destructive testing technologies are becoming more and more common, allowing the study of the internal state of objects and materials without violating their internal integrity. They bring huge benefits and can be used in many areas of human activity. These properties are possessed by devices using radio-wave methods [1-3]. The use of broadband and ultra-wideband signals, the development of microprocessor technology and new methods and algorithms for signal processing have made it possible to create a special type of radar that can detect moving people behind optically opaque barriers [4-7].

Such devices can be used in many areas of activity designed to save human lives: during counter-terrorism operations, security measures, when searching for people buried under rubble and snow avalanches, etc.

2. Comparison of the through-wall radar with its prototype
The radar proposed for consideration can be used to detect live objects behind optically opaque barriers. Its prototype is a wide-band radar for detecting people behind optically opaque barriers. "Dannik-5", developed by SDB IRE RAS [8]. The prototype used horn-type antennas, its
disadvantages are its large mass and dimensions, as well as its susceptibility to objects moving behind the radar, including the radar operator and third-party observers.

Taking into account the identified shortcomings, a radar with a new type of antenna system was developed. The block diagram of the radar is shown in figure 1. The radar includes a phased array reception antenna lattice, consisting of eight antennas 1, each of which is connected to the module adjusting the amplitude and phase of the signal (2), the block of adder (3), the inputs of which are connected to the outputs of blocks adjusting the amplitude and phase of the signal (2), the signal processing unit (4), the input of which is connected to the output of the adder (3), and the output connected to the input of the transmitting unit containing the modulator (5) and the antenna (6).

**Figure 1.** The block diagram of the radar

The proposed device works as follows. The transmitting unit emits a short radio pulse formed in the signal processing unit, which is reflected from objects encountered in the signal path and received by a phased receiving antenna array. After passing through the adder, the signal enters the input of the signal processing unit, where it is processed and the signal from the mobile object is displayed as a label on the computer screen, where the range and direction are determined, corresponding to the position of the mobile object and the time lag of the pulse reflected from it.

Due to the fact that the radar uses a compact printed antenna has been improved its radiation pattern provided a more precise adjustment of the area and a more accurate positioning of the movable object and, in addition, was improved shielding radar that eliminated his sensitivity to the moving side and rear of the radar objects. And the weight and size characteristics of the steel are 3.5 kg and 0.35x0.18m3, instead of 5kg and 0.5x0.37x0.13 for the prototype.

A comparative characteristic of the calculated antenna patterns is shown in figure 2. The circles show the signal attenuation levels in decibels, the numbers on the outer circle - the direction of the signal emission in degrees. Obviously, the new antenna system has a significantly greater directivity compared to the prototype, therefore, it is possible to more accurately determine the angular coordinate. In addition, the new antenna system has a rear lobe 25 dB less than the main one, while the prototype has only 12 dB.
Figure 2. The calculated antenna directivity diagrams of radars "Dannik-5" and “StenoV”.

3. Brief description of the radar “StenoV”.
The radar is designed to detect live objects and their location behind optically opaque environments (determining the direction and distance to them):

- when conducting operational activities by the Ministry of internal Affairs structures to detect live people outside the walls and monitor their movement, to detect the hidden transportation of people and animals in containers, wagons, and vans;
- when carrying out rescue operations by the Ministry of emergency situations in natural disasters, natural and man-made disasters to detect live people under rubble and avalanches, in burning and smoke-filled buildings;
- when conducting security measures of premises and territories to detect unauthorized entry of people and equipment, access control, monitoring internal movement of people (adults or children).

The appearance of the radar is shown in figure 3. It consists of a casing with two handles and an integrated touch screen. The screen is divided into 6 sectors, corresponding to 6 main directions of scanning the antenna system radiation pattern. Detected moving targets are displayed on the screen as red marks, stationary objects detected by breathing - as blue marks. In the lower left corner, the history of object movements for the last 30 seconds is displayed. In addition, it is possible to view the history of signal changes in a given sector at a selected distance, which allows you to analyze the breathing parameters of a detected stationary object.
Figure 3. Appearance of the radar “StenoV”.

4. Comparison of through-wall radar characteristics with its international counterparts
The main technical parameters of the radar are presented in table 1, and table 2 shows the comparative characteristics of the most common Russian and imported analogues: “Xaver 400” [9], “RO-400”, “RO-400 2D” [10].

Table 1. Technical characteristics of the radar “StenoV”

| Parameter                                           | Value                      |
|-----------------------------------------------------|----------------------------|
| Operating frequency, GHz                            | 3.5                        |
| Detection of people behind the wall at a distance of up to, m | ≤10                        |
| Radar detects people at angles in the horizontal plane up to, deg | 120°                       |
| in the vertical plane, deg                          | 90°                        |
| Resolution:                                         |                            |
| in range, m                                         | ≤ 0.3                      |
| in the horizontal field of view, deg                | 15°                        |
| Radar detects people behind a wall made of:         |                            |
| brick wall with thickness, m                        | 0.4                        |
| concrete wall, m                                    | 0.2                        |
| masonry thickness, m                                | 0.4                        |
| wood with thickness, m                              | 0.4                        |
| Independent power supply (from the battery), V      | 7.4                        |
| Average signal power, mW                            | 4                          |
| Continuous operation time:                          |                            |
| at ambient temperature from 0 to plus 40°C, h        | ≥4                         |
| at ambient temperature from 0 to minus 20°C, h       | ≥2                         |
| Overall dimensions, mm                              | 350x200x180                |
| Weight not more than, kg                            | 3.5                        |
Table 2. Comparative characteristics of wallvisors

| Name         | Xaver 400 | PO-400 | PO-400 2D | StenoV |
|--------------|-----------|--------|-----------|--------|
| Range, m     | 4, 8, 20  | 21     | 21        | 10     |
| Frequency, GHz | 3-10     | 0,4    | 0,4       | 3-4    |
| Viewing angles, deg | 120      | 120    | 120       | 90-120 |
| Weight, kg   | 3,2       | 4,4    | 5,8       | 3,5    |
| Dimensions, mm | 370 x 225 x 120 | 395 x 290 x 155 | 960 x 290 x 155 | 350 x 200 x 180 |

As can be seen from table 2, the radar “StenoV” is not inferior to foreign and domestic analogues in terms of both mass-dimensional and radiophysical parameters.

The radar tests performed showed satisfactory results. In empty rooms behind thin brick walls, the probability of detecting moving objects is close to one, and the probability of false alarms is minimal. If there is a large amount of furniture in the room, the device screen may sometimes show false targets caused by multiple re-reflections of the signal.

5. CONCLUSIONS

Studies have shown that the developed radar has some competitive advantages over not only the prototype, but also with some other similar devices. Currently, work is underway to improve the radar design, refine and verify algorithms for detecting mobile objects.

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