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A three-millimeter-wave array radar with a mirror objective

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The possibility of applying a mirror objective in a radar system based on a direct-conversion array receiver has been studied. A prototype has been developed for a 94 GHz array radar with a mirror objective formed as a parabolic reflector antenna which is widely used in satellite radio communications. The objective used has been shown to provide high-quality focusing of millimeter waves: radiation from a point reflector is focused into a spot with a size of about one pixel of the array receiver. The study has demonstrated that, in the case of the transmitted signal power of 4 mW, radiation beamwidth of 10°, and objective diameter of 60 cm, the system is able to detect an object with the effective scattering area of 1 m^2 at a distance of up to 50 m.

Keywords: millimeter waves, frequency-modulated continuous-wave radar, array receiver, quasioptical objective.

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At present, creation of a millimeter-wave array radar with satisfactory characteristics faces a number of problems [1]. To realize the classical array-radar method based on using a phased array antenna, it is necessary to apply highly integrable semiconductor technologies (SiGe technologies). Known problems of ultra-high-frequency SiGe microelectronics, namely the low output power of transmitters amplifiers and high noise level of receivers, prevent achieving acceptable sensitivity of radars; the range of devices developed by this date does not exceed 1 m [2,3].

The requirement of the microchip integrability may be made less strong via applying sparse arrays which are used in, e. g. MIMO (multiple input multiple output) radar systems [4]. At present, a range of about 10 m has been obtained in the systems of this type [5].

Another approach to creating millimeter-wave array radars is to simplify the design of the arrayś transceiver elements. In works [6,7], a new approach to creating array-type radar systems was proposed and investigated; the approach was based on using as elements of the receiving array simple-design direct-conversion receivers: the receiving element consists of a modified slot antenna, Schottky diode with a reduced barrier height, and low-noise amplifier of a low (below 100 kHz) frequency. The angular-coordinate resolution of objects is provided in this system by forming an image with a quasi-optical objective [8]; distances to the objects are determined by the frequency-modulated continuous-wave radar technique [9].

In the developed prototype of the radar system, a dielectric lens was used as a quasi-optical objective [10]. The use of dielectric lenses allows transferring to the millimeter-wavelength range the principle of constructing lenses for optical video cameras. Another possible type of the quasi-optical objective is a mirror antenna widely used in modern radio communication and radar systems. In this paper there is demonstrated the possibility of using a mirror antenna as an objective for an array radar system of the three-millimeter wavelength range.

Fig. 1, *a* presents a schematic diagram of the developed system. As a source of millimeter-wave radiation, a W-

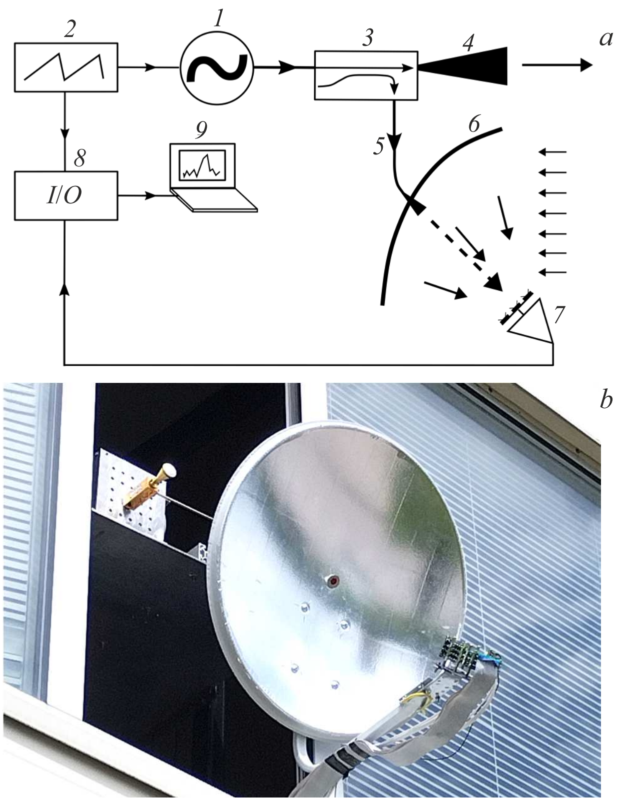

Figure 1. *a* — schematic diagram of the mirror-objective-based radar system. *1* — millimeter-wave oscillator, *2* — modulating signal generator, *3* — directional coupler, *4* — horn antenna for scene illumination, *5* — antenna-feeder path based on a metal waveguide and horn antenna for supplying the receiver with a reference signal, *6* — parabolic antenna, *7* — array receiver, *8* — data acquisition system, *9* — laptop. Solid arrows indicate the probing radiation; dashed arrows indicate the reference radiation.

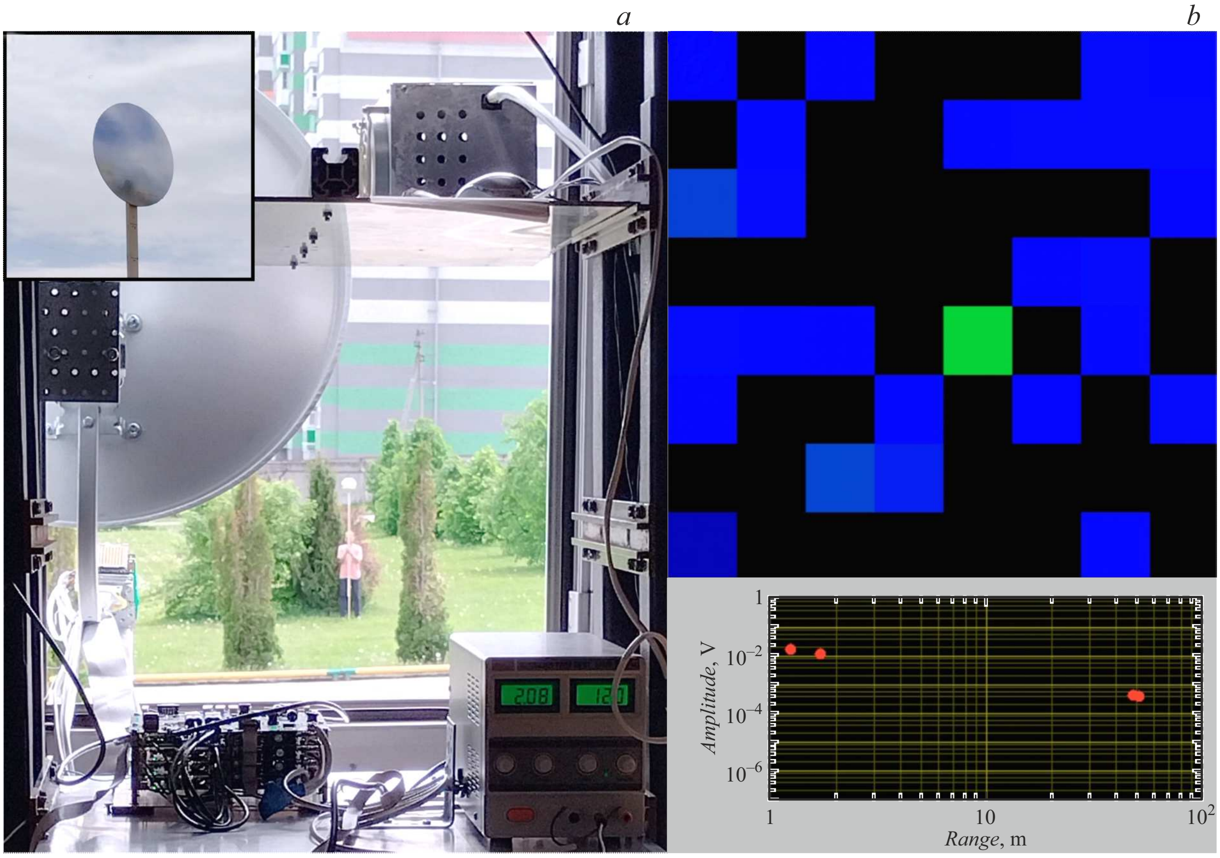

Figure 2. *a* — a photograph of the probed space region in determining the radar system range. The inset presents the test reflector. *b* — image (illuminated pixel) of the test reflector located at the distance of 50 m from the radar system (top panel), and the level of signal received by the illuminated pixel versus the distance to the object (visible is the useful signal at the distance of 50 m) (bottom panel).

band generator based on a backward-wave oscillator is used. The generator power in the vicinity of operating frequency 94 GHz is 10 mW. The modulation shape is triangular with the amplitude of 672 MHz. The generator power is divided with a directional coupler into two almost equal parts. Taking into account losses in the coupler, output power of the primary and secondary waveguides was estimated as 4 mW. Power from the primary waveguide output is supplied to a conical horn antenna with the gain of 25 dB (which corresponds to the beam width of about 10°) to illuminate the scene, while output power of the secondary waveguide is fed into the antenna-feeder path through which the reference radiation is supplied to the array receiver. The image is formed in the array plane with a mirror objective based on a parabolic reflector antenna commonly used in satellite radio communications. The objective aperture diameter is 60 cm. To smooth out the relief of the antenna having roughness with the characteristic lateral size of ~ 1 mm, and also to reduce power loss for reflection, the reflector antenna surface was covered with adhesive aluminum tape. Supplying the array with a reference signal is performed using a horn antenna placed in an orifice in the center of the mirror objective. An array receiver 8×8 pixels in resolution was used; detailed description of its design, as well as its basic characteristics, can be found in [7].

Adjustment of the array receiver arrangement with respect to the object was performed in two stages. At the first stage, there was used a laser beam incident on the reflector antenna from the scene central direction. The laser beam was directed to different antenna surface points, and the point (the focus of the quasi-optical objective) where the rays reflected from the reflector surface converged was found. After that, the array receiver was arranged so that the array center coincided with the focus. At the second stage, a point millimeter-wave reflector was used. In the radar system operating mode, the image of point reflector was captured, and position of the array receiver was adjusted so as to minimize the size of the resulting image (spot). Finally, the array receiver position was adjusted in such a way that signal reflected from the point source got focused into a single pixel of the array (the pixel size was 3.8×3.8 mm). As a result, the distance between the center of the reflector antenna surface and focus was 44 cm. The array shift either towards or away from the antenna by $\gtrsim 5$ mm made the image blurred.

To determine the systemś range, an experiment was performed in recording the image of the test reflector with effective scattering area of 1 m^2. The test reflector shown in the inset to Fig. 2, *a* is designed as a metallized spherical segment; the sphere radius is 60 cm, and the

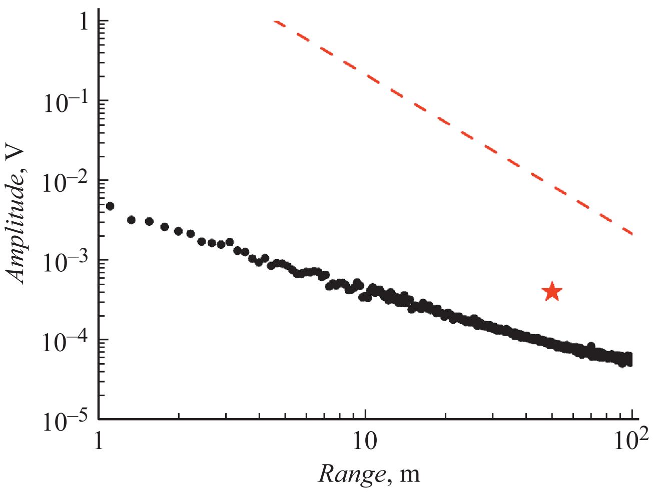

Figure 3. Calculated (dashed line) and measured (asterisk) amplitudes of the useful signal and measured noise amplitude (circles) versus the distance to the object.

segment base diameter is 30 cm. The radar system was installed near the open window on the building first floor (Fig. 1, *b*); the reflector moved on the street away from the system. The photograph of the probed space region is presented in Fig. 2, *a*. When the distance between the system and reflector exceeded 50 m, the useful signal at the receiver output became indistinguishable from noise. Fig. 2, *b* demonstrates the state of indicators of the control and data-representation program in case the reflector is located at the distance of 50 m. The Fig. 2, *b* top panel presents the image of the probed scene section; here the test reflector is represented as an illuminated pixel. The Fig. 2, *b* bottom panel presents the level of the signal received by the illuminated pixel versus the distance to the object; the useful signal at the distance of 50 m is visible.

Fig. 3 presents the dependences of the useful signal spectral amplitude (measured and calculated) and noise at the receiver output on the distance to the object. The noise amplitude depends on the distance to the object because it depends on the output signal frequency which is proportional to the distance to the object. The useful signal amplitude was calculated via the basic radar equation [1] and formula of the signal conversion in the receiver [7]. In calculations we used the radar parameters mentioned above and in [7]; in addition, there was used the measured power of the reference signal incident on the receiver (4.2 μW). The obtained discrepancy between the calculated and measured useful signal amplitudes is apparently caused by non-ideality of the mirror antenna shape, due to which only a small part of the antenna area efficiently focuses the received radiation onto the receiver. Based on this, we can conclude that using the mirror objective with optimized parameters enables increasing the signal-to-noise ratio by more than an order of magnitude and achieving the system range of more than 100 m.

Thus, the paper demonstrates the possibility of using the mirror objective in a millimeter-wave radar system with a direct-conversion array receiver. As an advantage of the mirror objective over a lens-type one, there may be mentioned availability of commercial technologies for creating centimeter-wave mirror antennas, which seem to be relatively easily adaptable to the millimeter-wave tasks. However, lens-type objectives can provide a more compact radar system configuration; therefore, a specific type of objectives should be selected based on specific operating conditions of the radar.

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Conflict of interests

The authors declare that they have no conflict of interests.

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