

# Study of high-frequency acoustic reflector-type parabolic antennas

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An antenna system providing for transmission and reception of a sonic signal is one of the most important parts of a sodar (sonic radar). Reflector-type parabolic antennas are now widely used in Russia because of their relatively simple design. In this paper, we present the results of theoretical and experimental studies of a high-frequency acoustic antenna designed for sensing of the lower atmosphere up to about 200 m altitudes.

## Introduction

The use of sound in remote sensing of the atmosphere has a long history.<sup>1</sup> It is based on the effect of strong interaction of acoustic waves with the atmosphere, in particular, on the capability of acoustic waves to scatter on the inhomogeneities of the refractive index due to atmospheric turbulence. This interaction proves to be much stronger than that for electromagnetic waves of the majority of spectral ranges. Therefore, relatively simple equipment can be used for sensing the atmosphere with acoustic waves.

An antenna is one of the most important parts of a sodar (sonic radar); it primarily determines the efficiency of sodar operation (sensing range, noise protection, and safety of the environment, people, and animals). The antenna design, size, and material completely determine its efficiency and, finally, the power potential of the sodar as a whole. The main requirement to any radar system is that it has as low as possible level of side lobes of the antenna directional pattern. This is especially urgent for systems of acoustic sensing of the atmosphere, because a sonic signal scattered by the atmosphere is rather weak due to strong attenuation by the atmosphere interaction.

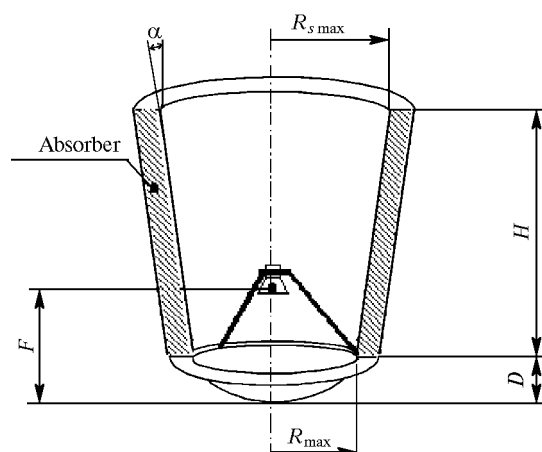
The problem formulated can be solved in three ways. First, we can use antennas with large effective aperture areas providing the level of the side lobes from  $-50$  to  $-60$  dB at small elevation angles. This requires large-size antennas that are not always convenient. Second, the level of side lobes can be decreased using specialized amplitude-phase distributions over the antenna aperture, however their implementation faces significant technical difficulties. Third, a soundproof blind can be applied to decrease the side lobes (Fig. 1).

The aim of this work was to study a high-frequency (frequency higher than 4 kHz) reflector-type parabolic acoustic antenna and to develop, based on

this study, a small-size antenna for application to sensing the lower atmosphere.

## 1. Theoretical studies

The antenna to be developed should meet the following requirements: the directional pattern at the half-power level from  $7$  to  $15^\circ$  wide, the level of side lobes no higher than  $-40$  dB in the direction normal to the acoustic axis and no higher than  $-35$  dB at an angle of  $70^\circ$  to the acoustic axis. The simplest design was chosen, namely, reflector-type antenna with a parabolic reflector and a protection blind having the shape of a truncated cone. It is shown in Fig. 1. A high-frequency acoustic head with an exponential horn having the mouth diameter of 76.5 mm was used as an antenna feed.



**Fig. 1.** Acoustic parabolic antenna with horn feed:  $\alpha$  is the aperture angle of the protection blind;  $F$  is the paraboloid focus;  $D$  is the paraboloid depth;  $H$  is the blind height;  $R_{\max}$  is the maximum radius of the paraboloid aperture;  $R_{s \max}$  is the maximum radius of the blind aperture.

The directional pattern of this antenna (in the far zone) is determined by the modified Kirchhoff diffraction integral<sup>2,3</sup>:

$$P(\theta) = \pi(1 + \cos\theta) \int_0^{R_{s,\max}} A(R_s) e^{j\varphi(R_s)} J_0(kR_s \sin\theta) R_s dR_s,$$

where  $\theta$  is the angle from the optical axis;  $A(R_s) e^{j\varphi(R_s)}$  is the amplitude-phase distribution of the acoustic pressure over the upper aperture of the blind;  $R_s$  is the current radius of the upper aperture;  $k$  is the wave number;  $J_0(\dots)$  is the zero-order Bessel function.

The distribution of the sonic pressure over the upper (emitting) aperture of the antenna is determined by the equation

$$A(R_s) e^{j\varphi(R_s)} = \int_0^{2\pi R_{\max}} \int_0 A(R) e^{j\varphi(R)} e^{jk(D-H)} \gamma(D) R dR d\Phi,$$

where  $R$  is the current radius of the parabolic aperture;  $H$  is the height of the protection blind;  $\Phi$  is the angle in the plane of the aperture of the parabolic reflector;  $A(R) e^{j\varphi(R)}$  is the field distribution over the aperture ( $H = 0$ ) of the unprotected antenna;

$$D = \sqrt{R^2 \sin^2(\Phi) + [R_s - R \cos(\Phi)]^2} + H^2;$$

$$\gamma(D) = (1 - H/D) / (2D)$$

is the coefficient accounting for the decrease of the amplitude with distance  $D$ ;  $RdRd\Phi$  is an elementary area at the antenna aperture.

The factor  $e^{jk(D-H)}$  describes the change of the phase of an acoustic signal with the distance  $D$ ;  $A(R) e^{j\varphi(R)}$  describes the amplitude-phase distribution of sonic pressure over the paraboloid aperture. It can be shown that if an exponential horn with the mouth diameter exceeding the critical one for a given wavelength (the reactive component of the emitted wave can be neglected) is used as a feed, then the distribution of the acoustic pressure over the paraboloid aperture can be presented as<sup>4</sup>:

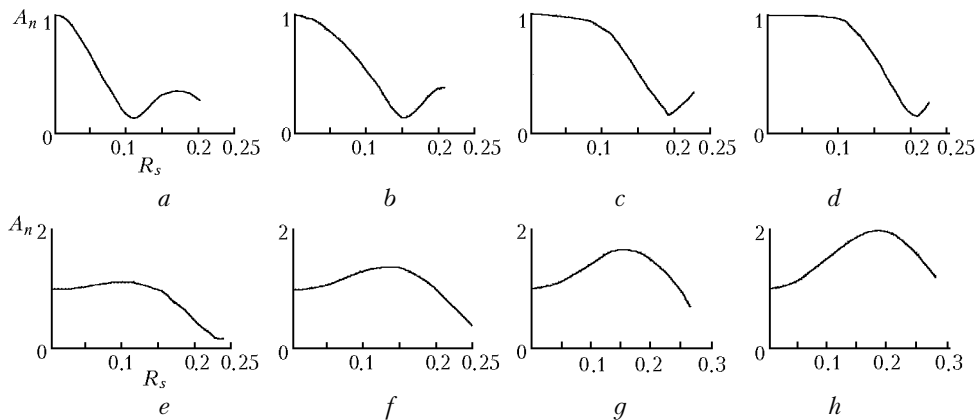
$$A(R) e^{j\varphi(R)} = \frac{(1 - e^2) \cos[\psi(R)]}{1 - e^2 \cos^2[\psi(R)]},$$

where  $\psi(R) = \arctan[R/(F - D)]$ ;  $e$  is the horn eccentricity;  $F$  is paraboloid focus;  $D$  is the paraboloid depth.

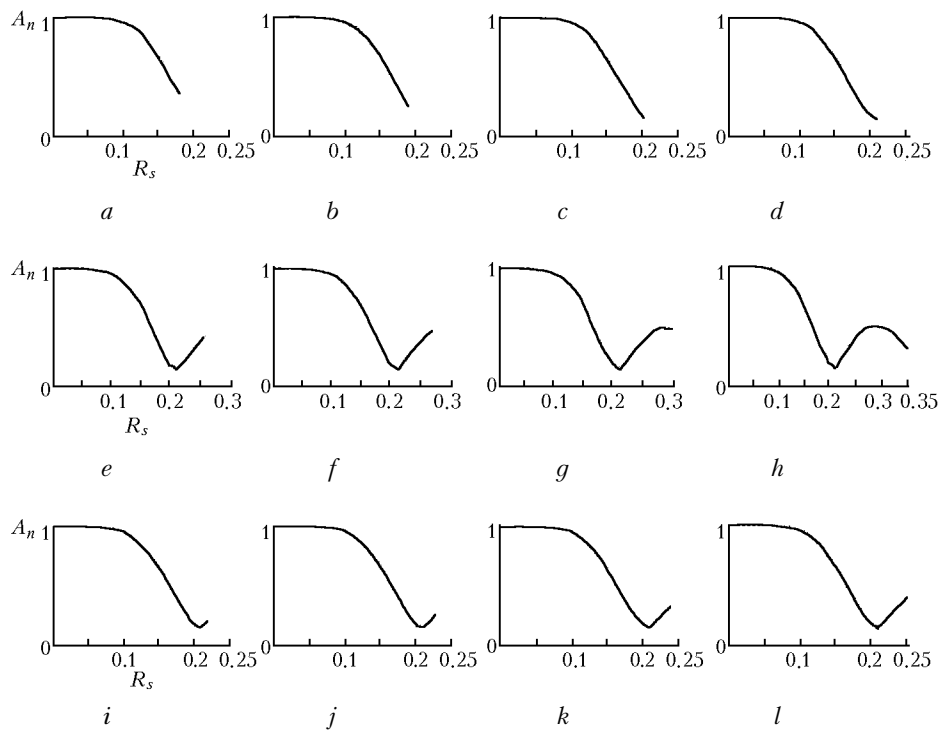
The exponential horn used has the eccentricity  $e = 0.6$ . For calculation of the geometric dimensions of the parabolic reflector, the equations relating the paraboloid gain with its dimensions were used.<sup>5</sup>

The antenna parameters were studied for the frequency of 4.273 kHz, which determines the first resonance frequency of the used head having the frequency range from 3 to 40 kHz. The second resonance frequency of the horn is 5.25 kHz. We have studied the influence of the dimensions of the protected antenna on the amplitude-phase distribution (APD) over the upper antenna aperture. The antenna dimensions were varied with a small step in the area that is optimal from the viewpoint of the maximum concentration factor, the required level of the side lobes, and the width of the antenna directional pattern.

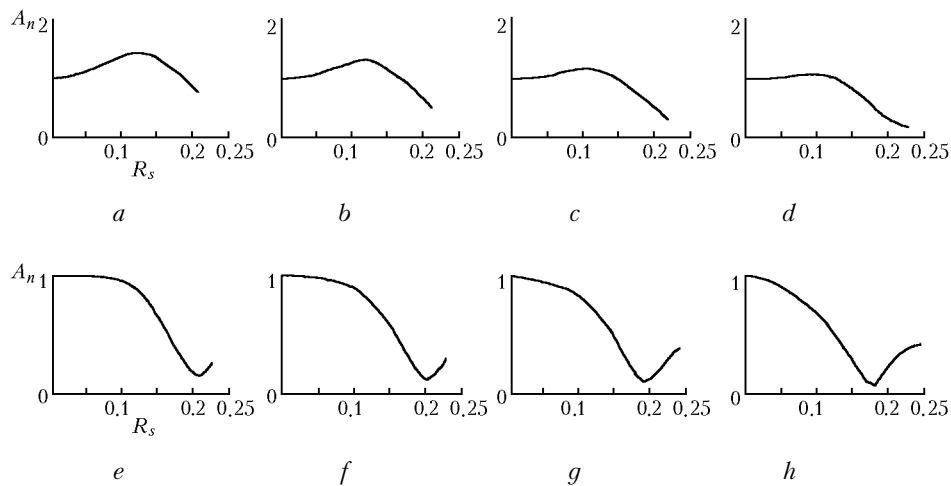
The plots of the APD variations in response to the height of the soundproof blind, the blind aperture angle, and the radius of the parabolic reflector are shown below. As the height of the soundproof blind decreases (Fig. 2), the major lobe of the APD becomes narrower, and the level of the field at the aperture edges increases. This leads to the growth of the level of side lobes and narrowing of the major lobe of the antenna directional pattern. As the height of the soundproof blind increases, the level of the field at the edges of the emitting aperture decreases and reaches its minimum at the height  $H = 60$  cm, but an inhomogeneity (outlier) arises in the distribution near the major lobe of the APD. With the increasing blind size, the value of this outlier increases. This leads to the increase of the level of side lobes of the antenna directional pattern. Thus, the optimal height of the blind should range from 0.532 to 0.545 m.



**Fig. 2.** Amplitude distribution [normalized to  $A(0)$ ] of the sonic pressure over the upper antenna aperture vs. blind height  $H$  at the reflector depth  $D = 0.047$  m, reflector radius  $R_{\max} = 0.161$  m, focal length 0.13 m, and blind aperture angle  $\alpha = 8^\circ$  for  $H = 0.3$  (a), 0.4 (b), 0.5 (c), 0.532 (d), 0.6 (e), 0.7 (f), 0.8 (g), and 0.9 m (h).



**Fig. 3.** Amplitude distribution [normalized to  $A(0)$ ] of the sonic pressure over the upper antenna aperture vs. blind aperture angle  $\alpha$  at reflector radius  $R_{\max} = 0.161$  m, reflector depth  $D = 0.047$  m, focal length 0.13 m, and blind height  $H = 0.532$  m: for  $\alpha = 3$  (a), 4 (b), 5 (c), 6 (d), 7 (e), 8 (f), 9 (g), 10 (h), 11 (i), 12 (j), 15 (k), and  $20^\circ$  (l).



**Fig. 4.** Amplitude distribution [normalized to  $A(0)$ ] of the sonic pressure over the upper antenna aperture vs. reflector radius  $R_{\max}$  at the blind aperture angle  $\alpha = 8^\circ$ , reflector depth  $D = 0.047$  m, focal length 0.13 m, and blind height  $H = 0.532$  m: for  $R_{\max} = 0.14$  (a), 0.145 (b), 0.15 (c), 0.155 (d), 0.161 (e), 0.165 (f), 0.17 (g), and 0.18 m (h).

As the aperture angle of the soundproof blind decreases (Fig. 3), the level of the field at the edges of the emitting aperture decreases, but the directional pattern of the antenna takes a needle shape. With the increasing aperture angle, the field level at the edges of the emitting aperture increases, and the level of the side lobes of the directional pattern increases correspondingly. From the viewpoint of the width of

the directional pattern, the optimal aperture angles of the soundproof blind are from 6 to  $8^\circ$ .

The study of the APD dependence (Fig. 4) on the reflector dimensions has shown that the decrease of the reflector dimensions leads to a sharp increase in the level of the field at the edges of the emitting aperture and to the occurrence of the outlier. With the increasing reflector dimensions, the value of the outlier

decreases, as well as the level of the field at the edges of the emitting aperture. With further increase in the reflector dimensions, the outlier vanishes, but the level of the field at the edges of the emitting aperture increases. The reflector dimensions from 155 to 165 mm are optimal from the viewpoint of the homogeneity of the characteristic and the level of the field at the edges of the emitting aperture.

In accordance with the results presented above, we took the following parameters when designing the antenna:

- Radius of parabolic reflector  $R_{max}$ , in m . . . . . 0.161
- Reflector depth, in m . . . . . 0.047
- Focal length of reflector, in m . . . . . 0.13
- Height of soundproof blind  $H$ , in m . . . . . 0.532
- Aperture angle of soundproof blind  $\alpha$ , in deg. . . 8

## 2. Experimental studies

At different stages of antenna design, we have recorded its directional patterns at the frequency of 4.273 kHz. Measurements were conducted in the far zone (at the distance of 5 m from the antenna) under calm weather conditions. The averaged measurement results are presented below.

Figure 5 shows the experimental directional patterns recorded with two types of head holders having different size. Thus, we succeeded to estimate the effect of the shaded area of the reflector on the directional pattern. It is seen from Fig. 5 that as the emitter size decreases, the level of side lobes decreases too, and the major lobe of the directional pattern widens a little bit.

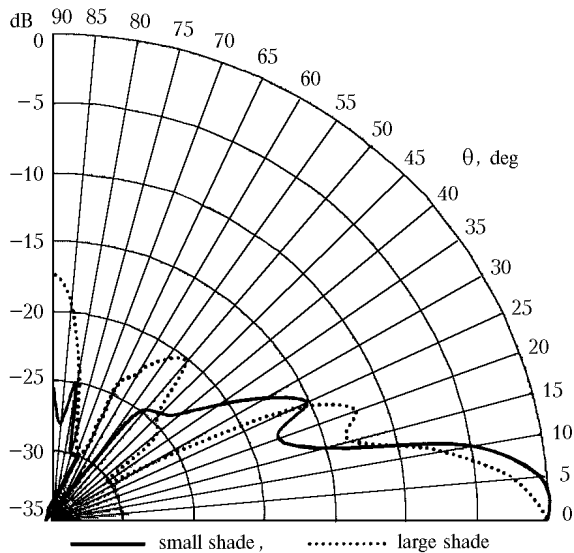


Fig. 5. Directional pattern of the antenna at different size of the shaded area.

For a convenience in comparing directional patterns at different stages of the antenna design, Fig. 6 shows the theoretical directional pattern of the protected antenna and the experimental directional patterns of

the parabolic reflector and protected antenna with the use of an absorber and without it. One experimental pattern corresponds to the soundproof blind without an absorber. The second experimental directional pattern was recorded with foamed polyethylene and foamed rubber used as an absorber. For a comparison, the third pattern corresponds to the directional pattern of the parabolic reflector with a small shaded area. The blind was coated with the plastic of glass fiber.

As is seen from Fig. 6, application of the absorber allows the side lobes to be decreased, on the average, by 15–20 dB.

It should be noted that in the absence of the absorber, the major lobe widens (the width of the directional pattern is 25°), and the level of the first side lobe is -11.5 dB as high. With the absorber the suppression of the first side lobe is 34.8 dB, and the width of the directional pattern of the protected antenna with the absorber at the half-power level coincides with the theoretical value. On the whole, the directional pattern of the protected antenna with an absorber closely copies the shape of the theoretical pattern. In this case, the level of suppression of the first side lobe proved to be much higher than in the theoretical pattern, namely, about 25 dB. The level of suppression of side lobes of the actual antenna at an angle of 70–75° also proved to be a little bit higher than the theoretically calculated value (on the average, by 5–6 dB). In the direction of the acoustic axis at the distance of 1 m from the antenna, the level of sonic pressure was 118.3 dB, the theoretical antenna gain was  $K_g = 10.07$ , and the concentration factor was  $K_c = 101.404$ .

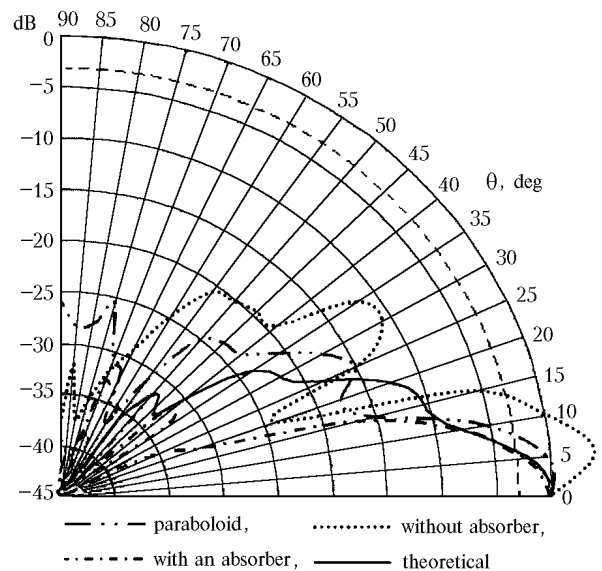


Fig. 6. Directional patterns of acoustic antenna: parabolic reflector, protected antenna without an absorber, protected antenna with the absorber, and theoretical protected antenna.

Taking into account that the power about 1 W was applied to the emitter and the maximum safe power

in the cw mode is 150 W (200 W in the pulsed mode), we can assume that the maximum sonic pressure in the direction of the acoustic axis for this antenna is from 140 to 150 dB at continuous emission. This allows the antenna to be used in the atmospheric research.

### Conclusion

The high-frequency protected parabolic antenna has passed the tests, and at the frequency of 4.273 kHz it has demonstrated high performance characteristics that meet the initial requirements needed for its operation as a part of a sodar for sensing of the atmosphere.

### References

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