THE EFFECT OF CONTINUOUSLY SCANNING ANTENNA DIRECTIONAL PATTERNS IN BISTATIC SOUNDING OF THE ATMOSPHERE AND OCEAN

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Fast scanning antenna directional patterns of a bistatic sodar are shown to cause a noticeable variation in the shape and peak power of pulsed scattered signals. This is confirmed by the results of numerical modeling in the case of bistatic acoustic sounding of the atmosphere. This effect is proposed to be used for purposeful control of duration and amplitude of a scattered signal for the invariable parameters of the emitted pulse.

The application of methods, which are known in radar and underwater sounding for the inertialess electronic scanning antenna directional patterns (DP's) of bistatic sounding systems, has opened up fresh opportunities for studies of the atmosphere. The above–indicated scanning can be performed when antenna operates in the mode of transmission or reception. This makes it possible to obtain much higher angular scanning rate of the DP axis vs time than that of the power–driven antennas.

The purpose of this paper is to show that the new effect which is manifested in the variation of the shape and the peak power of a scattered pulse accompanies such continuously scanning antenna DP's of a bistatic sodar. As a result, the control of the duration and amplitude of the scattered signal for the invariable parameters of the emitted signal turns out to be feasible. Below we explain the effect of the above–indicated transformation of the scattered signal and present the results of numerical modeling.

Let us consider the bistatic sounding geometry shown in Fig. 1. We assume the start of the sounding pulse to be made at the instant of time t'_1 while its termination – at the time $t'_2 = t'_1 + \tau_t$. Let us assume, for definiteness, that the angle of orientation of the DP axis of the transmitting antenna α_t varied during the transmission time τ_t in such a way that the mean length S_0 of the signal propagation path from the transmitting antenna to the receiving antenna decreases progressively with constant velocity $\vartheta'_s < 0$, i.e.,

$$S_0(t') = S_0(t'_0) + \vartheta'_s(t' - t'_0) , \qquad (1)$$

where $t'_0 = (t'_2 + t'_1)/2$ and $\vartheta'_s = \partial S_0(t')/\partial t'\big|_{t'=t'_0}$.

Let us make use of the formal representation $S_{\min}(t') = S_0(t') + \Delta S_{\min}(t')$, where $\Delta S_{\min} = S_{\min} - S_0$ (see Fig. 1). The transmitting ($\psi_{\alpha t}$) and receiving ($\psi_{\alpha r}$) beamwidths are usually such that $\psi_{\alpha t} \ll 1$ and $\psi_{\alpha r} \ll 1$ in radians and hence $|\Delta S_{\min}|/S_0 \ll 1$. As a result, in the approximate estimates we may ignore the temporal variations of $\Delta S_{\min}$ at $\vartheta'_s \neq 0$ in comparison to the analogous variations of $S_0(t')$. Finally from Eq. (1) we derive

$$S_{\min}(t') \approx S_0(t'_0) + \vartheta'_s(t' - t'_0) + \Delta S_{\min} . \qquad (2)$$

Using Eq. (2) the relation for the time of arrival of the scattered pulse at the receiving antenna $t_1 = t'_1 + S_{\min}(t'_1)/c$, where c is the speed of the signal propagation through the medium, may be written in the form

$$t_1 \approx t'_1 + \frac{S_0(t'_0)}{c} + \frac{\vartheta'_s(t'_1 - t'_0)}{c} + \frac{\Delta S_{\min}}{c} . \qquad (3)$$

Since the relation for the time of arrival of the trailing edge of the scattered pulse t_2 is analogous, the pulse duration $\tau_r = t_2 - t_1$ is equal to

$$\tau_r \approx \left| \tau_t + \vartheta'_s \tau_t/c + \Delta S/c \right| . \qquad (4)$$

Here $\Delta S/c = (S_{\max} - S_{\min})/c$ is the scattered signal broadening caused by ambiguity of the propagation path from the transmitting to receiving antennas (see Fig. 1).

For the case of the scanning antenna DP we introduce the coefficient of the scattered pulse compression K_t as the ratio of the value of τ_r at $\vartheta'_s = 0$ to the value of the same parameter at $\vartheta'_s \neq 0$. In the case of the scanning receiving antenna DP the coefficient K_t can be described on account of Eq. (4) by the relation

$$K_t \approx 1 \Bigg/ \left| 1 + \frac{\vartheta'_s}{c} \frac{\tau_t}{\tau_t + \Delta S/c} \right| . \qquad (5)$$

According to relation (5), if the angular scanning rate of the receiving antenna DP during the time of transmission of the sounding pulse is $\Omega_t = \partial\alpha_t/\partial t' > 0$ (at $\vartheta'_s < 0$), then the scattered pulse will have the duration shorter than that for the stationary DP. The above–indicated temporal compression of the scattered pulse increases up to maximum as the parameter ϑ'_s decreases from zero to the negative quantity

$$\vartheta'_{s\ \mathrm{opt}} \approx -c\left(1 + \frac{\Delta S}{c\,\tau_t}\right) \qquad (6)$$

and starts to decrease with further decrease of ϑ'_s. In addition, if $\vartheta'_s < 2\vartheta'_{s\ \mathrm{opt}}$ then $K_t < 1$. This means that the duration of the scattered pulse becomes longer than the initial pulse duration at $\vartheta'_s = 0$.

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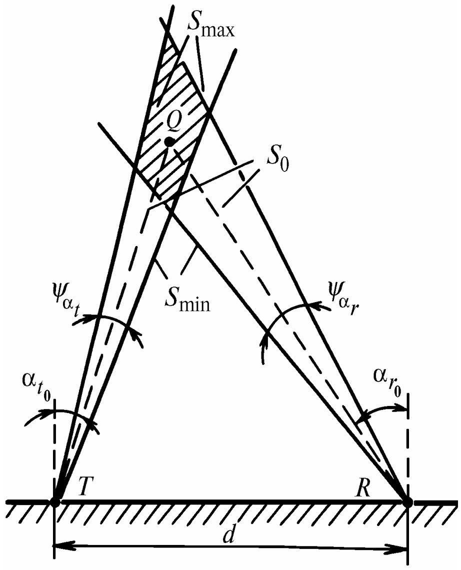

FIG. 1. Bistatic sounding geometry. Here T and R denote the location of transmitting and receiving antennas, Q specifies the center of the scattering volume, α_{t_0} and α_{r_0} are the angles of orientation of the antenna DP axes, ψ_{a_t} and ψ_{α_r} are the widths of the main lobes, S_0 is the length of the signal propagation path from the transmitter to the receiver through the point Q, and S_{min} and S_{max} are the minimum and maximum path lengths on account of ψ_{α_t} and ψ_{α_r}.

The above–described effect of the scattered pulse compression can be physically explained by the fact that at the fixed scanning rates Ω_t of the transmitting antenna DP the signal is first emitted in the directions α_t corresponding to longer paths of signal propagation while at a later time in the directions corresponding to shorter paths. As a result, it arrives at the receiving antenna from different directions α_r during shorter time than that at $\Omega_t = 0$. If the pulse shape undergoes no significant variation due to compression of the scattered pulse, then according to the energy conservation law, the peak power P_r must be simultaneously increased approximately by the factor of K_t.

There exists the one–to–one correspondence between the quantities ϑ_s' and Ω_t, which is determined solely by the geometry of sounding

$$\Omega_t = -\vartheta_s' F_t/d , \tag{7}$$

where $F_t = \sin^2(\alpha_{t_0} + \alpha_r)/\{\cos\alpha_r[1 + \cos(\alpha_{t_0} + \alpha_r)]\}$, α_{t_0} is the angle of orientation of the DP axis of the receiving antenna at $t' = t_0'$, and d is the distance between the antennas of the bistatic sodar.

By substituting Eq. (7) into Eqs. (5) and (6) for the scanning receiving antenna DP alone, we finally derive

$$K_t \approx 1 \Bigg/ \left| 1 - \left(F_t \frac{d}{c} \frac{\tau_t}{\tau_t + \Delta S/c} \right) \Omega_t \right| , \tag{8}$$

$$\Omega_{t\ \mathrm{opt}} \approx \frac{180}{\pi} \frac{c}{d} \left(1 + \frac{\Delta S}{c + \tau_t} \right) F_t , \tag{9}$$

where $\Omega_{t\ \mathrm{opt}}$ is in deg/s.

We give a numerical example for acoustic sounding of the atmosphere to have an idea of $\Omega_{t\ \mathrm{opt}}$. Let $c = 343$ m/s, $d = 400$ m, and $\alpha_{t_0} = \alpha_{r_0} = 33°$. Then $\Omega_{t\ \mathrm{opt}} \approx 35$deg/s if the angular beamwidths ψ_{at} and ψ_{ar} are so small that $\tau_t \gg \Delta S/c$. Due to beam broadening and the corresponding increase in the parameter $\Delta S/c$ in comparison to τ_t, the value of Ω_t also increases.

Analogously to the foregoing we can consider the case of the scanning receiving antenna DP with the angular rate $\Omega_r = \partial\alpha_r/\partial t$. Let t_1 be the time of the pulse arrival at the receiving antenna, while t_2 be the time of the pulse termination. At $\Omega_r \neq 0$, we have

$$S_0(t) = S_0(t_0) + \vartheta_s(t - t_0) ,$$

where $t = (t_1 + t_2)/2$ and $\vartheta_s = \partial S_0(t)/\partial t \,\big|_{t-t_0}$. Since in this case $t_1 = t_1' + S_{min}(t_1)/c$, the relation being analogous to Eq. (3) has the form

$$t_1 \approx t_1' + \frac{S_0(t_0)}{c} + \frac{\vartheta_s(t - t_0)}{c} + \frac{\Delta S_{min}}{c} .$$

Thus, by analogy with Eq. (4) we obtain

$$\tau_r \approx \tau_{r_0} / |1 - \vartheta_s/c| ,$$

where $\tau_{r_0} = \tau_t + \Delta S/c$ is the duration of the scattered pulse at $\vartheta_s = 0$. Accordingly, the coefficient of pulse compression is equal to

$$K_t \approx |1 - \vartheta_s/c| . \tag{10}$$

As opposed to the previous case, according to Eq. (10) the receiving antenna scanning DP results in the pulse compression and then the pulse peak power increases not only at the negative values of the parameter ϑ_s but also at its positive values $\vartheta_s > 2c$. Taking into account the relation between Ω_r and ϑ_s in Eq. (10) analogous to Eq. (7), we obtain

$$K_t \approx \left| 1 - \left(F_r \frac{d}{c} \right) \Omega_r \right| , \tag{11}$$

where $F_r = \sin^2(\alpha_t + \alpha_{r0})/\{\cos\alpha_r[1 + \cos(\alpha_t + \alpha_{r0})]\}$, α_{r0} is the angle of orientation of the DP axis of the receiving antenna at the instant of time $t = t_0$.

The above–given considerations are to a great extent qualitative. They do not give a comprehensive idea of the variation in the shape and amplitude of the scattered pulse envelope caused by the scanning antenna DP's. In particular, no consideration has been given to the effect of the shape of the antenna DP's themselves, including their side lobes, on the scattered signal.

To obtain more rigorous results for the system of bistatic acoustic sounding of the atmosphere, the special program for an IBM PC AT series computer has been developed. It can be used to calculate the temporal dependence of the scattered signal power $P_r(t)$ for any specifications of the sodar, shape of the antenna DP, and meteorological conditions assigned by an interactive menu.

The algorithm for calculating the function $P_r(t)$ was developed based on the expression for the intensity of the sound field singly scattered by the atmosphere.[1,2] In this case the formula for $P_r(t)$ disregarding the energy losses in electro–acoustic converters has the form

$$P_r(t) = \int_V D_t(t - S/c)\, D_r(t)\, P_t(t - S/c)\, \sigma(\theta)\, S_t^{-2} S_r^{-2} \times \exp\{-\alpha_c (S_t + S_r)\}\, dV , \quad (12)$$

where integration is performed over the points **r** being inside the scattering volume V. Here $D_t(\mathbf{r}, t - S(\mathbf{r})/c)$ and $D_r(\mathbf{r}, t)$ are the weighting factors which take into account the effect of the transmitting and receiving antenna DP's on the signal scattered at the point **r**, $P_t(t - S(\mathbf{r})/c)$ describes the temporal behavior of the power of the sounding pulse delayed for the time of sound propagation from one antenna to another antenna, $\sigma(\mathbf{r}, \theta)$ is the cross section of sound scattering by the atmospheric turbulent inhomogeneities at the point **r** at the angle θ (Ref. 2), $\alpha_t = \alpha_c + \alpha_m + \alpha_{ex}$ is the total coefficient of the classical, molecular, and turbulent excess attenuation of sound by the atmosphere,[3] $S_t(\mathbf{r})$ and $S_r(\mathbf{r})$ are the distances from the point **r** to the transmitting and receiving antenna locations, and $S(\mathbf{r}) = S_t(\mathbf{r}) + S_r(\mathbf{r})$. If the transmitting antenna is placed at the origin of the radius vector $\mathbf{r} = \mathbf{i}\,x + \mathbf{j}\,y + \mathbf{k}\,z$, then

$$S_t = \sqrt{x^2 + y^2 + z^2} , \quad S_r = \sqrt{(d - x)^2 + y^2 + z^2} ,$$

$$\cos\theta = -(x(x - d) + y^2 + z^2)/(S_t S_r) .$$

The sounding pulse is usually bell–shaped. Therefore, in the calculations from Eq. (12) it was fitted by the relation

$$P_t(t) = P_{t_{\max}} \exp\{-0.69(2t/\tau_t)^2\} ,$$

where $P_t(t) = 0.5P_{t_{\max}}$ at $|t| = \tau_t/2$.

Both antennas of the sodar were assumed to be identical. In this case in Eq. (12) the functions D_t and D_r describing the shape of the antenna DP's have similar forms but depend on different arguments. In the function D_t the angular detunings are the arguments

$$\Delta\alpha_t(\mathbf{r}, t) = \alpha_t(\mathbf{r}) - \alpha_{t_0} - \Omega_t[t - S(\mathbf{r})/c] ,$$

$$\Delta\varphi_t(\mathbf{r}) = \varphi_t(\mathbf{r}) - \varphi_{t_0} , \quad (13)$$

where $\alpha_t(\mathbf{r}) = \arctan(x/z)$, $\varphi_t(\mathbf{r}) = \arctan\left(y/\sqrt{x^2 + z^2}\right)$.

Analogously, D_r is the function of the arguments

$$\Delta\alpha_r(\mathbf{r}, t) = \alpha_r(\mathbf{r}) - \alpha_{r0} - \Omega_r[t - t_0] ,$$

$$\Delta\varphi_r(\mathbf{r}) = \varphi_r(\mathbf{r}) - \varphi_{r0} , \quad (14)$$

where $\alpha_r(\mathbf{r}) = \arctan[(d - x)/z]$, $\varphi_r(\mathbf{r}) = \arctan[x - \tan\varphi_t(\mathbf{r})/(d - x)]$, and t_0 is the time of signal arrival from the geometric center of the scattering volume V (denoted by the point Q in Fig. 1).

Two approximations for the antenna DP's were used in the calculations. The first function of the angular arguments $\Delta\alpha$ and $\Delta\varphi$ described by Eqs. (13) and (14) has the form

$$D(\Delta\alpha, \Delta\varphi) = G \exp\left\{-0.69\left[\left(\frac{2\Delta\alpha}{\psi_\alpha}\right)^2 + \frac{2\Delta\varphi}{\psi_\varphi}\right]^2\right\} , \quad (15)$$

where G is the antenna power gain. It corresponds to the acoustic field distribution over the antenna aperture without side lobes (Gaussian beam approximation). The second function of the same arguments

$$D(\Delta\alpha, \Delta\varphi) = G \frac{\sin^2[180/\psi_\alpha \sin(\Delta\alpha)]}{[180/\psi_\alpha \sin(\Delta\alpha)]^2} \cdot \frac{\sin^2[180/\psi_\varphi \sin(\Delta\varphi)]}{[180/\psi_\varphi \sin(\Delta\varphi)]^2} \quad (16)$$

corresponds to another limiting case of the acoustic field homogeneously distributed over the antenna aperture. In this case the side lobe level is maximum.

Since the scattering volume V is generally formed by the volume where the beam crosses the field of view of the detector, it was found very convenient to change the Cartesian coordinates to the angular variables of integration in Eq. (12). The angles $\alpha_t = \alpha_t(\mathbf{r})$, $\varphi_t = \varphi_t(\mathbf{r})$, and $\alpha_r = \alpha_r(\mathbf{r})$ entering into relations (13) and (14) were chosen for them. It can be easily verified that in this case in Eq. (12)

$$dV = \left(S_t^2\, S_r/\sin\theta\right) d\alpha_t\, d\alpha_r\, d\varphi_t .$$

The integration limits for the new variables in Eq. (12) were found from the condition that the functions D_t and D_r decay down to $q = 0.1$ from their maximum values. The calculations were performed to three significant digits beyond the decimal point which was determined by the number of the integration nodes.

In accordance with the developed program, the calculations are performed by the comparison method. First, thirty discrete values of the function $P_r(t)$ are calculated in the selected temporal window with regard to the introduced parameters of the problem without scanning antenna DP's ($\Omega_t = 0$ and $\Omega_r = 0$). The maximum value of $P_r(t)$ being equal to $P_{r1\,m}$, the duration of the given signal τ_{r1} at half maximum of the power $P_{r1\,m}$, the instant of time t_{10} at which $P_r(t) = P_{r1\,m}$, and the difference $\Delta t_{10} = t_{10} - t_0$ are determined. In so doing the parabolic interpolation of the function $P_r(t)$ between its discrete counts is used. After that these calculations are repeated for the scanning antenna DP's with the scanning rates Ω_t and Ω_r entered by a menu. The quantities $P_{r2\,m}$, τ_{r2}, t_{20}, and Δt_{20} analogous to the above–described ones are also determined. We can display additionally the compression coefficient of the scattered pulse $K_t = \tau_{r1}/\tau_{r2}$, its peak power gain $K_p = P_{r2\,m}/P_{r1\,m}$, and temporal behavior $P_r(t)$ normalized to $P_{r1\,m}$ with and without scanning of the antenna DP's.

Figures 2 and 3 show some examples of these plots. The signal calculated with specified values of Ω_t and Ω_r is shown by solid curve, and the signal calculated for the stationary antenna DP's – by dashed curve. The points corresponding to the signal powers at $t = t_0$ are denoted by asterisks. In calculations the angles α_{t0} and α_{r0} were specially assigned identical with the purpose of convenient comparison of the results obtained at $\Omega_t \neq 0$ with that at $\Omega_r \neq 0$. For this geometry of sounding at $d = 400$ m the calculated value of $\Omega_{t\,\mathrm{opt}}$ appears to be equal to about 38 deg/s, that with regard to the possible contribution of the parameter $\Delta S/c$ to Eq. (9) agrees well with the earlier predicted value.

Figure 2 illustrates the case of the scanning single–lobe (Gaussian) antenna DP's. Here at $\Omega_t \approx \Omega_{t\,\mathrm{opt}}$, the temporal compression of the scattered signal and nearly proportional increase in its peak power are clearly observed (Fig. 2*a*). For large values of $|\Omega_t|$ the scattered pulse broadens and this broadening is accompanied by the increasing dips in its envelope. In particular, as a result of the above–indicated transformation of the pulse shape, it is actually manifested in Fig. 2*b* as the shorter pulse train. In this case the behavior of the coefficients K_t and K_p as functions of the value of Ω_t is shown in Fig. 4. Here, the sharp increase of K_t at $\Omega_t \lesssim -40$ deg/s is caused by the initial pulse decay. When the depth of the dips in the signal envelope exceeded half maximum of $P_{r_{2\,m}}$, we calculated only the duration of the single pulse with the maximum amplitude from the pulse train.

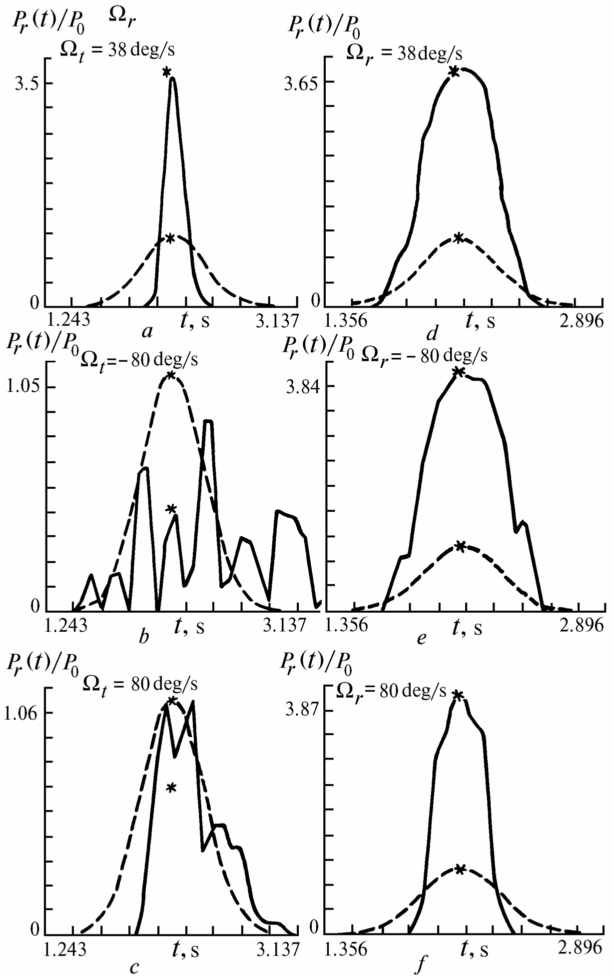

FIG. 2. Normalized time dependences of the scattered signal power at different scanning rates of the single–lobe DP's of the transmitting (a, b, and c) or receiving (d, e, and f) antennas for $\alpha_{t_0} = 33°$, $\alpha_{r_0} = 33°$, $\psi_{\alpha_t} = 3°$, $\psi_{\alpha_r} = 3°$, $\psi_{\varphi_t} = 6°$, $\psi_{\varphi_r} = 6°$, $d = 400$ m, *and* $\tau_t = 0.5$ s *at* $f = 1500$ Hz.

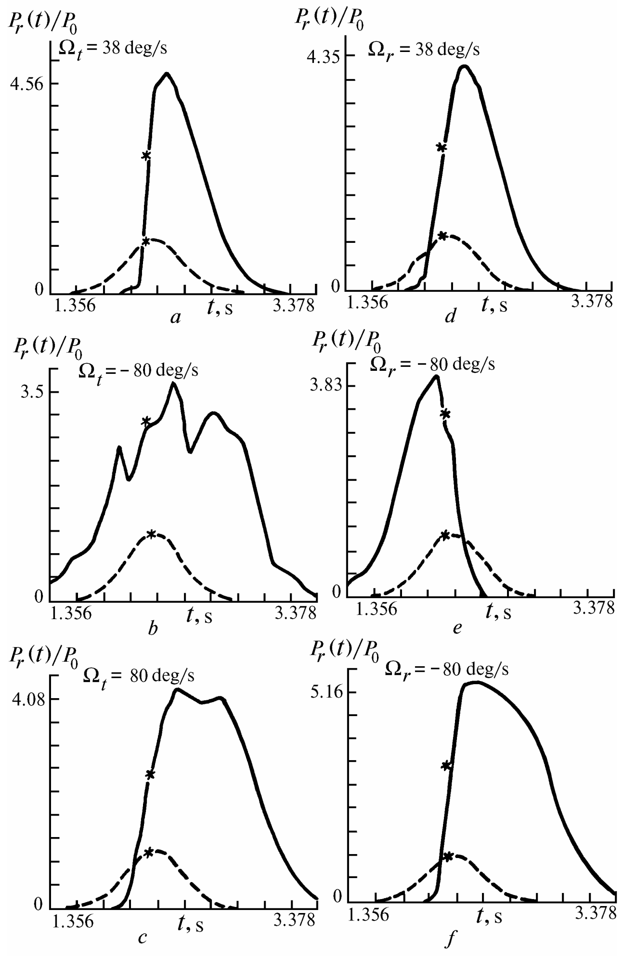

FIG. 3. Normalized time dependences of the scattered signal power at different scanning rates of the multilobe DP's of the transmitting (a, b, and c) or receiving (d, e, and f) antenna for ${}_{t_0} = 33$, ${}_{r_0} = 33$, ${}_{t} = 3$, ${}_{r} = 3$, ${}_{\varphi_0} = 6$, ${}_{\varphi_r} = 6$, $d = 400$ m, *and* ${}_{t} = 0.5$ s *at* $f = 1500$ Hz.

The beamwidth in the plane of beam scanning ψ_{at} appeared to affect strongly the maximum values of K_t and K_p at $\Omega_t = \Omega_{t\,\mathrm{opt}}$. As $\psi_{at} \to 0$ it follows from Eq. (8) that as $\Omega_t \to \Omega_{t\,\mathrm{opt}}$, the values of K_t and K_p infinitely increase. The real shape of the DP's has a smoothing effect on the peak values of K_t and K_p. The reason for that is the following. Relation (12) is the convolution equation which describes the transformation of the sounding pulse $P_t(t)$ to the signal $P_r(t)$ by a spatiotemporal filter. The impulse transfer function of this filter depends on the form of the functions $D_s(\mathbf{r}, t)$ and $D_r(\mathbf{r}, t)$. The angular beamwidths ψ_{at} and ψ_{ar} determine directly the value of the parameter $\Delta S/c$ which is the integration time constant of the given filter. The larger is the beamwidths, the larger is the parameter $\Delta S/c$ in comparison to τ_t, and the stronger is the smoothing effect of the filter.

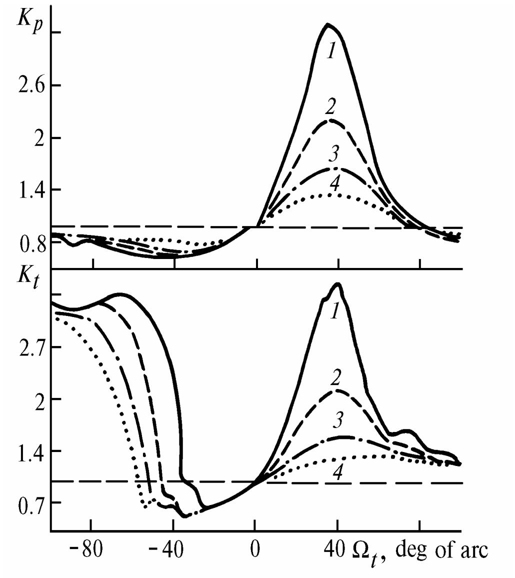

FIG. 4. The peak power gain K_p and the duration compression coefficient K_t of the scattered signals vs the scanning rate Ω_t of the single–lobe transmitting antenna DP at different values of the beamwidth ψ_{α_t} for $\alpha_{t_0} = 33°$, $\alpha_{r_0} = 33°$, $\psi_{\alpha_r} = 3°$, $\psi_{\varphi_t} = 6°$, $\psi_{\varphi_r} = 6°$, $d = 400$ m, *and* $\tau_t = 0.5$ s *at* $f = 1500$ Hz. $\psi_{\alpha_t} = 3°$ *(1),* $6°$ *(2),* $9°$ *(3), and* $12°$ *(4).*

The case of scanning single–lobe receiving antenna DP noticeably differed in the obtained results from the last case (Figs. 2*d*, *e*, and *f*). Here the duration of the scattered pulse depends weakly on Ω_r and the pulse does not decay at large values of $|\Omega_r|$. As $|\Omega_r|$ increases, the peak power first increases sharply up to the maximum depending on the beamwidth and then remains virtually unchanged (Fig. 5). The maximum values of K_t and K_p are limited by the smoothing effects of the above–described filter as well as in the case of scanning transmitting antenna DP.

The presence of the side lobes in the scanning DP produces qualitative changes in the shape and power of the scattered pulses (Fig. 3). In this case no noticeable decrease of the pulse duration is observed virtually at any Ω_t and Ω_r. For such antenna DP's the scattered signal is formed due to scattering of sound emitted within both main and side lobes.

Angular scanning of each of these lobes results also in the additional increase in the power of the scattered signal received from them. For this reason, first, the stretching takes place of the leading edge or trailing edge of the received signal depending on the sign of Ω_t or Ω_r and, second, the larger amount of increase in its total peak power is found in comparison to the case of scanning single–lobe DP's. You can find the values of the coefficients K_t and K_p as functions of Ω_t and Ω_r in Figs. 6 and 7. As earlier, K_t and K_p reach their maximum values.

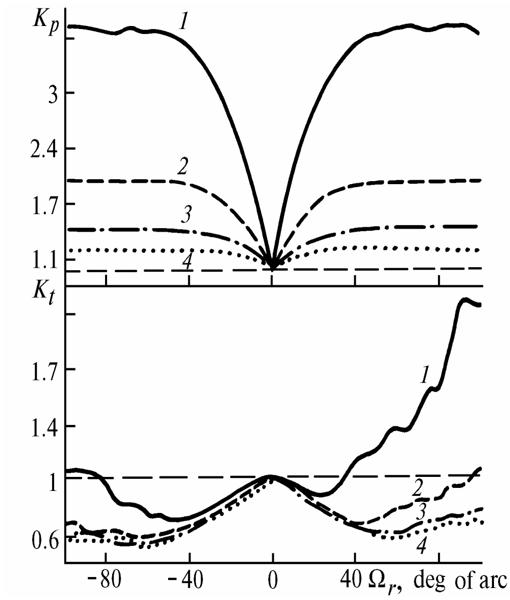

FIG. 5. The peak power gain K_p and the duration compression coefficient K_t of the scattered signals vs the scanning rate Ω_r of the single–lobe receiving antenna DP at different values of the beamwidth ψ_{α_r} for $\alpha_{t_0} = 33°$, $\alpha_{r_0} = 33°$, $\psi_{\alpha_t} = 3°$, $\psi_{\varphi_t} = 6°$, $\psi_{\varphi_r} = 6°$, $d = 400$ m, *and* $\tau_t = 0.5$ s *at* $f = 1500$ Hz. $\psi_{\alpha_r} = 3°$ *(1),* $6°$ *(2),* $9°$ *(3), and* $12°$ *(4).*

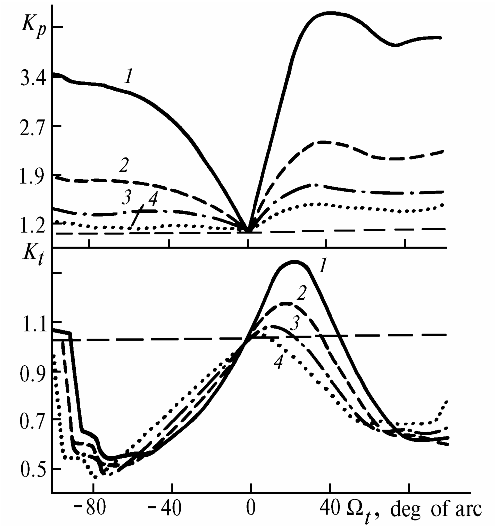

FIG. 6. The peak power gain K_p and the duration compression coefficient K_t of the scattered signals vs the scanning rate Ω_t of the multilobe transmitting antenna DP at different values of the main lobe width $\psi_{\alpha t}$ for $\alpha_{t_0} = 33°$, $\alpha_{r_0} = 33°$, $\psi_{\alpha_r} = 3°$, $\psi_{\varphi_t} = 6°$, $\psi_{\varphi_r} = 6°$, $d = 400$ m, *and* $\tau_t = 0.5$ s *at* $f = 1500$ Hz. $\psi_{\alpha_t} = 3°$ *(1),* $6°$ *(2),* $9°$ *(3), and* $12°$ *(4).*

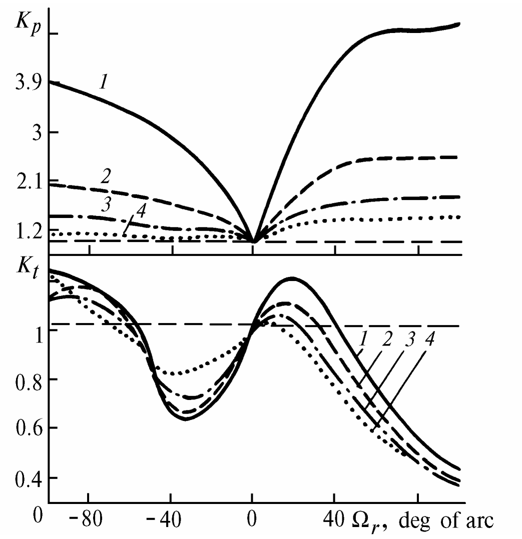

FIG. 7. The peak power gain K_p and the duration compression coefficient K_t of the scattered signals vs the scanning rate Ω_r of the multilobe transmitting antenna DP at different values of the main lobe width ψ_{α_r} for $\alpha_{t_0} = 33°$, $\alpha_{r_0} = 33°$, $\psi_{\alpha_t} = 3°$, $\psi_{\varphi t} = 6°$, $\psi_{\varphi_r} = 6°$, $d = 400$ m, and $\tau_t = 0.5$ s at $f = 1500$ Hz. $\psi_{\alpha_r} = 3°$ (1), 6° (2), 9° (3), and 12° (4).

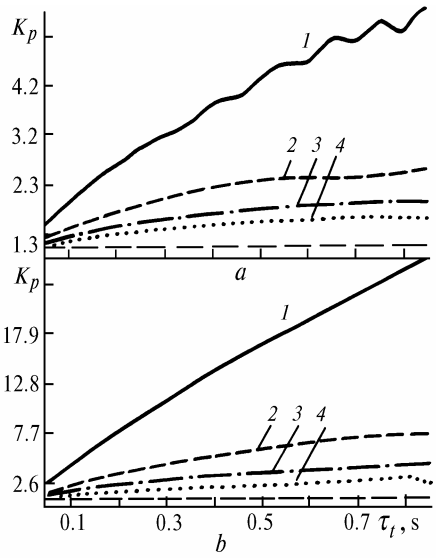

FIG. 8. The peak power gain K_p of the scattered signal vs the sounding pulse duration τ_t for the simultaneous scanning of the transmitting and receiving antenna DP's with a scanning rate of 38 deg/s and different angular beamwidths ψ_{α_t} and ψ_{α_r} for $\alpha_{t_0} = 33°$, $\alpha_{r_0} = 33°$, $\psi_{a_t} = 6°$, $\psi_{\alpha_r} = 6°$, and $d = 400$ m at $f = 1500$ Hz. $\psi_{\alpha_t} = \psi_{\alpha_r} = 3°$ (1), 6° (2), 9° (3), and 12° (4). a) Single–lobe DP's and b) multilobe DP's.

The above–described effect of the increase in the peak power of the scattered signals depends strongly on the duration of the sounding pulse τ_t in comparison to the parameter $\Delta S/c$ in the case of scanning antenna DP's. This is illustrated by Fig. 8 in which the values of K_p as functions of τ_t are shown for the simultaneously scanning transmitting and receiving antenna DP's with different angular widths and the same scanning rates $\Omega_t = \Omega_r = \Omega_{t\ \mathrm{opt}}$. An especially pronounced gain in the power of the scattered signal can be obtained by using the antennas with the high level of side lobes of the DP's.

Thus, we can specially change the shape and energy parameters of the signal of the bistatic sodar with the use of the scanning antenna DP's. The most pronounced positive effect is obtained from the view-point of increasing the energy potential of the sodar that improves its noise proof characteristics. As the investigation show, one can obtain approximately 5–10 times larger peak power of the scattered signal without increase in the power of the signal emitted in the atmosphere. However, it should be noted that the use of the scanning antenna DP's leads to lower spatial resolution of the sodar. In particular, the spatial resolution is determined by the size of the angular sector $\Delta\alpha_t = \Omega_t \cdot \tau_t$ in the case of the scanning transmitting antenna DP. Therefore, the very large values of Ω_t may be impermissible. One should also take into account that usually $\tau_t \ll 1$ s when estimating the admissible values of Ω_t.

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