Artificial defocusing lens in the ionosphere

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It has been observed that probing radio signals undergo a pronounced defocusing as they propagate through an ionosphere perturbed by an intense radio wave.

Intense rf radiation changes the ionization of the ionosphere. These changes should lead to the formation of a nonuniform structure in an ionospheric layer with a thickness on the order of 100–200 km and a horizontal scale dimension determined by the directional pattern of the antenna of the perturbing transmitter. A large-scale nonuniformity of this sort can act as a lens that focuses or defocuses radio waves.[1] In this letter we report experimental observation of a pronounced defocusing of radio waves probing a perturbed region. The effect is evidence that an effective defocusing lens forms in the ionosphere.

When an intense radio wave of ordinary polarization at a frequency below the critical frequency of the ionospheric $F2$ layer acts on the ionosphere, there is an anomalous wide-band attenuation of radio waves,[2,3] whose nature has been studied quite thoroughly.[4] In order to unambiguously distinguish the defocusing effects in these experiments we arranged conditions without any anomalous absorption. The experiments were carried out at the Surg heating facility of the Scientific-Research Radiophysics Institute, which has a high equivalent radiation power, up to 300 MW, and a narrow directional pattern. For diagnostics of the density perturbations we used vertical sounding simultaneously at eight frequencies with the help of the Doppler complex of the Institute of Terrestrial Magnetism, the Ionosphere, and Radio Wave Propagation.[5] The frequencies of the probing waves were chosen to sound ionospheric layers ranging in height from 100 to 300 km. The Doppler frequency shift f_D and the signal amplitude A were measured for each of the probing waves.

The experimental results reported here were obtained in May and July 1983 under daytime conditions. Figure 1 shows typical curves of the Doppler shift $f_D(t)$ and of the amplitude $A(t)$ for a probing wave in one of the heating cycles. A wave of the extraordinary polarization was transmitted. Similar $f_D(t)$ and $A(t)$ curves were recorded at the other seven sounding frequencies, between 4 and 8.4 MHz. Analysis of the curves of the Doppler shift $f_D(t)$ at all the frequencies reveals that the electron density increases by about 10% in the altitude interval $100 \lesssim z \lesssim 200$ km when the perturbing station is turned on.

As can be seen from Fig. 1a, the amplitude of the probing wave decreases abruptly, in less than 0.1 s, by an amount δA^- when the perturbing station is turned on. A change of exactly the same magnitude, but in the opposite direction, δA^+, is observed

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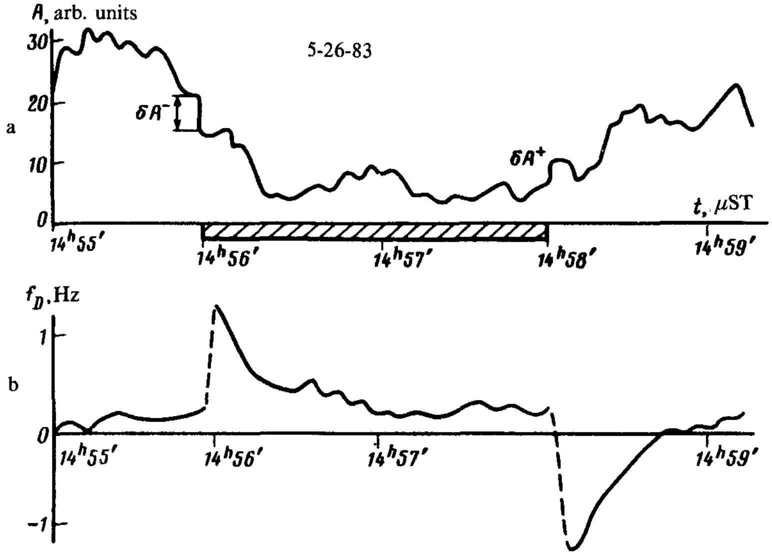

FIG. 1. Time evolution of the amplitude (a) and Doppler frequency shift (b) of a probing wave at the frequency $f = 6.71$ MHz during intense heating by a radio wave at the frequency $f_0 = 7.82$ MHz with a power $P = 200$ MW. The hatching shows the time interval during which the high-power transmitter is operating. The time scale is Moscow Standard Time.

when the station is turned off. These effects are caused by a decrease in the amplitude of the probing wave caused by an increase in the collision rate ν as the electrons are heated (cross-modulation absorption, K_ν; Ref. 1). As can be seen from Fig. 1a, however, the amplitude of the probing signal continues to decrease slowly after the perturbing station is turned on, and it continues to increase after the station is turned off. This effect correlates completely with the behavior $f_D(t)$, i.e., with the increase and decrease in the ionization in the altitude interval 100 km $\lesssim z \lesssim$ 200 km. We may there-

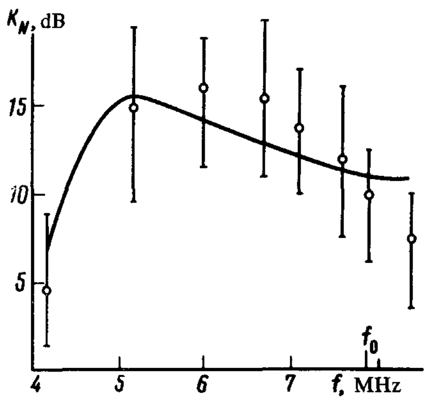

FIG. 2. The defocusing coefficient K_N as a function of the frequency of the probing radio waves (heating at the frequency $f_0 = 7.82$ MHz at a power $P = 200$ MW). Points—Experimental; curve—theoretical.

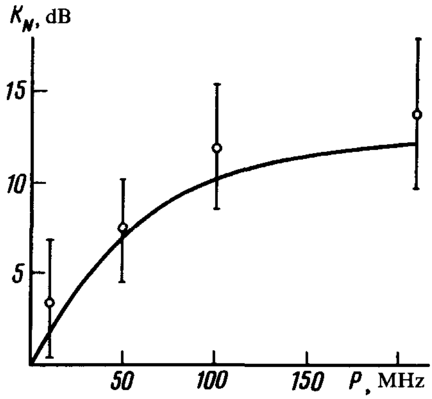

FIG. 3. The defocusing coefficient K_N as a function of the power of the heating wave (heating at the frequency $f_0 = 7.82$ MHz; the frequency of the probing wave is $f = 7.02$ MHz). Points—Experimental; curve—theoretical.

fore conclude that the slow but significant change in the amplitude of the probing wave is a consequence of a defocusing of this wave caused by a change in the electron density in the ionosphere.

Figure 2 shows the frequency dependence of the defocusing coefficient $K_N(f) = K_{\text{tot}}(f) - K_\nu(f)$, where $K_{\text{tot}} = 20 \log(A_p/A_h)$, A_p is the average amplitude during the pause between heating intervals, and A_h is the average amplitude during a heating interval, calculated over the interval from the time at which $A(t)$ and $f_D(t)$ reach steady states to the time in which the heating is turned off. Here $K_\nu = 20 \log[A_1/(A_1 - \delta A)]$, where A_1 is the amplitude just before the heating is turned on. We see that the signal power is reduced by a factor of 10–30 by the defocusing. This behavior of $K_N(f)$ implies that the defocusing lens is at the level of the E and $F1$ layers. Figure 3 shows the dependence $K_N(P)$, where P is the heating power. A similar behavior of $A(t)$, $f_D(t)$, and K_N was observed when the ionosphere was heated in a "transillumination" arrangement and also when the polarization of the intense wave was switched from extraordinary to ordinary.

Gurevich[6] has theoretically predicted a nonlinear defocusing of radio waves due to a change in ionization of the ionosphere when it is heated by an intense radio wave. We calculated the functions $K_N(f)$ and $K_N(P)$ according to Refs. 1 and 6 for a typical altitude profile of the properties of the daytime ionosphere. The results are shown by the solid curves in Figs. 2 and 3. We see a good agreement with experiment.

In summary, it can be asserted that these experiments have revealed the appearance of an artificial ionospheric lens which leads to a significant attenuation of the field of radio waves passing through this lens.

[1]A. V. Gurevich, Nonlinear Phenomena in the Ionosphere, Springer-Verlag, New York, 1978.
[2]W. F. Utlaut, Proc. IEEE **63**, 1022 (1975).
[3]L. M. Erukhimov, S. A. Metelev *et al.*, in: Teplovye nelineĭnye yavleniya v plazme (Thermal Nonlinear

Effects in Plasmas), IPF, Academy of Sciences, USSR, Gor'kiĭ, 1979, p. 81.
[4]V. V. Vas'kov and A. V. Gurevich, in: Teplovye nelineĭnye yavleniya v plazme (Thermal Nonlinear Effects in Plasmas), IPF, Academy of Sciences, USSR, Gor'kiĭ, 1979, p. 81.
[5]V. V. Vas'kov, S. F. Golyan, Yu. V. Gruzdev, A. V. Gurevich, Ya. S. Dimant, V. Yu. Kim, L. A. Lobachevskiĭ, V. V. Migulin, V. A. Panchenko, M. S. Petrov *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **34**, 582 (1981) [JETP Lett. **34**, 558 (1981)].
[6]A. V. Gurevich, Geomagnetizm i aéronomiya **5**, 70 (1965); **12**, 24 (1972).

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