Excitation of upper hybrid resonance in the ionospheric plasma by an intense radio wave

V. V. Vas'kov, S. F. Golyan, A. V. Gurevich, Ya. S. Dimant, V. A. Zyuzin, V. Yu. Kim, G. P. Komrakov, L. A. Lobachevskiĭ, V. V. Migulin, N. A. Mityakov, V. A. Panchenko, and V. P. Polimatidi

Institute of Terrestrial Magnetism, the Ionosphere, and Radio Wave Propagation, Academy of Sciences of the USSR; Scientific-Research Radiophysics Institute, Ministry of Higher and Middle Education, Russian Soviet Federated Socialist Republic

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An effective displacement of ionospheric plasma from a localized region in the vicinity of the upper hybrid resonance of an intense radio wave has been observed. A "plasma reflector" which focuses test waves has been observed to appear in this region. The observed effects are evidence of the local excitation of plasma turbulence.

A distinctive feature of the interaction of an intense, ordinary-polarization radio wave with the magnetized plasma of the upper ionosphere is the development of a sharply defined region of an upper hybrid resonance (uhr), some 3–10 km below the reflection point for an ordinary wave near the level

$$f_p = f_{\rm uhr} \equiv \sqrt{f_0^2 - f_H^2},$$

Here $f_p = (e^2N/\pi m)^{1/2}$ is the electron plasma frequency, which depends on the local electron density (N) at the height z, f_0 is the frequency of the intense radio wave, and $f_H = eH/2\pi mc \approx 1.4$ MHz is the electron gyrofrequency. According to a theoretical interpretation,[1,2] a strong anomalous absorption of the intense radio wave should occur here as a result of a conversion of its energy into short-wave plasma oscillations, i.e., plasma waves.[3,4] The nature of the conversion is determined by the effect of the small-scale inhomogeneities which are stretched out along the magnetic field and in which the density gradient is perpendicualar to the magnetic field **H**. These inhomogeneities are themselves generated rapidly in the uhr region by the intense radio wave in the course of the heating of electrons in a collisional dissipation of plasma waves.[3–5] Estimates show that the thickness (Δz) of the zone of anomalous absorption is small: $\Delta z \lesssim 1$ km. An important point is that in such a narrow layer there should be not only an intense excitation but also a significant buildup of the energy of slow waves. A local anomalous absorption of an intense radio wave should therefore cause an effective thermal and strictive displacement of plasma from the uhr region at heights $z > 200$ km.

The present letter is the first report on an experimental observation of this effect. The experiments were carried out at the high-power Sura installation of the Scientific-Research Radiophysics Institute in 1983–1985 in daytime and evening hours under quiet geophysical conditions. The ionosphere was perturbed by waves of ordinary polarization at the frequencies $f_0 = 4.785$ and 5.828 MHz with equivalent radiated power levels $PG = 150$ and 220 MW, respectively. The high-power transmitter worked

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in cycles of 20–30 s of heating followed by a 9-min pause. The state of the unperturbed ionosphere was monitored by the Bazis ionospheric station. For diagnostics of the artificial perturbations we use a multifrequency Doppler sounding of the ionosphere through the measurement of the amplitude (A) and Doppler frequency shift (f_D) of weak, ordinary-polarization test waves at eight to twelve frequencies f_i simultaneously. By using this large number of sounding frequenices we have been able (for the first time) to study the spatial structure of the artificial perturbations of the ionosphere is some detail, i.e., with a height resolution of 0.1 km.

Experiments with a widely spaced grid of test waves showed that at sufficiently great heights, $z > 200$ km, the uhr region of the intense radio wave is sharply defined. Figure 1 shows the corresponding structural feature on the time evolution of the Doppler frequency shift of the test waves, $f_D(\Delta t)$. We see that when the high-power transmitter is turned on, there is an increase in f_D for all the test waves which are reflected at a significant distance from the uhr level. The observed behavior of the Doppler shift corresponds to an average increase in the plasma density due to a slowing of recombination during the heating of thermal electrons and an additional ionization upon the acceleration of epithermal electrons by the field of the electromagnetic pump wave and the excited plasma waves (these nonlinear processes were studied in

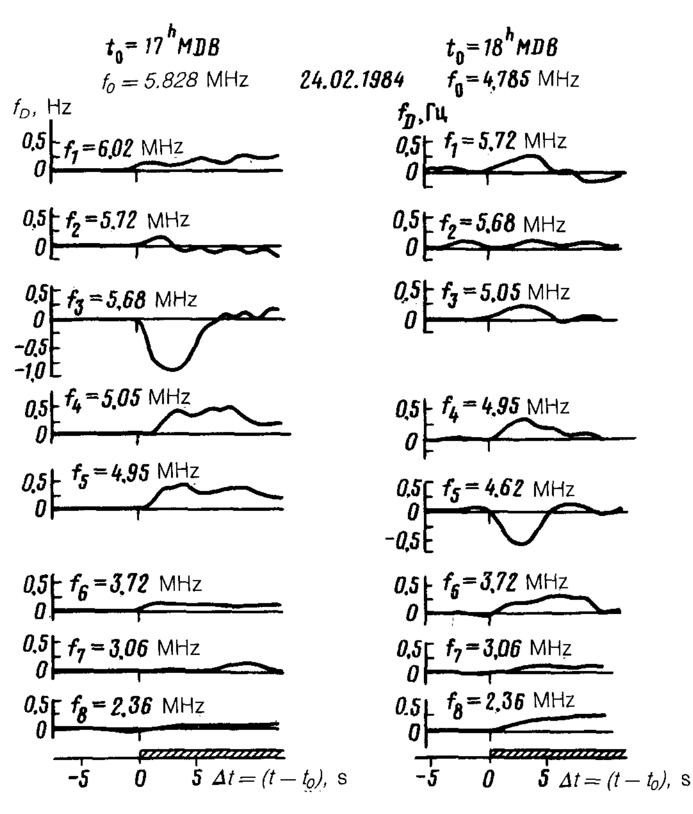

FIG. 1. Dynamics of the Doppler frequency shift of test radio waves for two different frequencies of the intense radio wave, f_0. The hatching shows the time the high-power transmitter is operating.

detail in Refs. 6–9). On the other hand, as can be seen from Fig. 1, a significant negative shift of the frequency f_D arises for the test waves which are reflected in the immediate vicinity of the uhr level of the intense radio wave. This negative shift, which persists for several seconds after the high-power transmitter is turned on, implies a sharp local reduction of the plasma density in the uhr region.

A detailed study of this effect in experiments with a finely spaced grid of test-wave frequencies $f_i \approx f_{\rm uhr}$ showed that negative values of f_D are observed in a narrow frequency band $|\Delta f| = |f_i - f_{\rm uhr}| \sim 30$–$50$ kHz. This observation means that the density perturbations in the density well formed in the uhr region reach values $|\Delta N|/N \approx \Delta f/f_0 \sim 1\%$, and the dimensions of the well along height are, in order of magnitude, $\Delta z \approx L(|\Delta N|/N) \sim 1$ km (here $L \sim 100$ km is the scale dimension of the inhomogeneity of the unperturbed ionosphere).

An important point is that the displacement of plasma is most effective at the center of the heated spot, where the intensity of the intense radio wave is at a maximum; the displacement falls off smoothly toward the edges of the heated spot. As a result, a concave mirror forms for the test waves which are reflected in the region of reduced density. This "plasma reflector" should lead to a focusing of the reflected wave, i.e., to an increase in the amplitude of the received signal. The appearance of a focusing reflector of this type has also been observed experimentally. It can be seen from Fig. 2 that after the high-power transmitter is turned on, the test waves reflected outside the uhr region experience an anomalous attenuation, while the amplitudes of the waves with frequency deviations $|\Delta f| = |f_i - f_{\rm uhr}| < 50$ kHz, which are reflected in the immediate vicinity of the uhr region, increase by a factor of 1.5–2. The bandwidth of this effect agrees well with the results of the Doppler measurements, while the magnitude of the effect agrees well with a theoretical estimate of the focusing of radio waves with the observed values of the perturbation ΔN.

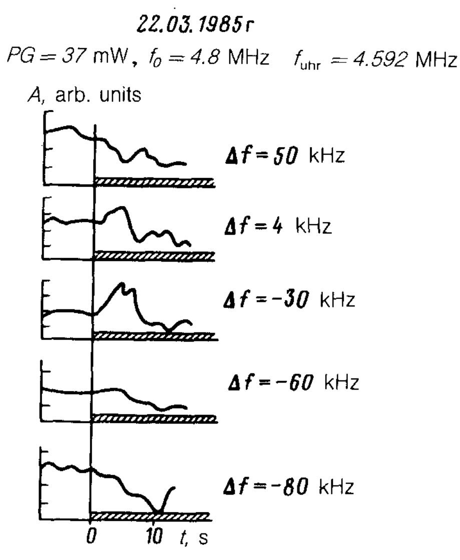

FIG. 2. Increase in the amplitudes of test radio waves reflected from the uhr region. The quantity Δf is reckoned from the uhr level. The hatching shows the time the high-power transmitter is operating.

In summary, the features observed experimentally in the behavior of the Doppler frequency shift and the amplitude of test waves with frequencies $f_i \approx f_{\rm uhr}$ are in complete accordance with the theoretical ideas regarding a local excitation of plasma turbulence in a small neighborhood of the upper hybrid resonance of an intense electromagnetic wave.

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