Preliminary Results of the Artificial Periodic Irregularities Excited by the HAARP HF Heater

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ABSTRACT

First results on the ionospheric sensing by the resonant scattering of HF radio waves by the Artificial Periodic Irregularities (APIs) using HAARP heating facility are presented. The experiments were carried out in May and June, 2014. The processes of both API development and decay were studied.

1. INRODUCTION

The APIs are formed by a standing wave that occurs due to interference between the upward propagating radio waves and that reflected from the ionosphere. The reflection is due either to the ponderomotive force that develops near the wave reflection point in the F region of the ionosphere, or to the electron heating in the D and E regions of the lower ionosphere, that occurred in the antinodes of the standing wave. Current studies of this phenomenon are carried out at the SURA heating facility (56.15 N; 46.11 E). The results of these API studies and the relevant theory are summarized in the monograph [1] and papers [2-4].

On base of the theory some methods for determining a number of parameters of the ionospheric plasma and the neutral atmosphere have been developed.

The processes responsible for the API formation and relaxation (after the incident wave turns off) are excitation and decay of the ion sound wave in the F-region, ambipolar diffusion in the E-region and temperature dependence of the electron attachment rate to the oxygen molecules during three-body collisions in the D-region.

API studies are based on the observation of the Bragg backscattering of the probe radio waves. Sounding probe radio pulses are radiated during the API relaxation stage; amplitudes and phases of scattered pulse signals are measured. The API formation and their sounding by probe radio waves are schematically shown in the Figure 1.

2. OBSEVATIONS and RESULTS

The experiments were carried out at the HAARP heating facility (62.65 N; 145.25 W) from May, 30 till June, 5, 2014 at 19–24 UT. In the HAARP experiment, the processes of both API development and decay were studied. On the first time the similar API studies were carried out by Bakhmet'eva and Belikovich [4] and then by Rietveld et al. [5].

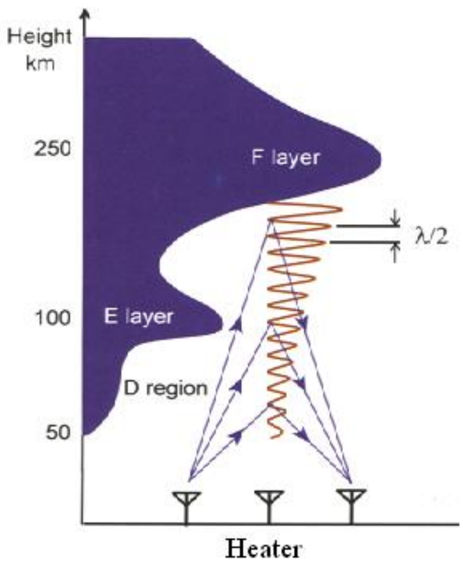

Figure 1. The scheme for the API formation and their sounding by pulsed signals.

The HAARP facility operated with periodicity of 15(30) s. This period consisted of (i) 70 ms pulses separated by 30-ms pauses and short (20 μs) sounding pulsed during first 3 (10) s, and (ii) 20 μs sounding pulses with IPP 20 ms during the following 12 (20) s. The pulse train (i) used for study of the API development and stationary states, while the train (ii) used for the relaxation stage. The X-polarization of the heating and sounding modes was applied. The timing diagram of the heater is shown in the Figure 2.

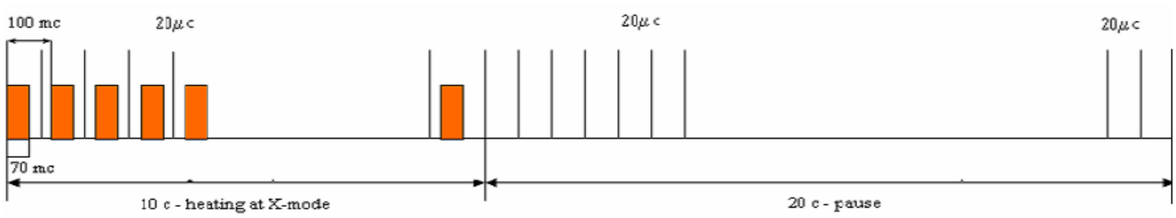

Figure 2. The diagram of the timing of API diagnostics during the pumping and relaxation phases of the plasma striations.

During the experiment with the heating frequencies 4.1, 5.1 and 5.925 MHz, the APIs were observed in the D-region (occasionally), E- and F-regions. A weak scattering on the API in the sporadic-E layer were also detected. An example of signals reflected from the ionosphere and API scattered signals are presented in the Figure 3.One can see signals reflected from F-region (the red thick line), signals reflected from E-region and sporadic-E layer (the thin green-blue line) and API scattered signals in the D-, E- and F-regions.
For comparison we present in the Figure 4 an example of the API scattered signals obtained in the new SURA heating facility experiment on September 3, 2014. The Figure shows that the signals scattered by inhomogeneities pumped during different HF pulses are very similar.
The primary data processing involves calculating the signal phase φ and amplitude A at the each altitude for each heating cycle and approximating their time dependences by linear functions of the form $\ln A(t) = \ln A_0 - t/\tau$ and $\varphi(t) = \varphi_0 + 4\pi V t/\lambda$, where τ characterizes the API relaxation time after switching off the heating transmitter, V is the plasma vertical velocity, λ is the power wave length. Phase deviation of the scattered signal defines vertical

speed plasmas velocity. The temperature and density of the neutral components derived from the altitude dependence of the relaxation time [1].

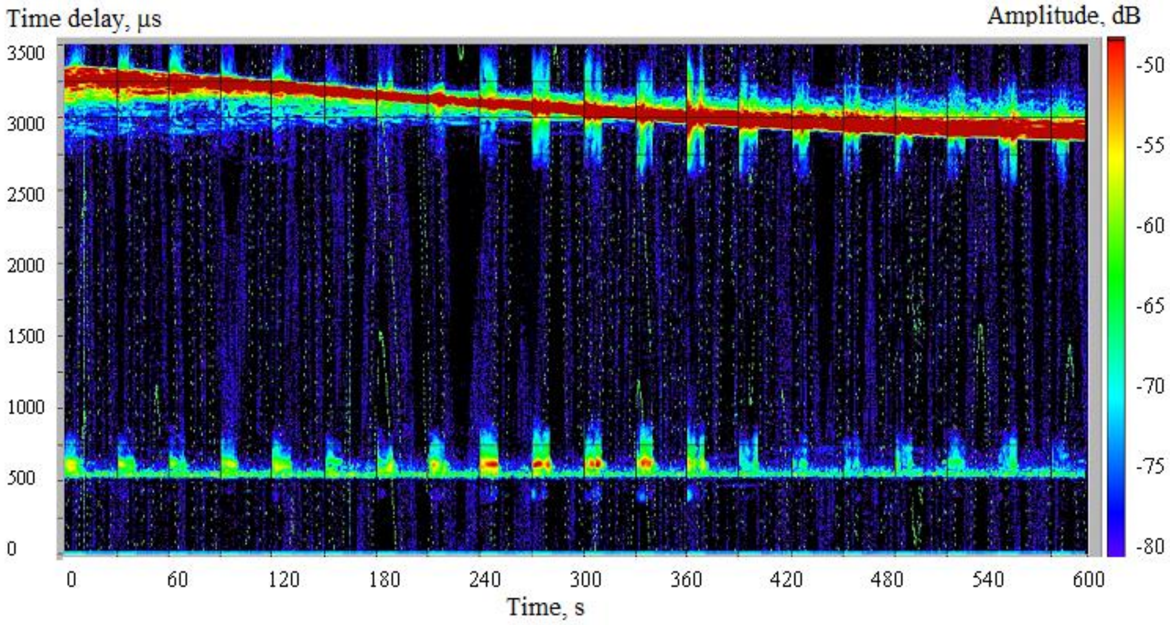

Figure 3. The time-altitude-time delay plot of reflected from the ionosphere and API scattered signals at the frequency 5.925 MHz obtained in June 5, 2014.

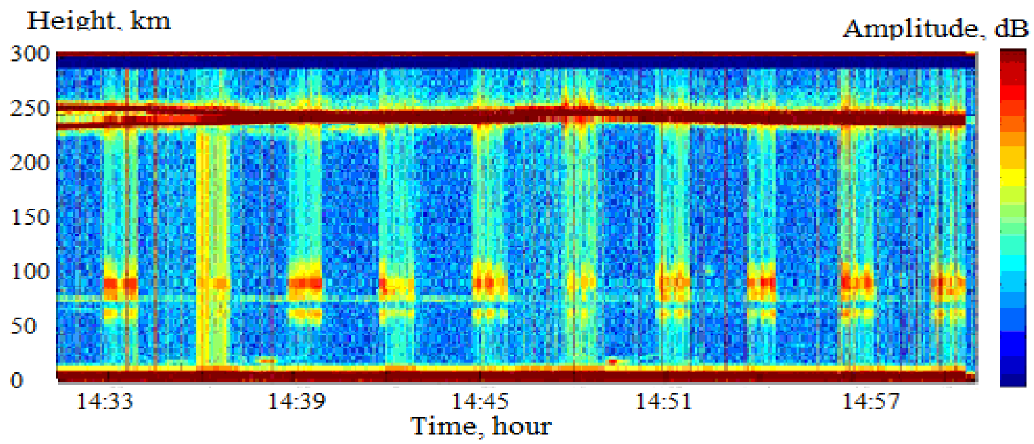

Figure 4. An example of the API amplitude temporal-spatial plot for the SURA facility experiment conducted on September 3, 2014 at the frequency 5.6 MHz.

It is shown that the API relaxation time τ in the E-region it is defined by ambipolar diffusion [1]. In this case, τ is determined by the following formula $\tau = \frac{1}{K^2 D} = \frac{M_i \nu_{im}}{\kappa (T_{e0} + T_{io}) K^2}$, where κ is the Boltzmann constant, is a wave number of the standing wave, is the wave length in the medium, D_a is the ambipolar diffusion coefficient, M is molecular mass of positive ions, T_{e0} and T_{i0} are background (undisturbed) electron and ion temperatures, ν_{im} is the ion-molecule collision frequency. Relaxation time is defined at a decrease of the amplitude of the scattered signal in e time.

As indicated above, API scattered signals at the HAARP were similar to those at SURA. Characteristic times of the API rise and relaxation in the E-region amounted 1-1.5 s, which corresponds to the API theory. Examples of one of the records of the API scattered signal and amplitude for 8 time delays corresponding to the different heights of the E-region are shown in Figures 5 and 6, respectively. It is apparent that the API characteristic relaxation time decreases with the altitude. It is due to the nature of the API diffusional relaxation in the E-region.

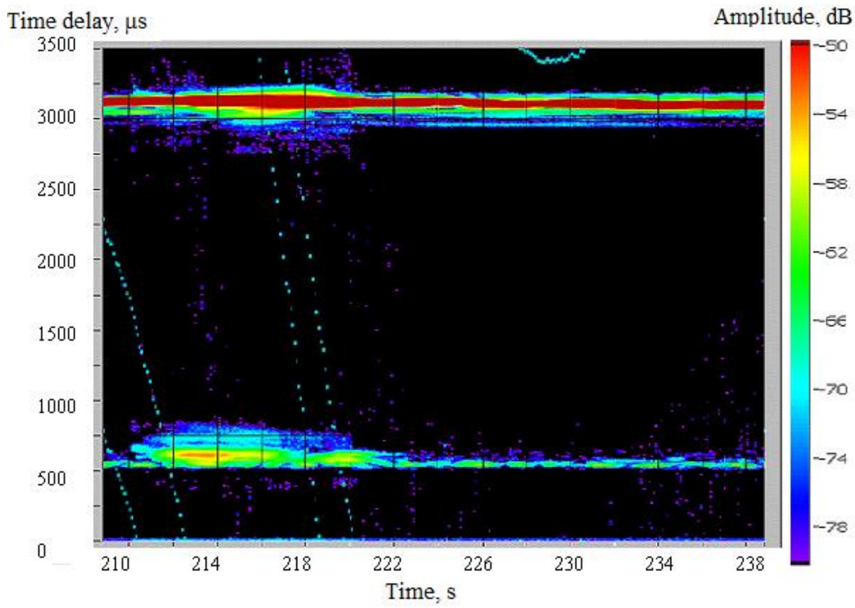

Figure 5. An example of the API scattered signal in the E- and F-regions for HAARP experiment.

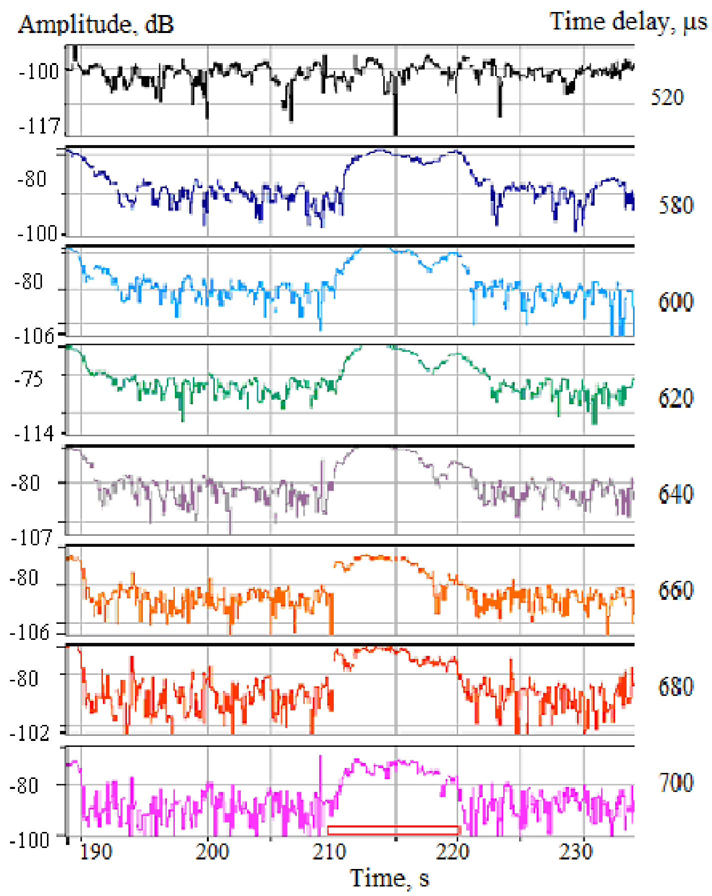

Figure 6. An example of the API development and relaxation at the E-region heights.

3. THE POSSIBILITY of the IONOSPHERE STUDIES by the API TECHNIQUE

Analysis of the space-temporal dependence of the amplitude and the phase of the API scattered signal makes it possible to get information on a number of the ionospheric parameters [1]: (i) altitude distribution of the electron number density, including the interlayer E–F valley (altitudes 60–250 km); (ii) temperature and density of the atmosphere at the E-region altitudes (100–130 km); (iii) velocity of the vertical motion in the D- and E-regions (60–130 km); (iv) turbulent velocity near the turbopause and its altitude (90–110 km); (v) relative number density of negative ions of oxygen and concentrations of atomic oxygen and excited molecular oxygen in the $^1\Delta_g$ state in the D-region (60–90 km), the lower boundary of the region enriched by the atomic oxygen; (vi) ion composition of the sporadic E-layer (85–130 km); (vii) electron and ion temperatures in the F region (200–300 km).
Some of results of the determination of these parameters are presented in the monograph [1] and in recent papers [2-4].
APIs permits one to (i) determine reliably the parameters of internal gravity waves and their spectral characteristics, (ii) study the inhomogeneous structure of the lower ionosphere, including the stratification of the regular E layer, (iii) detect weak sporadic layers of ionization, which are inaccessible for detection by standard ionosonde, and additional layers of the electron density profiles from the lower part of the D-region to the altitude of the F-layer maximum.

4. CONCLUSIONS

In this paper we presented the first results of the API in the E-region observed at HAARP facility. Further, we plan to study in detail the API characteristics in the D- and F-regions.

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