Artificial Periodic Irregularities and Investigations of Sporadic E-Layers

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Abstract

Artificial periodic irregularities (API) formed in the antinodes of the high-power standing radio wave in the Earth's ionosphere are proven to be a powerful tool for studying E-region sporadic ionization (E_s). We present some applications of the API technique for experimental studies of the E_s-layer formations and parameters, and vertical motions in the lower ionosphere. We discuss too our studies of effects of the high-power radio wave pumping on the parameters of sporadic ionization that include a modification of a patchy-type E_s-layer and an ionosphere diagnostics by the API technique. All experiments were carried out at the SURA heating facility (56.1 N, 46.1 E).

1. Introduction

Artificial periodic irregularities (API) of the ionospheric plasma are generated in antinodes of the standing electromagnetic wave formed due to interference of HF radio waves transmitted vertically and reflected from the ionosphere. The API are horizontally aligned with a vertical scale of one-half of the wavelength λ of the transmitted power wave (for more details on the API method and its applications see [1]). When probed with radio waves of the same wavelength, this weak API structure returns an enhanced signal from the altitudes occupied by artificial plasma irregularities, thus giving information about the ionosphere structure and dynamics up to the pump wave reflection level. At SURA facility the receiver and transmitter are located at the same site.
The diagnostics of the ionosphere parameters by API technique bases upon the Bragg scattering of probe radio waves from artificial periodic structure and the measurements of an amplitude and phase of the scattered signal.
There are two ways to satisfy the Bragg resonant backscatter condition, namely, using the same frequency and polarization for the pump and probe waves and using different frequencies and polarization for it. As a rule the API method uses X-mode to avoid generation of plasma instabilities. We present the results of some experiments carried out at the SURA facility. The scheme of the API formation (left panel) and an example of the height-time-amplitude plot (the right panel) of the API scattered signal is shown in the Figure 1.

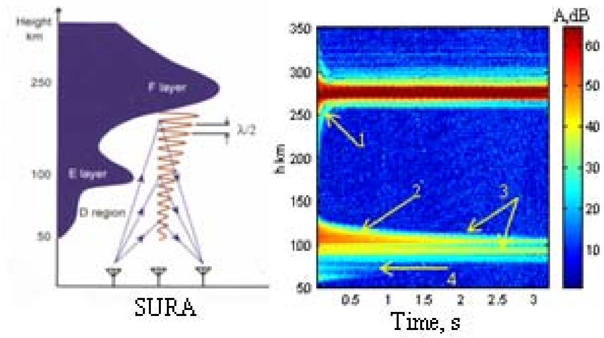

Figure 1. Schematic illustration of the API formation (the left panel) and an example of the height-time-amplitude plot (the right panel) of the API scattered signal: 1 - API signal from the F-region; 2 - API signal from the E-region; 3 - scattered signal from «double» E_s-layer; 4 - API signal from the stratified D-region. The vertical scale on the right panel shows the amplitude A of API scattered signal and horizontal axis is a time in seconds.

APIs are proven to be a powerful tool for studying E-region sporadic ionization (E_s). We present some applications of API technique for experimental studies of E_s-layers.

2. Vertical velocity of the plasma motion in the height range 50-120 km

Vertical motion is one of the component of the general atmospheric circulation. In the height range 50-120 km plasma moves with a neutral particles and its velocity V is equal to the neutrals velocity. V is determined by measuring the phase of the probe radio waves scattered by the API structure after switching off the power heating facility, i.e., at the API relaxation stage. V is related to the phase variation φ of the scattered signal by the equation

$$V = \frac{\lambda}{4\pi} \cdot \frac{d\varphi}{dt}, \qquad (1)$$

where λ is the wavelength of the probe wave and dφ/dt is the phase derivative. A negative V value corresponds to upward motion. We have studied the dynamic and spectral parameters of the V-data [1,2]. Spectra of the vertical plasma velocity demonstrated the presence of wave like motions with amplitudes up to 10m/s. Periods from 5 minutes to a few hours correspond to internal gravity waves and tides.

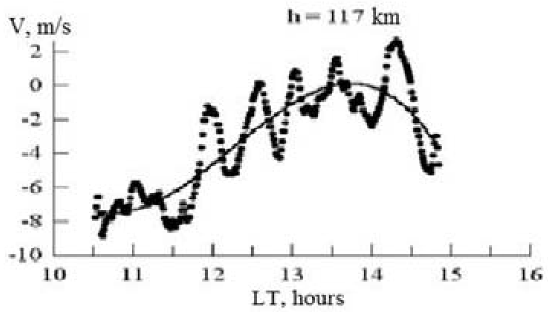

Figure 2. Wave-like time variations of the vertical velocity of the ionospheric plasma.

The estimates based on the vertical velocity measurements show that internal gravity waves can really ensure the wind shears required for the formation of sporadic E-layer.

3. The sporadic E-layer ion composition

One of the API applications is a determination of the masses of the predominant metallic ions at the Es-layer height. This method bases on observations that height dependence of the API relaxation time $\tau(h)$ has a local maximum at the sporadic E-layer location.

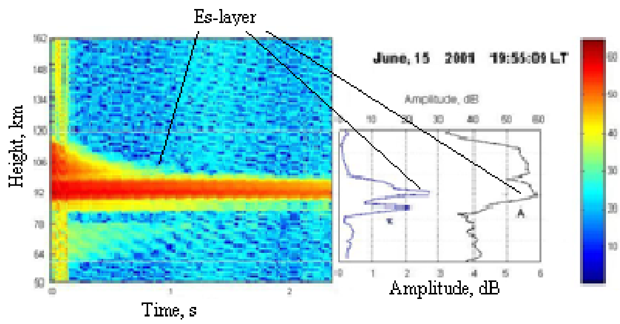

Figure 3. The height-time-amplitude plot of the API scattered signal with the sporadic-E layer reflection (the left panel) and local maxima on the height profiles of the amplitude A and relaxation time.

The heavy (compared to atmospheric molecular ions NO^+ and O_2^+) long-lived metallic ions cause the increase of the relaxation time τ inside Es-layer. In the ionospheric E-region the API decay process after SURA switching is determined by ambipolar diffusion process [1] and API and scattered signal relaxation time τ is proportional to the ion mass (2):

$$\tau = \frac{1}{K^2 D} = \frac{M\, \nu_{im}}{\kappa (T_{eo} + T_{io}) K^2}, \qquad (2)$$

where κ is the Boltzmann constant, $K=4\pi n/\lambda$ is the wave number of the standing electromagnetic wave, λ is the wave length of the SURA facility, n is a refractive index, D is the ambipolar diffusion coefficient. T_{e0} and T_{i0} are the background electron and ion temperatures and ν_{im} is the ion-molecule collision frequency. In the height of the sporadic layer the API is proportional to the mass of the positive metallic ions M formed sporadic E layer and the ion-molecule collision frequency. If the critical frequencies of the E region and the sporadic layer are measured one can estimate the mass of the predominant atomic metallic ion M_M from the equation (3):

$$\frac{\tau_{Es}}{\tau_E} = \left(\frac{n_E}{n_{Es}}\right)^2 \left(\frac{M_M\, \nu_{imM}}{M_A\, \nu_{imA}}\right), \qquad (3)$$

where the rate τ_{Es}/τ_E is determine of "sporadic" and diffusion effects on the API relaxation time; and the rate n_E/n_{Es} characterizes the refractive indices of the E-region a sporadic E-layer at the height of the scattered signal. In the equation 3 indices 'M" and "A" are denoted the masses and the ion-molecule collision frequencies for metallic "M" and atmospheric "A" ions respectively.
Experimental studies of the structure of sporadic ionization layers in the E region carried out at the SURA facility in August 2000, in June 2001, in June and in September 2006 and in May and September 2010. Measuring the height dependence relaxation time $\tau(h)$ we obtained that sporadic E-layer contained ions Fe^+ (2001), Ca^+ and Fe^+ (2000) and Ca^+ ions in the lower E_s-layer (h=90 km) and Fe^+ in the E_s-layer at height about 100 km (2006, 2010).

4. The features of the modification of the sporadic E-layer

In July, 2006 and in August, 2014 we used API technique based on compound heating scheme at the O- or X-mode polarization for pumping (1 min on, 2 min off) with effective radiate power PG=60-100 MW at the frequency of 4.7 MHz [5]. For the first time both mode polarizations of API scattered signal were recorded.

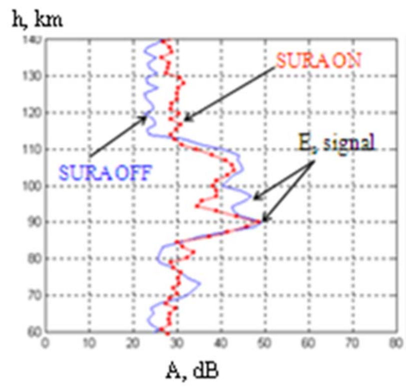

Figure 4. The height modified profile (red line) of the API signal amplitude. API method is capable of seeing sporadic ionization with plasma densities as low as about 1000 cm^{-3}. The violet line show the undisturbed A(h)-profile.

During the heating period API were formed and they scattered probe waves. In the sequently pause, only probe diagnostic waves were emitted. The disturbance of the sporadic E-layer resulted to increasing of amplitudes of all ionospheric scattered signals by 5-20 dB. It was a new effect watched for the first time in the API measurements. The effect occurred for the both mode of the pumping wave and was more expressive for the X-mode. The effect was resonance on frequency. The observed effect of the increasing of amplitudes all ionospheric signals at the pumping period is undoubtedly connected with formation artificial periodic irregularities. The modulation of the natural $N_e(h)$-profile by the artificial periodic structure initiated the growth of the signal amplitudes. In the experiment at increasing of all signals during the pumping there was often a division (stratification) of the sporadic E-layer on two thin close laying layers sub layer. It seems obvious, that these stratifications became more appreciable as a result of growth of amplitudes of all reflexions. The difference of heights such sub layers was in order of 1–3 km. Probably it is caused by formation of the E_s-layer from the different sorts of metallic ions at which heights of the maxima concentration differ on some kilometers.

The interesting phenomenon was observed too. At the pumping of the ionosphere by the X-mode of the powerful wave API scattered signals were observed in the lower ionosphere in the D - and E-regions on reception X-mode, and opposite in the F-region it was observed on reception O-mode. This unusual effect was registered in 20 sessions. Usually it was observed the thick diffusive reflections from E_s-layer at heights of 100-120 km and the thin “underlying” E_s-layers at height of 85-90 km. This is the filtering effect of the sporadic E-layer for different mode of the powerful and probe waves.

5. APIs and diagnostics of weak and transient sporadic E-layers

The long-lived sporadic layers (they can already be called "classical E_s-layers") exist for several hours, often they have a constant height and a horizontal scale from a few to hundreds kilometers and an irregular structure. Application of the API technique to the E_s-layer observation allows us to detect weak layers with critical frequency is less than 1.5 MHz, inaccessible to ionosonde observation.

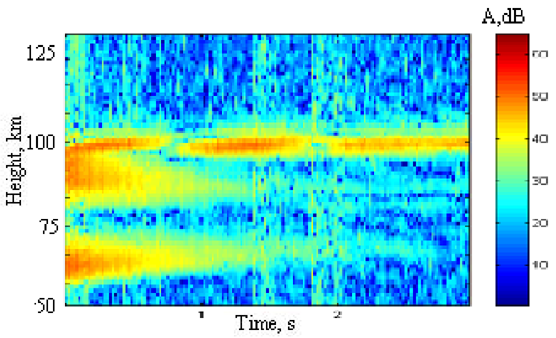

Figure 5. An example of the weak and transient E_s-layer observed by the API technique.

An unusual short-lived sporadic layers, also called transient E_s-layers, whose traces are often recorded on the “Cyclon” ionosonde (Kazan), are also observed by the API method [6]. These traces on ionograms have many common properties with the «classical» sporadic E_s-layer and signs of reflections from meteors, but transient traces do not fully correspond to E_s-traces or meteor echoes. We discuss some features of these layers.

6. References

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7. Acknowledgements

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