Attenuation of Scintillation of Discrete Cosmic Sources in the Case of Non-Resonance HF Heating of the Upper Ionosphere

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1. Introduction

As is known [1], imaging HF riometers represent receiving radio systems consisting of a multi-beam phased array and output radiometer. Systems of the kind are intended for monitoring space-and-time distribution of cosmic radio noise absorption in the lower ionosphere. Today there is a chain of such instruments over the world. Most of these operate at 38.2 MHz. In our earlier studies [2-5] we used these facilities to investigate inhomogeneous structure of the ionospheric F-region by the scintillation technique. Four most powerful discrete cosmic HF sources in the Northern sky, namely, Cassiopeia A, Cygnus A, Taurus A and Virgin A, have been selected as sources of the probe signal.

The present paper is aimed at analyzing the scintillation effect for the radiation from discrete cosmic sources (DCS) during an ionospheric HF modification experiment. The measurement campaign was carried out in November 13, 2012 using the powerful HF transmitter of the HAARP heater (Alaska, USA). During each cycle radiation from Cygnus A transmitted through the HF modified region of the ionosphere was recorded.

2. Description of the experiment

A 64-beam riometer located at Gakona (Alaska, USA) in the immediate vicinity of the HAARP heater was used in the capacity of the receiving system. A detailed description of the riometer can be found in papers [3, 4]. The powerful transmitter radiated O-polarization at 6.9 MHz in the 5 min ON/5 min OFF regime. So, full cycle was equal 10 min. The measuring session lasted 30 minutes from 02:35 to 03:05 UT. Throughout this time interval the radiation from Cygnus A was observed. The main lobe of the heater was pointed at the zenith angle 22 degrees southward within the plane of the magnetic meridian.

During the experiment the HAARP dynasonde operated as well. The data obtained with this instrument characterize the ionospheric condition outside the heating region and are presented in the Table 1.

Table 1. Ionospheric parameters in the unperturbed region.

OFF / ON	OFF1	ON1	OFF2	ON2	OFF3	ON3
UT	02:35 02:40	02:40 02:45	02:45 02:50	02:50 02:55	02:55 03:00	03:00 03:05
LT	16:55 17:00	17:00 17:05	17:05 17:10	17:10 17:15	17:15 17:20	17:20 17:25
z_m, km	249	246	235	236	264	230
f_{pm}, MHz	6.600	6.542	6.337	6.350	7.117	5.633
f_{UHm}, MHz	6.747	6.690	6.490	6.502	7.253	5.805
$f_m(\alpha_0)$, MHz	7.120	7.056	6.835	6.849	7.677	6.075

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Here z_m is the height of the electron density maximum in the ionospheric F-layer, f_{pm} and $f_{UHm} = \sqrt{f_{pm}^2 + f_H^2}$ are the plasma and upper hybrid resonance (UHR) frequencies, respectively, at the height z_m, and $f_m(\alpha_0) = f_{pm} / \cos\alpha_0$ is the maximum frequency of the heating radiation with the incident angle α_0 that can be reflected from the ionosphere. As can be seen, during each heater-on interval the frequency of the HAARP emission exceeded the plasma and UHR frequencies. However, during cycles 1 and 2 it was lower while in cycle 3 higher than the frequency $f_m(\alpha_0)$.

The scintillations were simultaneously registered by two riometer beams. Figure 1 presents fragments of records from the riometer beams through witch Cygnus A passed during the experiment. The black rectangles indicate heater-on intervals. Shown by the thick solid and dashed curves are approximations by 3d-order polynomials each constructed using three values of the signal intensity averaged, respectively, over each heater-off and heater-on interval. As can be seen, the mean intensity for the heater-on intervals is less than that for the heater-off periods. The effect is associated with enhancement of the absorption in the lower ionosphere. The thin solid line shows time variations in the cosmic noise background, $< I_B(t) >$, interpolated by a linear function.

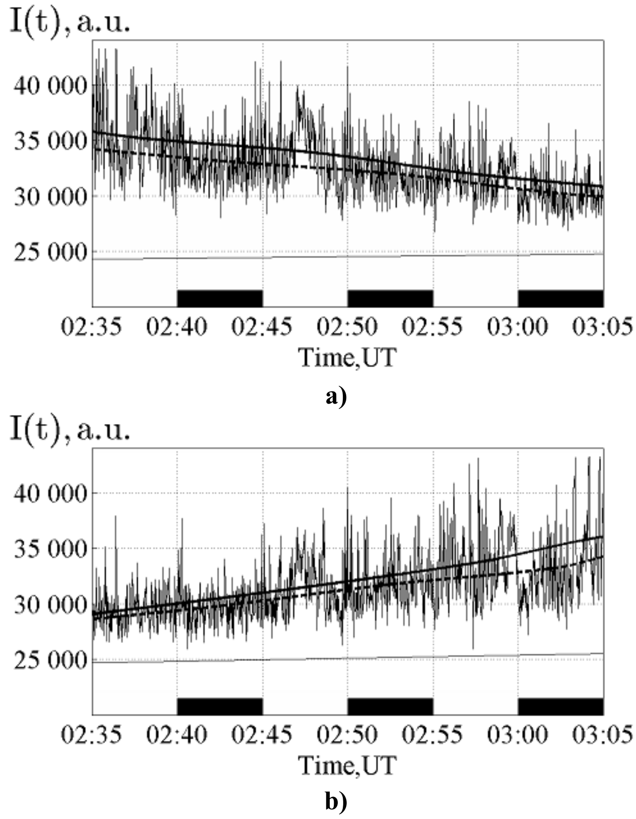

Figure 1. Results of primarily data processing for beam 1 (a) and beam 2 (b). Thick curves show mean intensities for the heater-on (dashed curve) and heater-off (solid curve) intervals. The thin solid line corresponds to the level of mean intensity of the cosmic noise

3. Discussion of results

It should be noted, that Cygnus A was observed in both beams at a low level of the antenna pattern. For this reason, the technique of inter-beam cross-correlation processing the riometric data [5] was used to increase the signal-to-noise ratio, i.e. to decrease the contribution of the cosmic noise fluctuations. As a result, averaged cross spectra of scintillations for each of the heating cycles have been obtained. They are represented in Figure 2. The thick and thin curves correspond to the heater-on and heater-off intervals, respectively. Also shown in the figure are the scintillations indices

$$\beta^2 \equiv < \left(\frac{\delta I(t)}{< I(t) >} \right)^2 > .$$

It is worth noting that during the heater-on intervals the scintillations showed a decrease, which effect is especially pronounced in the first two cycles. The scintillations indices were smaller as well, being equal to $\beta^2_{ON1}/\beta^2_{OFF1} = 0{,}60$; $\beta^2_{ON2}/\beta^2_{OFF2} = 0{,}51$; and $\beta^2_{ON3}/\beta^2_{OFF3} = 0{,}99$.

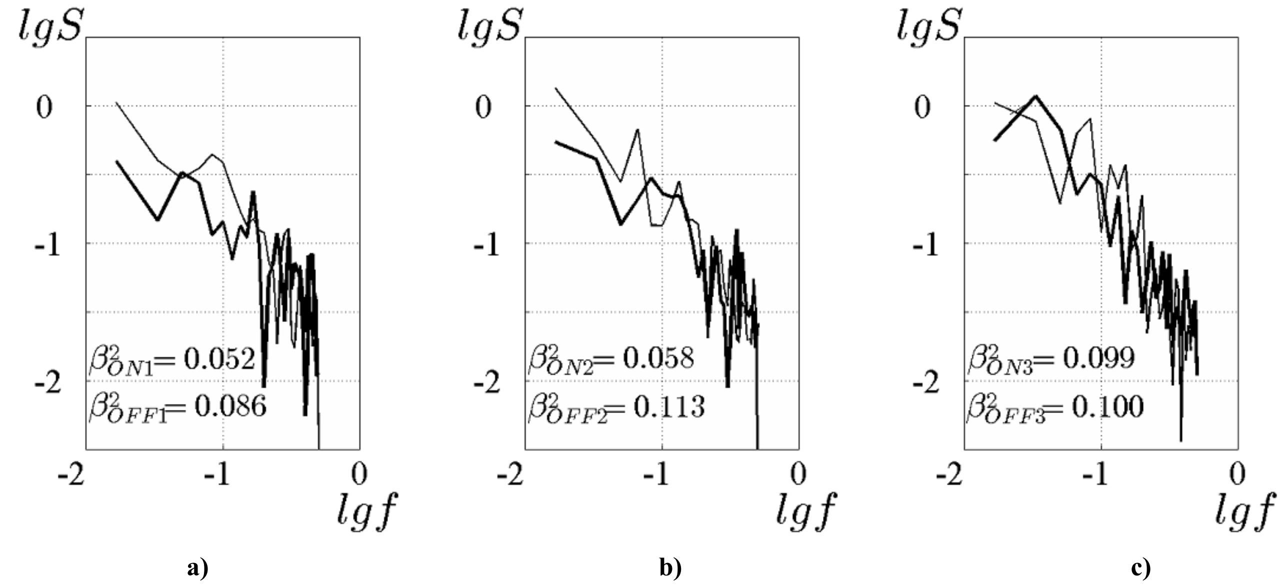

Figure 2. Scintillation spectra averaged separately over the heater-on (thick curves) and previous heater-off (thin curves) intervals for each cycle, namely, 02:35-02:45 UT (a); 02:45-02:55 UT (b); and 02:55-03:05 UT (c)

The observed effect can be explained using the results by A. V. Gurevich [6]. According to these results modification of the ionospheric F-region due to absorption of the powerful HF radiation leads to decrease of the plasma density because of effects of thermal expansion of the heating region and diffusion of electrons from it. Changes in the regular electron concentration, $\Delta N_e \equiv N_e(T_e) - N_e(T_0)$, and electron temperature, $\Delta T \equiv T_e - T_0$, in each point of the modified region are related as

$$\frac{\Delta N_e}{N_{e0}} = -C\frac{\Delta T}{T_0}. \quad (1)$$

Here $N_{e0} \equiv N_e(T_0)$; T_e and T_0 are the electron and neutral particle temperatures, respectively. The factor C magnitude can be selected to be 0.7 according to the results of paper [6]. On the assumption that the non-resonance heating does not increase the relative fluctuations of the ionospheric plasma electron density, variations in the scintillation index in the case under consideration are determined by changes in the mean electron density in the heating region. Accordingly, it makes it possible to estimate relative changes of the electron temperature and electron density in the modified F-region from registrations of the ionospheric scintillations using relation (1):

$$\frac{<N_{ON}> - <N_{OFF}>}{<N_{OFF}>} = -\left(1 - \frac{\beta_{ON}}{\beta_{OFF}}\right); \qquad \frac{<T_{ON}> - <T_{OFF}>}{<T_{OFF}>} = \left(1 - \frac{\beta_{ON}}{\beta_{OFF}}\right)\Big/ C.$$

Substitution of the ratios β_{ON}/β_{OFF} for each of the three measuring cycles yields the following estimates:

$$\frac{<N_{ON1}> - <N_{OFF1}>}{<N_{OFF1}>} \approx -0{,}22; \quad \frac{<T_{ON1}> - <T_{OFF1}>}{<T_{OFF1}>} \approx 0{,}32$$

$$\frac{<N_{ON2}> - <N_{OFF2}>}{<N_{OFF2}>} \approx 0{,}29; \quad \frac{<T_{ON2}> - <T_{OFF2}>}{<T_{OFF2}>} \approx 0{,}41$$

$$\frac{<N_{ON3}> - <N_{OFF3}>}{<N_{OFF3}>} \approx -0{,}005; \quad \frac{<T_{ON3}> - <T_{OFF3}>}{<T_{OFF3}>} \approx 0{,}007.$$

As is known (see, for example, [7]), the strongest attenuation of HF waves (and the strongest heating of plasma) takes place in the deviating region of the ionosphere heights where the wave trajectory is the most refracted, and the wave amplitude increases. Such conditions were realized in the two first heating cycles, while during the 3-rd cycle the frequency of the heating wave exceeded the critical frequency of the F-layer. As a result, the wave propagated along a less deviated trajectory and underwent a less absorption.

4. Conclusions

1. In the course of the experiment on ionospheric modification by the powerful electromagnetic radiation at a frequency exceeding the Langmuir and upper hybrid resonance frequencies, the previously unknown effect of the attenuation of DCS scintillations has been discovered.
2. It has been found that the necessary condition for the effect to be observed is closeness of the heating radiation frequency to that of critical reflection from the ionospheric layer for the given angle of incidence.
3. A theoretical model has been suggested for the explanation of the attenuation of DCS scintillations in the modified ionosphere due to decrease of the mean electron density in the plasma because of the effects of thermal expansion of the modified region and further diffusion of electrons from it.
4. An algorithm has been developed for estimating the relative changes in the mean electron density and electron temperature of the ionospheric plasma within the non-resonance heated region from registrations of the ionospheric scintillations. The respective estimates have been obtained for the experiment of November 13, 2012 with the use of the HAARP heater and Gakona HF riometer.

5. References

1. D. L. Detrick and T. J. Rosenberg, “A phased-array radiowave imager for studies of cosmic noise absorption,” *Radio Sci.*, 1990, 25, p. 325-338.
2. V. G. Bezrodny, O. V. Charkina, V. G. Galushko1, K. Groves, A. S. Kashcheyev, B. Watkins, Y. M. Yampolski, and Y. Murayama, “Application of an imaging HF riometer for the observation of scintillations of discrete cosmic sources,” *Rado Sci.*, 2008, doi:10.1029/2007RS0037.
3. V. G. Bezrodny, O. V. Charkina, Y. M. Yampolski, B. Watkins, K. Groves, “Application of an Imaging Riometer to Investigating Stimulated Ionospheric Scintillations and Absorption of Radiation from Discrete Cosmic Sources,” *Radio Physics and Radio Astronomy, Vol. 1*, № 4, p. 291-302, 2010.
4. O. V. Charkina, “On the Possibility of Recovering Spatial Distribution of Ionospheric Inhomogeneities Using Data from Imaging Riometers,” *Radio Physics and Radio Astronomy* 3(4), 303-309 (2012).
5. V. G. Bezrodny, B. Watkins, O. V. Charkina, and Y. M. Yampolski, “Inter-Beam Cross-Correlation Processing of Ionospheric Scintillations of Discrete Cosmic Sources Observed by Imaging HF Riomiters,” *Radiofizika i Radioastronomia, Volume 18*, № 3, pp.. 224-230, 2010 [In Russian].
6. A. V. Gurevich, “Influence of Radio Waves on the Ionospheric F-region,” Geomagnetizm *i Aeronomiya, Volume VII, (2),* 291-299, 1967.
7. K. Davies, “Ionospheric radio,” London: Peter Peregrinus LTD, 1989. -580 p.