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Nonreciprocity Effect in Quasi-Vertical Sounding of the Ionosphere

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Abstract

The paper considers an automated system for ionosphere sounding by chirp signals. The experimental scheme for quasi-vertical sounding of the ionosphere is described. It has been experimentally shown that there is no reciprocity in the characteristics of the signal propagation when changing the direction of propagation. This effect is explained by the difference in the phase incursion due to the rotation of the polarization plane. The results of numerical simulation are presented.

1 Introduction

The effect of the Earth's magnetic field on the electromagnetic wave propagating in the ionosphere leads to the fact that characteristics of signals propagating in opposite directions can vary. The effects of the magnetic field – magnetoionic splitting and rotation of a polarization plane linearly polarized wave [1]. These effects can change characteristics of signals on oblique radio paths when the direction of sounding changes (receiver and transmitter points are interchanged).

Recently, broadband electronic radio engineering systems using spread spectrum signals (broadband systems) have been intensively introduced in radio communications, radar and radio navigation with HF signals. The use of broadband systems can significantly increase the reliability and noise immunity of communication systems, improve the metrological characteristics of over-the-horizon radar systems with a simultaneous decrease in their mass overall dimensions and power consumption [2]. Promising are ionospheric stations that use broadband chirp signals for the diagnosis of ionospheric radio links [3,4].

In this paper, we consider the effects of nonreciprocity during the propagation of chirp signals on quasi-vertical radio links.

2 The Experimental Scheme and Sounding Equipment

Figure 1 shows a geometry of an experimental radio path. Transmitting and receiving of the signal occurred in points of Yoshkar-Ola city (56°37'12"N, 47°52'12"E) and Kazan city (55°48'N, 49°7'12"E). An azimuth of the radio path "Yoshkar-Ola – Kazan" is ~ 140°. A distance between the points of transmitting and receiving is 121 km. A middle of the radio path has geographic coordinates 56°12'42"N and 48°30'6"E. The blue arrow in Fig. 1 shows a direction of the horizontal component of the Earth's magnetic field vector at the indicated point (azimuth ~ 14°). An angle between the radio path "Yoshkar-Ola – Kazan" and the direction of the horizontal component of the magnetic field was 126°, and an angle between the radio path "Kazan – Yoshkar-Ola" and the direction of the magnetic field was 56°. Both points are equipped with oblique sounding equipment with chirps made by "SITCOM" LLC.

Currently, "SITCOM" LLC manufactures automated two-channel ionosphere sounding equipment (EIS) with chirp signals using standard HF radio equipment "ICOM" (Japan) .

Figure 2 shows a photograph of a single-position version of an automated two-channel ionosphere sounding equipment.

3 Experimental results

The experiment using the described equipment was performed on November 27, 2019 in a two-minute mode: the chirp signal was transmitted at the Kazan point in even minutes, and receiving at the Yoshkar-Ola point.

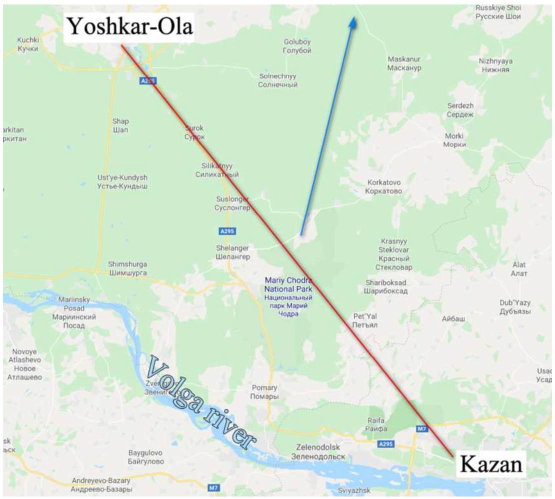

Figure 1. Experiment scheme.

Figure 2. A single-position version of an automated two-channel EIS.

The chirp signal was transmitted at the Yoshkar-Ola point in odd minutes, and receiving – at the Kazan point. The ionosphere was sounding in the frequency range from 2 to 7 MHz with a frequency tuning rate of 90 kHz / s. There was a dipole antenna at Yoshkar-Ola, and a beam-type antenna at Kazan. A linearly polarized signal was transmitted and received at each point. These paths can be defined as quasi-vertical – there is a wave oblique incidence on the layer, but the propagation by the upper beam (Pedersen mode) is not observed.

Figures 3 a), b), c), d) show fragments of ionograms containing frequency ranges with separated magnetoionic components propagating via the F2 layer. Figures 3 a), c) show the radio path “Yoshkar-Ola – Kazan” (1st path) at 8h 33min and at 8h 35min, and Fig. 3 b), d) show the “Kazan – Yoshkar-Ola” radio path (2nd path) at 8h 34min and 8h 36min UTC, respectively. The sounding frequency (in MHz) is plotted on the horizontal axis, and the group delay time (in milliseconds) on the vertical axis in these figures.

As can be seen from these figures, the amplitude A_O of the *O*-component is significantly smaller than the amplitude A_X of the *X*-component for 1st radio path at high frequencies, and smaller than the amplitude of the *X*-component: $A_{O1}<A_{X1}$, $A_{O2}>A_{X2}$ for the opposite propagation of the signal (2nd radio path). A_{O1}, A_{X1} are the amplitudes of the *O*- and *X*-components on the 1st path, respectively, A_{O2}, A_{X2} are amplitudes of *O*- and *X*-components on 2nd path. In addition, there is a change in the ratio of amplitudes between modes. Figure 4 a) shows the frequency dependences of the ratio of amplitudes *O*-components A_{O1} / A_{O1} for ionograms obtained at 8h 33min and 8h 34min (marked 1) and for ionograms obtained at 8h 35min and 8h 36min (marked 2). Figure 4 b) shows the frequency dependences of the ratio of the amplitudes of the *X*-components A_{X1} / A_{X1} for ionograms obtained at 8h 33min and 8h 34min (marked 1) and for ionograms obtained at 8h 35min and 8h 36min (marked 2).

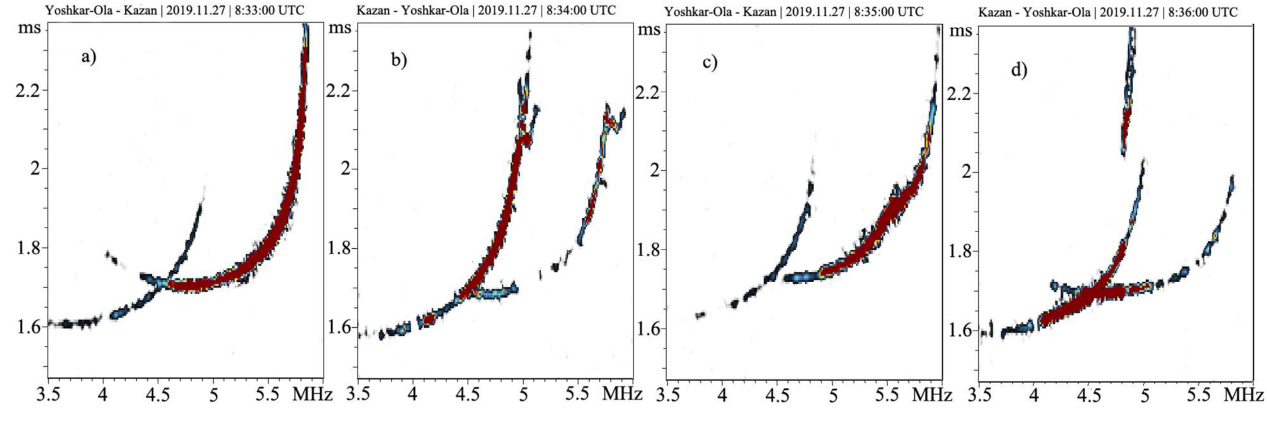

Figure 3. Fragments of ionograms obtained in the experiment. a), c) – the radio path “Yoshkar-Ola – Kazan”; b), d) – the radio path “Kazan – Yoshkar-Ola”.

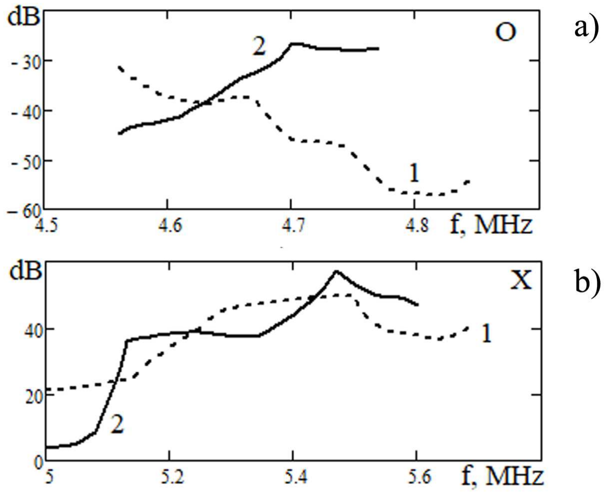

Figure 4. A single-position version of an automated two-channel EIS.

From Fig. 4 a) it is clear that the slope of the frequency dependence can change from decreasing (marked 1) to increasing (marked 2) dependence. Since a linearly polarized wave is emitted, such amplitude variations can be explained by a rotation of the polarization plane during the propagation of an electromagnetic wave in the ionosphere.

The angle of rotation of the wave polarization plane emitted by the transmitter is found by the equation:

$$\vartheta = \frac{e^3}{2\pi c^2 m^2}\frac{1}{f^2}\int_{L_1}^{L_2} H_L N dl \qquad (1)$$

where ϑ is an angle of rotation of the polarization plane when the radio waves propagate along the distance beam L_2-L_1 for an arbitrary direction of radio waves propagation relative to the magnetic field; e and m are charge and mass of the electron; H_L is a component of the magnetic field along the direction of propagation; N is an electron density.

A constancy over the time of sounding the spatial distribution H_L and N is assumed in the experiment. Equation (1) shows that under these assumptions, trajectories of radio waves propagation should differ on radio paths 1st and 2nd.

As indicated in [1], nonreciprocity is associated with the polarization properties of waves and antennas. The change in amplitude in Fig. 4 correspond to changes in the angle of rotation of the polarization plane. These data can be used to estimate changes in the characteristics of the ionosphere plasma using Eq. (1).

4 Conclusion

The paper presents an experimental scheme for the study of nonreciprocity in the ionospheric propagation of radio waves. The experimental results of quasi-vertical sounding of the ionosphere by chirp signals are considered. It is shown that the proposed research scheme is highly sensitive to variations in the characteristics of the propagation environment.

6 Acknowledgements

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7 References

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