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Session 6B Paper 2

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## **HOW ULF/ELF WAVES GENERATED IN UPPER IONOSPHERE BY HAARP CAN PROPAGATE OVER LONG DISTANCE**

It were observed the ULF/ELF signals generated by HAARP heating facility at several sites on the surface of the Earth at a distance of 350-500 km and 7700 km from the source in experiments on artificial excitation of ULF waves in upper ionosphere [1]. In addition there was observed a so-called "spotting" – the signal can be resaved not in all remote sites at the same time. Modal theory of wave propagation in the ionosphere MHD waveguide does not allow exploring the possibility to escape the radiation from the waveguide because the model assumes homogeneity of the structure along the earth's surface [2]. On the other hand, our estimates show that for frequencies above 5-10 Hz on the heights of the ionospheric MHD waveguide satisfies the conditions of geometrical optics. We investigated the possibility of exit the fast magnetosonic (FMS) waves from the ionospheric waveguide using the ray tracing technique. It were used models ionosphere IRI-2016, atmosphere NRLMSISE-00 and the geomagnetic field IGRF-12 picketed up for the experimental conditions [1] for the calculations the FMS waves ray paths in the waveguide. It were obtained three-dimensional distribution of the ULF complex permittivity tensor components in ionospheric plasma on the basis of mentioned models, allowing to analyze the effect of the horizontal gradient of the plasma parameters in the terminator region, the main ionospheric trough, etc. Analysis of the rays tracing pattern can be concluded about the presence characteristic of the refractive waveguide caustics, leading to the complex structure of the wave field in the waveguide. It could be emphasize two kinds of rays deducing the ULF waves from MHD waveguide in the E-layer from which they can reach the surface of the earth. One group of rays comes out at a distance of 400-500 km from the source, and the other at a considerable large distance in the middle of the Pacific Ocean. It should be noted that we constantly monitor the applicability of the geometric optic approximation during the calculations.

[1] Eliasson B., Chang C.-L., Papadopoulos K., J. Generation of ELF and ULF electromagnetic waves by modulated heating of the ionospheric F2 region, *Geophys. Res.*, 2012. Vol. 117, A10320. doi:10.1029/2012JA017935.

[2] Greifinger C., Greifinger P. Theory of Hydromagnetic Propagation in the Ionospheric Waveguide. *J. Geophys. Res.*, 1968. Vol. 73. P. 7473.

