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# High-frequency (HF) wave Propagation in the Small Scale Ionospheric Density Irregularities: Full-wave Simulations

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We investigate the effect of small-scale ionospheric density irregularities, including equatorial plasma bubbles (EPBs), on the propagation of high-frequency (HF, 3–30 MHz) radio waves. Since HF communications used ionospheric wave reflection, these communications are sensitive to ionospheric conditions including density irregularities like EPBs. We first introduce an advanced full-wave simulation code, Petra-M [1][2]. This code is an open-source finite element method platform based on a scalable MFEM finite element library and the accuracy was well verified by several code benchmarking activities. This code has already been widely used in many fusion devices and space plasmas. By adopting the Petra-M, we then examine HF wave propagations in the ionospheric density irregularity structure. In particular, we adopt a high-resolution electron density instability simulation result in the Petra-M code and examine the wave properties inside the equatorial plasma bubble. As shown in Figure 1. we found that small-scale plasma density irregularities significantly alter the direction of the wave in the ionosphere. More specifically, waves can penetrate the plasma bubble structure and reach higher altitudes. Additionally, the waves are trapped in the bubble, and mode conversion from incoming electromagnetic wave to localized electrostatic waves at the electron plasma frequency occurs near the density gradient. We predict that these phenomena - wave trapping and mode conversion - can lead to a reduction in radio power in addition to the ionospheric collisional absorption. We also discuss an application of the numerical investigation of HF wave propagation, such as amateur communications and the High-frequency Active Auroral Research Program (HAARP).

[1] Shiraiwa, S., T. Fredian, J. Hillairet, and J. Stillerman (2016), πScope: Python based scientific workbench with MDSplus data visualization tool, Fusion Engineering and Design, 112, 835–838, doi:10.1016/j.fusengdes.2016.06.050.

[2] Shiraiwa, S., J. C. Wright, P. T. Bonoli, T. Kolev, and M. Stowell (2017), RF wave simulation for cold edge plasmas using the MFEM library, EPJ Web of Conferences, 157, 03048, https://doi.org/10.1051/epjconf/201715703048

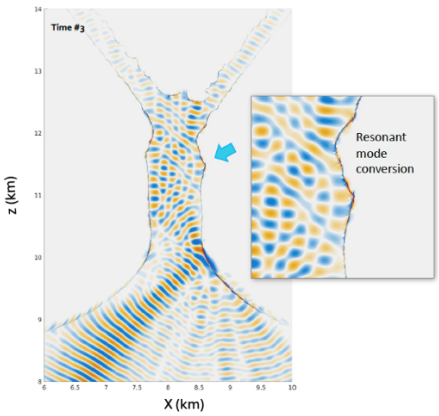


**Figure 1**. Electromagnetic wave propagation in the density bubble