Simulation of Whistler Mode Waves in Magnetospheric Ducts Using FDTD

Raahima Khatun-E-Zannat [(1)], Vijay Harid* [(1)], Mark Golkowski*[(1)] and Oleksiy Agapitov[(2)]
(1) University of Colorado Denver, Colorado, USA; e-mail: raahima.khatun-e-zannat@ucdenver.edu ; vijay.harid@ucdenver.edu; mark.golkowski@ucdenver.edu;
(2) Space Science Laboratory, University of California, Berkley, USA; e-mail: gapitov@ssl.berkley.edu

Radio waves in the ELF/VLF band (3-30 kHz) propagate in the Earth's magnetosphere as whistler mode waves and play an important role in near-Earth space weather. Of particular interest is the generation and propagation of naturally occurring whistler-mode waves known as chorus. Chorus is well-known to play a pivotal role in acceleration and losses of energetic electrons in the radiation belts. As such, an accurate theoretical understanding of chorus wave propagation within the magnetosphere is extremely valuable for the space physics community.

The most common methodology for modeling the propagation of chorus waves within the magnetosphere is ray tracing. Ray theory has been successful for explaining various observed phenomena such as magnetospheric reflection (MR) of lightning-whistlers and the conversion of chorus to hiss. In a smooth magnetosphere, ray theory predicts a linear increase in wave normal angle with latitude for chorus waves generated at the equator. However, observations show that at high latitudes, the wave normal angles become closer to zero and the waves are more parallel propagating than expected from ray tracing in a smooth magnetosphere. This contradiction suggests the requirement of field aligned density irregularities known as "magnetospheric ducts", which can effectively guide whistler-mode waves to high latitudes and enforce parallel propagation. Although ray tracing has been used to model electrically large ducts, the equations are formally invalid for density changes that approach single wavelength scales. Under these considerations, a more sophisticated simulation technique is required to model the propagation of whistler mode waves.

In this work, we use a finite difference time domain (FDTD) model to simulate the propagation of whistler mode waves in a realistic dipole geomagnetic field. In the case of a smooth background plasma, the FDTD code reproduces the linear increase in wave normal angle with latitude as predicted by raytracing. However, once ducts are introduced, the waves show a combination of guiding and refraction that is considerably more complex. The wave normal angle distribution is shown to decrease at high latitudes, which is consistent with spacecraft observations. The ducts also enforce strong spatial modulation and focusing of wave amplitudes which is consistent with recent observations on MMS. The wave effects can be explained through a full wave simulation as a combination of shadowing due to propagation outside the duct, confinement and focusing inside the duct and, wave normal angle conservation. The results suggest that density irregularities can have a significant impact on the distribution of whistler-mode wave power and should be carefully included in global magnetospheric models.

References

[1] Bortnik, J., Thorne, R. M., Meredith, N. P., and Santolik, O. (2007), Ray tracing of penetrating chorus and its implications for the radiation belts, *Geophys. Res. Lett.*, 34, L15109, doi:10.1029/2007GL030040.

[2] Smith, R. L., Helliwell, R. A., and Yabroff, I. W. (1960), A theory of trapping of whistlers in field-aligned columns of enhanced ionization, *J. Geophys. Res.*, 65(3), 815– 823, doi:10.1029/JZ065i003p00815.

[3] Santolík, O., Macúšová, E., Kolmašová, I., Cornilleau-Wehrlin, N., and de Conchy, Y. (2014), Propagation of lower-band whistler-mode waves in the outer Van Allen belt: Systematic analysis of 11 years of multi-component data from the Cluster spacecraft, *Geophys. Res. Lett.*, 41, 2729– 2737, doi:10.1002/2014GL059815.

This paper's copyright is held by the author(s). It is published in these proceedings and included in any archive such as IEEE Xplore under the license granted by the "Agreement Granting URSI and IEICE Rights Related to Publication of Scholarly Work."