Observation of Whistler Wave Resonances in Laboratory Plasma

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Abstract

Standing whistler wave have been investigated in the NRL Space Physics Simulation Chamber. Partial reflection of antenna-launched whistler waves from the chamber end boundaries creates a combination of standing and traveling waves. By controlling the axial magnetic field profile, cyclotron absorption of whistlers can occur before reflection, leaving only the forward propagating waves. By comparing standing wave amplitudes to the forward propagating, cavity Q's in excess of 30 have been observed. Under uniform axial magnetic field conditions, the addition of planar conducting grids near the ends of the plasma column improves reflection and increases the value of Q.

1. Experiment

Whistler waves are ubiquitous in ionospheric and magnetospheric plasmas [1-6]. The whistler mode propagates along the magnetic field as a right-hand elliptically polarized wave with frequency well above the ion cyclotron frequency but below the electron cyclotron frequency. Broadband bursts of electromagnetic noise released during lightning discharges provide a steady terrestrial source of whistlers in space, while within the magnetosphere itself, locally generated whistler modes such as chorus and VLF hiss are abundant. Naturally occurring electromagnetic whistler mode signals frequently propagate down to the surface of the Earth, where they can be detected in the Very Low Frequency (VLF) range.

Numerous advances in understanding the basic whistler wave propagation physics have been made since the earliest observations [1,2]. The waves have been extensively studied in situ using sounding rockets and satellites, via ground-based transmitters and receivers, through theoretical investigations, and they have also been studied in laboratory experiments. Numerous laboratory and space experiments have investigated many aspects of whistler waves, from the basic propagation characteristics to interesting nonlinear effects. Observations of whistlers in the ionosphere and magnetosphere are abundant. Yet, despite the wealth of space and laboratory observations, many important issues regarding the nonlinear behavior of these waves, such as self-ducting of large amplitude whistlers, amplification and secondary whistler emission in the presence of energetic electrons, and whistler-plasma interactions are not yet fully understood.

Experiments in the Naval Research Laboratory's Space Physics Simulation Chamber (SPSC) are focused on investigation of the nonlinear characteristics of whistler waves [7]. The objective of the experimental program is to examine the key physics associated with formation of ducts, propagation of whistler waves with minimal loss, amplification of whistler waves, and whistler-energetic particle interactions. To that end, initial experiments have been performed to investigate the linear propagation characteristics of whistler waves launched by various antenna configurations, including magnetic loop antennas, monopole, and dipole antennas. The experiments are performed in plasma conditions with key dimensionless parameters scaled to those of the inner magnetosphere. While no laboratory device can reproduce the exact space plasma parameters, appropriately scaling to the important dimensionless parameters allows for investigation of the essential underlying physical processes. However, boundary conditions imposed by the finite size of laboratory devices must always be considered.

In the experiments described here, reflection of whistler waves from the electrically conducting end caps of the cylindrical vacuum vessel are investigated. We demonstrate that resonances observed in the whistler wave frequency spectrum are associated with the formation of standing whistler modes with integer numbers of half-wavelengths fitting within the vacuum vessel. By modifying a localized portion of the axial magnetic field from the typical uniform profile, the propagation of the forward traveling wave can be arrested by local cyclotron absorption, allowing for control of wave reflection. Furthermore, the addition of planar conducting grids normal to the axial magnetic field improves wave reflection, increasing the standing wave amplitude. The ability to form whistler wave resonances in the experimental device can be exploited for these investigations in two main fashions: large whistler amplitudes can be excited and the effective wave interaction time with particles can be significantly increased. This paper focuses on details regarding the excitation of such whistler wave resonances.

2. Acknowledgments

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3. References

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