§7. Feasibility Study of Wave-number Measurement of Electron Bernstein Wave with Use of Enhanced forward Scattering Interferometer Technique

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This research project has carried out a feasibility study of a newly proposed microwave-scattering technique to measure wave-numbers of electron gyroscale density fluctuations. Specifically, we have implemented a particle-in-cell (PIC) simulation as a proof-of-principle numerical experiment. One of the physics targets which motivate us to initiate this study is experimental identification of electron Bernstein waves (EBWs).

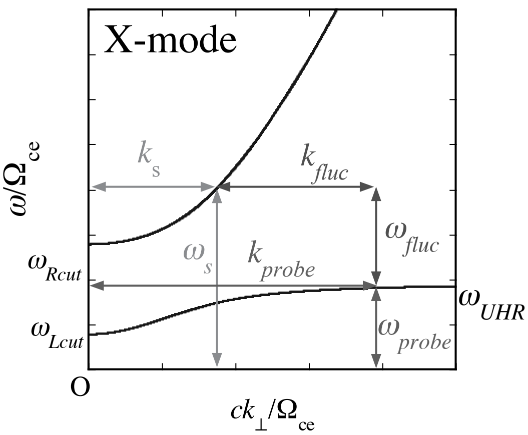

Fig. 1. Relationship among the frequencies ω and wave-numbers k of the probe wave(suffix: probe), the density fluctuation (suffix: fluc) and the scattered wave(suffix: s) in the ω-k space. The bottom solid curve corresponds to the dispersion relation of the slow X-mode and the upper one is that of the fast X-mode.

The basic principle of the microwave-scattering technique was originally proposed by Novik, Piliya et al for aiming to measure amplitude of low frequency fluctuation [1,2]. Our proposal is a modification to the original scheme so that it allows for measuring wave-numbers of density fluctuations in electron cyclotron frequency band. In this method, a slow X-mode probe wave is injected to a target density fluctuation from the high field side. Amplitude and the wave-number of the probe wave get larger exponentially as they approach the upper-hybrid resonance (UHR) layer. If a density fluctuation exists in the vicinity of the UHR layer, the probe wave is scattered as a result of a nonlinear coupling between the probe wave and the density fluctuation. The scattered wave has the summed frequency of those of the probe wave and the density fluctuation. The longitudinal component becomes dominant in the electric field polarization of the scattered wave as a result of the nonlinear coupling. Hence the scattered wave belongs to the fast X-mode branch and propagates toward the low field side, being to be detected in the vacuum region. The relationship among the frequencies ω and wave-numbers k of the probe wave, the density fluctuation and the scattered wave is shown in Fig. 1 together with dispersion relations of the slow X-mode and the fast X-mode. Note that the scattered wave contains information on phase of the target density fluctuation. Therefore, by extracting the phase information for example by a frequency scan of the probe wave, the wave-number of the fluctuation can be obtained.

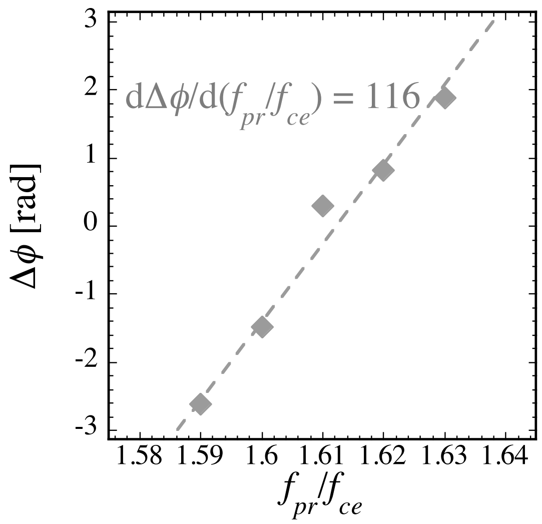

Fig. 2. Relationship between the phase shift of the scattered wave and the frequency of the probe wave normalized by the electron cyclotron frequency.

The following are features of the proposed scheme in addition to those mentioned above: (i) There is no need of system expansion for getting a spatial profile of wave-number of the target density fluctuation. What's necessary is a frequency scan of the probe wave. (ii) Small power requirement for the probe wave; This stems from a consequence of a significant interaction between the probe wave and the target plasma, which is a contrasting difference from the collective Thomson scattering technique. (iii) Good spatial resolution; This is because the region where the scattering takes place is localized in the vicinity of the UHR layer.

In the proof-of-principle numerical experiment using the PIC code, that takes into account a one-dimension in space and three-dimension in velocity space, a probe wave is launched from the high field side into a prepared density fluctuation having the wave-number of $k_\perp \rho_e \sim 0.1$, where $k_\perp$ and ρ_e are the wave-number perpendicular to the background magnetic field and the gyro-radius of the electrons, respectively. Firstly we confirmed that the region where the probe wave amplitude is enhanced is localized around the UHR layer. The width of the region is approximately $10\rho_e$. The wave scattered at the UHR layer is received to pick up its phase at the low field side in the vacuum region.

Figure 2 shows relationship, that is obtained in the numerical test, between the phase shift $\Delta\phi$ of the scattered wave and the frequency of the probe wave normalized by the electron cyclotron frequency f_{pr}/f_{ce}. It can be seen that $\Delta\phi$ is proportional to f_{pr}, which agrees with a prediction by the theory. The wave-number obtained by a method proposed in this research, that combines the probe frequency scan and a measurement of the group delay of a probe wave-packet, agrees well with that of the target density fluctuation we prepared for the numerical test.

[1] K. M. Novik, A. D. Piliya, Plasma Phys. Controlled Fusion **35** (1994) 357-381.
[2] E. Z. Gusakov, et al., Plasma Phys. Controlled Fusion **41** (1999) 899-912.