Simulation Study on Cross Polarization Scattering of Ultrashort-Pulse Electromagnetic Waves

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Abstract

Simulation study on cross polarization scattering of ultrashort-pulse electromagnetic waves due to magnetic field fluctuations is presented. Coupled wave equations for O and X modes in an inhomogeneous magnetized plasma are solved for incident sub-cycle pulses in a one-dimensional model. It is shown that the spectral signals of cross-polarized waves follow the Bragg condition for localized magnetic fluctuations and are insensitive to the Bragg condition for global magnetic fluctuations.

I. Introduction

Reflectometry utilizing microwaves is receiving recent growing attentions as a non-perturbing diagnostic for probing density profiles and fluctuations in magnetically confined plasmas. In tandem mirrors, reflectometry with both O and X modes has been applied to GAMMA 10. The density and magnetic field fluctuations of Alfvén ion cyclotron modes were observed.[2)] More recently, in the GAMMA10 experiment, cross polarization scattering of microwaves has been observed.[3)] Since the cross polarization scattering from the O to X mode (and vice versa) is caused by magnetic fluctuations, it is of importance for probing magnetic fluctuations in magnetically confined plasmas.

In this paper, we study numerically the cross polarization scattering of electromagnetic waves in a magnetized plasma. We here consider an incident wave is an unipolar sub-cycle pulse.[4,5)] As an unipolar sub-cycle pulse can be considered as a set of many monochromatic plane waves with different frequencies, it possesses an advantage that the reflected or transmitted wave carries a lot of information on fluctuations and plasma as compared with the case of a monochromatic incident wave.

II. Model and Basic Equations

In this section, we present our model on cross polarization scattering of electromagnetic waves propagating perpendicular to a constant external magnetic field $\mathbf{B}_0 (= B_0 \mathbf{e}_z)$ in a magnetized plasma. The linear wave equations describing the O and X modes are given by:

$$(\frac{\partial^2}{\partial t^2} + c^2 \nabla \times \nabla \times) \mathbf{E} + \frac{1}{\epsilon_0} \frac{\partial}{\partial t} \mathbf{J} = 0 \tag{1}$$

$$\frac{1}{\epsilon_0} \frac{\partial}{\partial t} \mathbf{J} = \omega_{pe}^2 \mathbf{E} - \frac{1}{\epsilon_0} |\omega_{ce}| \mathbf{J} \times (\mathbf{B}_0 + \tilde{\mathbf{B}}) \tag{2}$$

where $\mathbf{E}$ is the electric wave field, $\mathbf{J}$ is the current density, ω_{pe} the electron plasma frequency, ω_{ce} the electron cyclotron frequency, and $\tilde{\mathbf{B}}$ the low frequency magnetic field fluctuations which is treated to be static so that $\tilde{\mathbf{B}} = B_y \mathbf{e}_y$. We here neglect the effect of low-frequency density fluctuations for simplicity. Lorentz force term $\mathbf{J} \times \tilde{\mathbf{B}}$ in eq.(2) expresses the effects of cross polarization scattering of electromagnetic waves due to the low-frequency magnetic fluctuations.

We restrict ourselves to study one-dimensional wave propagation for simplicity. An equilibrium density profile is assumed to be Gaussian in the x-direction and is given by $n_0(x) = N_0 \exp(-x^2/L^2)$. In the simulation, we assumed $N_0 = 3 \times 10^{12} \mathrm{cm}^3$ i.e. $\omega_{pe}(0)/2\pi \simeq 20\mathrm{GHz}$, $L = 200\mathrm{mm}$ and $|\omega_{ce}| = \omega_{pe}(x = 0)$. The configuration for the present model is shown in Fig.1, where ω_R is the right-hand cutoff, ω_L the left-hand cutoff and ω_{UH} the upper-hybrid frequency. In the configuration, E_z denotes the O mode and E_x and E_y correspond to the X mode. We solve eqs.(1) and (2) by using a finite difference scheme.

III. Numerical Results

In this section, we present computational results of eqs.(1) and (2). The incident wave is a sub-cycle O mode pulse located at $x = -x_0$ and a Gaussian waveform of $\exp(-(x+x_0)^2/L_P^2)$ with L_P=5mm and x_0=600mm is assumed. In this case, the width of the pulse τ_p is about 30ps and $1/\tau_p$ exceeds the maximum of the right-hand cutoff ω_R. We assume that for the magnetic fluctuation $By(x) = B_f \exp[-(x+x_B)^2/L_B^2] * \sin[2\pi(x+x_B)/L_B]$ with $B_f/B_0 = 0.01$. Here, the parameters L_B and x_B characterize the waveform of the fluctuation.

We here perform the computations for following two cases. The first case is that L_B=20mm and x_B=100mm. In Fig.2, we show the waveform of the magnetic fluctuation (dotted line), the density profile (dashed line) and the wave pattern (solid line) of the X mode (E_y) caused by the cross polarization scattering at t=4ns. In this case, the magnetic fluctuation is localized in a relatively narrow region. In Fig.3, we show the spectral signal of the cross-polarized reflected X mode at x=-600mm. We see that the spectral signal consists of two frequency domains and the lower(higher) one is localized in the vicinity of 12.5GHz (22.5GHz). There exist two types of the cross polarization scattering from the O to X mode. One is the forward cross polarization scattering and the other is the backward scattering. We here consider that the lower spectral signal is caused by the backward scattering with the Bragg condition of $k_f = k_O + k_X$ where k_O is the wave number of the O mode, k_X the wave number of the X mode and k_f the wave number of the magnetic fluctuation. On the other hand, the higher spectral signal is considered to be caused by the forward scattering with the Bragg condition of $k_f = k_O - k_X$.

The second case is that L_B=200mm and x_B=0mm. In Fig.4, we show the waveform of the magnetic fluctuation (dotted line), the density profile (dashed line) and the wave pattern (solid line) of the cross-polarized X mode (E_y) at t=4ns. In Fig.5, we show the spectral signal of the cross-polarized reflected X mode. As in this case the magnetic fluctuation exists over the whole plasma region, we see that the spectral signal of the cross-polarized reflected pulse also exists continuously up to 25GHz. In this case, the reflected signal is supposed to be scarcely sensitive to the Bragg condition. The cross-polarized X modes with higher frequencies above 25GHz can transmit through the plasma and are not reflected so that they are not observed.

Summary

We studied numerically the cross polarization scattering of sub-cycle electromagnetic waves due to low-frequency magnetic fluctuations in a magnetized plasma. We showed that the spectral signals of the cross-polarized waves for localized magnetic fluctuations follow the Bragg condition. The signals are supposed to be hardly sensitive to the condition for global magnetic fluctuations.

References

1) A. Mase, M. Ichimura, H. Satake, R. Katsumata, T. Tokuzawa, Y. Ito, H. Hojo, E. J. Doyle, A. Itakura, M. Inutake and T. Tamano : Phys. Fluids **B5** (1993) 1677
2) H. Hojo, A .Mase, M. Inutake and M. Ichimura : J. Plasma Fusion Res. **69** (1993) 1043
3) A. Mase, T. Tokuzawa, N. Oyama, Y. Ito, A. Itakura, H. Hojo, M. Ichimura and T. Tamano : Rev. Sci. Instru. **66** (1995) 821
4) N. Katsuragawa, H. Hojo, H. Honda and A. Mase : *Proc. 7th Int. Symp. Laser-Aided Plasma Diagnostics* (Dec. 1995, Fukuoka) p.345
5) H. Hojo, H. Honda, N. Katsuragawa and A. Mase : to be published in Fusion Design and Technology

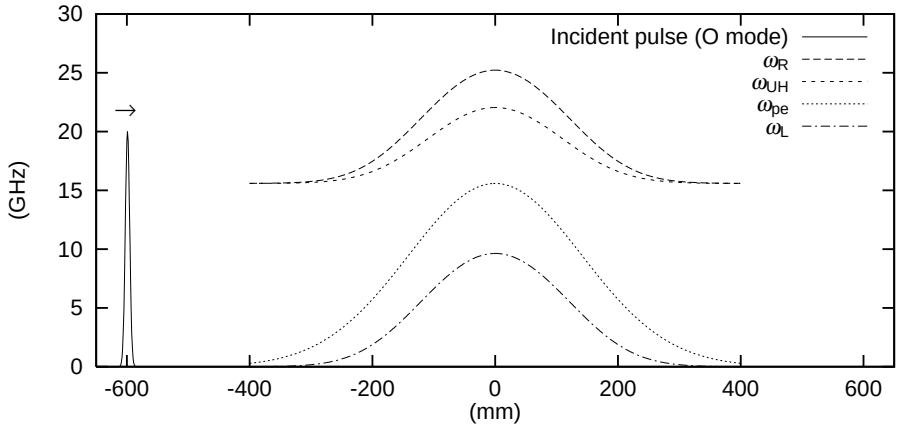

Fig.1 Plasma configurations and an incident O mode pulse

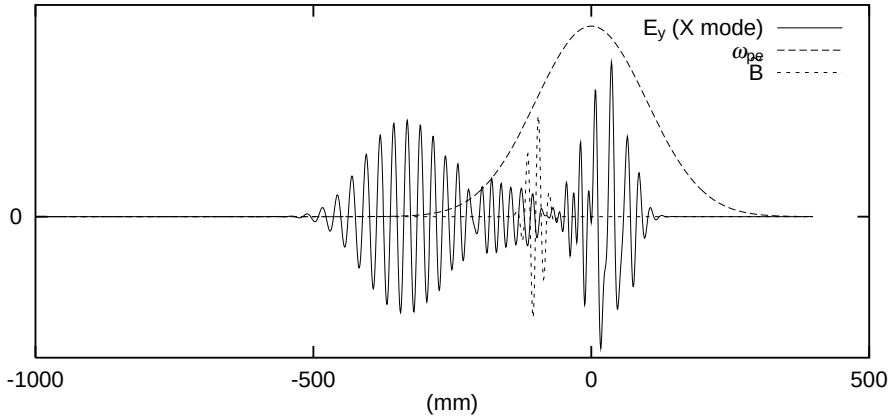

Fig.2 The cross-polarized reflected X mode(E_y, solid line) for an incident O Mode(E_z) with a localized magnetic fluctuation (dotted line) at t=4ns

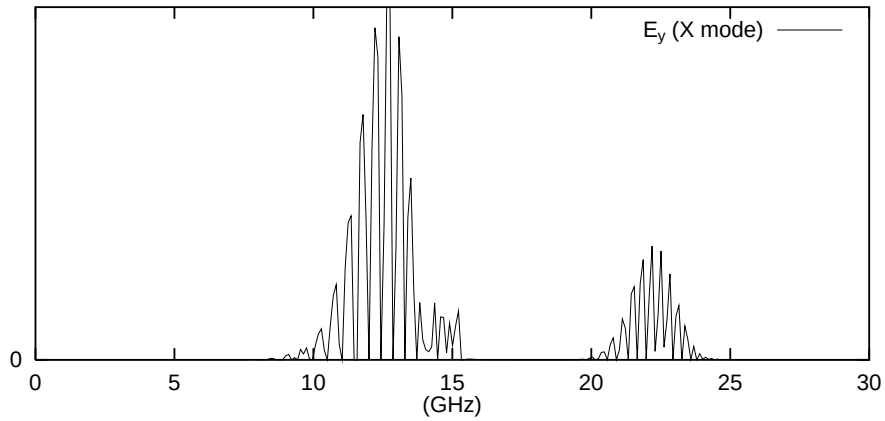

Fig.3 The spectral signal for the reflected X mode (E_y) with the localized magnetic fluctuation of Fig.2

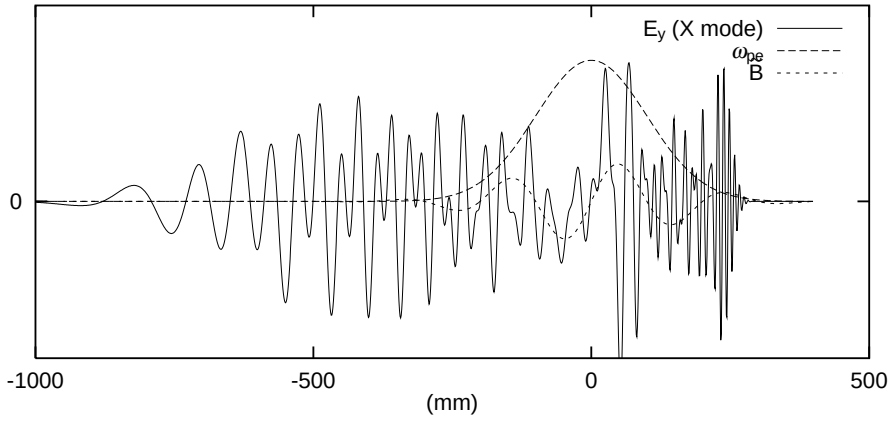

Fig.4 The cross-polarized reflected X mode(E_y, solid line) for an incident O mode(E_z) with a global magnetic fluctuation (dotted line) at t=4ns

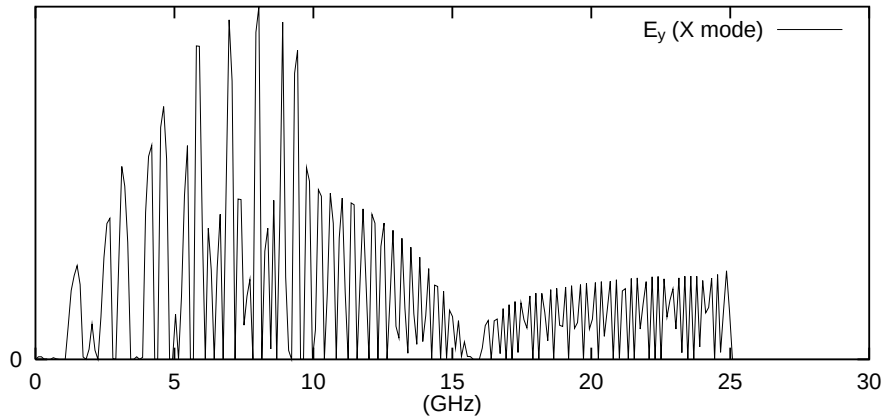

Fig.5 The spectral signal for the reflected X mode (E_y) with a global magnetic fluctuation of Fig.4