Effect of third harmonic generation on the growth rate of Raman forward scattering of an X-mode laser pulse in magnetized cold plasma

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Nonlinear Raman forward scattering (NRFS) in the propagation of an X-mode laser pulse in a magnetized cold plasma channel is analyzed for the third harmonic scattered waves. 3rd harmonic nonlinear wave equation is set up to obtain the coupling equations and dispersion relation of excited upper-hybrid wave. Using Fourier transform and matching condition, the nonlinear growth rate of third harmonic NRFS is analytically calculated. It is shown that unlike the fundamental NRFS, the growth rate of third harmonic NRFS instability increases by increasing the external magnetic field.

Keywords: third harmonic NRFS, X-mode laser pulse, upper-hybrid wave, growth rate.

1 INTRODUCTION

Raman scattering is a parametric instability in which an incident light wave decays resonantly into an electron plasma wave and a scattered light wave [1]. Raman forward scattering (RFS) process in the transversely magnetized plasma includes the decay of an electromagnetic pump wave into an upper hybrid wave and two scattered Stokes/anti-Stokes sidebands. The laser and the sidebands exert the ponderomotive force on plasma electrons driving the excited upper hybrid wave. RFS is an important nonlinear process in laser beat wave and laser wake field accelerators [2]. It decreases the laser-plasma coupling during confinement fusion experiments so the nonlinear saturation of the RFS instability at high pump wave power is also a considerable problem in the high-energy laser-plasma interactions. In addition, RFS plays a dominant role in the evolution of the pulse in distances less than a Rayleigh length. It produces a plasma wave with large phase velocity (near the speed of light) that could accelerate charged particles to high energies [3].

Our purpose in this work is to find the growth rate of RFS instability in the presence of third harmonic generation in a transversely magnetized cold plasma when relativistic and ponderomotive nonlinearities are operative. Physically, this instability arises due to the coupling of density perturbation associated with the upper hybrid electrostatic wave and the oscillatory velocity of plasma electrons at $(2\omega_0, 2k_0)$. This coupling provides density perturbation at the upper-hybrid frequency ω_{UH} shifted by the second harmonic frequency, which when beats with the velocity at ω_0 gives rise to $3\omega_0$ shifted by ω_{UH}. In the case of Raman shifted third harmonic forward scattering, nonlinear current density is generated at $(3\omega_0 \pm \omega_{UH})$ [4]. In order to study this phenomenon, we firstly find the nonlinear wave equation and the nonlinear equation of plasma motions in the laser radiation field to obtain the two coupled equations describing the third harmonic Raman scattering process. Based on our model, we solve the coupled equations to find the growth rate of RFS instability in the magnetized cold plasma. Finally, we investigate the variation of the growth rate with plasma density and static magnetic field.

2 3rd HARMONIC NONLINEAR WAVE EQUATION

Consider the propagation of an X-mode laser pulse with electric field $\boldsymbol{E} = E_0(\hat{x} + i\beta_0\hat{z})e^{i\theta_0}$ at (ω_0, k_0) in a plasma channel immersed in a static magnetic field $B\hat{y}$. Where,

$$\theta_0 = (k_0 z - \omega_0 t), \qquad \beta_0 = \frac{\omega_c}{\omega_0}\frac{\omega_p^2}{\omega_0^2 - \omega_{UH}^2}$$

and ω_p, ω_c, ω_{UH} are the plasma frequency, electron cyclotron frequency, and upper-hybrid frequency, respectively [4]. Using the expansions of continuity equation and equation of motion for plasma electrons, the nonlinear current density is obtained to set up