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# 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 fluctuations is presented. One-dimensional coupled wave equations for the ordinary and extraordinary modes are solved for incident unipolar sub-cycle pulses in an inhomogeneous magnetized plasma. It is shown that the peak frequencies in the frequency-spectral signals of the mode-converted reflected waves are determined from the Bragg resonance condition in the wave numbers of the ordinary mode, the extraordinary mode and the magnetic fluctuations for relatively short-wavelength localized magnetic fluctuations.

Microwave-based diagnostics such as reflectometry are receiving recent growing attentions as a nonperturbing diagnostic for probing density profiles and fluctuations in magnetically confined plasmas.<sup>1-5)</sup> In the tandem mirror GAMMA10, reflectometry with both the ordinary (O) and extraordinary (X) modes has been applied and the density and magnetic field fluctuations of the Alfvén ion cyclotron modes were observed.<sup>1-3)</sup> More recently, cross polarization scattering phenomena of microwaves were observed in GAMMA10<sup>6)</sup> and the Tore Supra tokamak.<sup>7)</sup> Since the cross polarization scattering from the O to X mode or the X to O mode is caused by magnetic field fluctuations, it is of importance for probing magnetic fluctuations in magnetically confined plasmas.

In this Letter, we study numerically the cross polarization scattering of electromagnetic waves due to magnetic fluctuations in a magnetized cold plasma and discuss its diagnostic application for probing the magnetic fluctuations. For incident pulses, we assume unipolar sub-cycle pulses like as ultrashort-pulse reflectometry.<sup>8-10)</sup> 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 waves can carry a lot of information on fluctuations in a plasma as compared with the case of a monochromatic incident wave.

We consider electromagnetic waves (the O and X modes) propagating perpendicular to an constant external magnetic field  $\mathbf{B}_0(= B_0\mathbf{e}_z, \mathbf{e}_z$  being the unit vector in the  $z$ -direction). The linearized wave equations describing the O and X modes are given by

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

$$\frac{1}{\epsilon_0} \frac{\partial}{\partial t} \mathbf{J} = \omega_{pe}^2 \mathbf{E} - \frac{1}{\epsilon_0} |\omega_{ce}| \mathbf{J} \times \left( \mathbf{e}_z + \frac{\tilde{\mathbf{B}}}{B_0} \right) \quad (2)$$

where  $\mathbf{E}$  is the electric wave field,  $\mathbf{J}$  is the current density,  $\omega_{pe} (= \sqrt{e^2 n_0 / m_e \epsilon_0})$  the electron plasma frequency,  $\omega_{ce} (= -e B_0 / m_e)$  the electron cyclotron frequency,  $-e$  the charge of the electron,  $m_e$  the electron mass,  $n_0$  the plasma density and  $\epsilon_0$  the permittivity of vacuum. In the derivation of eq.(2), we assumed that the current density is approximated as  $\mathbf{J} = -en_0 \mathbf{v}_e$ ,  $\mathbf{v}_e$  being the electron flow velocity, as we consider the electromagnetic waves in GHz range. Here  $\tilde{\mathbf{B}}$  denotes the low-frequency magnetic fluctuations that are assumed to be static and  $\tilde{\mathbf{B}} = \tilde{B} \mathbf{e}_y$  is also assumed. As the electromagnetic waves are in GHz range, the fluctuations in MHz or the lower-frequency range can be treated as static. We here neglect the effect of the density fluctuations associated with magnetic fluctuations for simplicity. We see that the Lorentz force term  $\mathbf{J} \times \tilde{\mathbf{B}}$  in eq.(2) expresses the cross polarization scattering of electromagnetic waves due to magnetic fluctuations.

We here restrict ourselves to study one-dimensional wave propagation in the  $x$ -direction. We assume a Gaussian density profile given by  $n_0(x) = N_0 \exp(-x^2/L^2)$ . In the numerical computation, we assumed  $N_0 = 3 \times 10^{12} \text{cm}^{-3}$  ( $\omega_{pe}(0)/2\pi \simeq 15.6 \text{GHz}$ ),  $L = 20 \text{cm}$  and  $|\omega_{ce}| = \omega_{pe}(x=0)$ . We show the configuration for the present model in Fig.1, where the profiles of the right-hand cutoff  $\omega_R$  (dashed line), the upper-hybrid frequency  $\omega_{UH}$  (dotted line),  $\omega_{pe}$  (solid line) and the left-hand cutoff  $\omega_L$  (chain line) are shown. In the present configuration,  $E_z$  expresses the O mode and  $E_x$  and  $E_y$  correspond to the X mode. We here consider an unipolar O-mode pulse located at  $x = x_0$  as the incident pulse at  $t = 0$ . The waveform of the incident pulse is assumed to be a Gaussian profile given by  $E_z(x, t=0) = E_0 \exp[-(x - x_0)^2 / L_P^2]$  with  $L_P = 0.5 \text{cm}$  and  $x_0 = -60 \text{cm}$ . In this case, the

pulse width  $\tau_p (= 2L_P/c, c$  being the speed of light) is about 33ps and  $1/\tau_p$  exceeds the maximum of  $\omega_R/2\pi$ . The incident pulse is also shown by a solid line in Fig.1. The waveform of the magnetic fluctuations is given by  $\hat{B}(x) = B_f \exp[-(x - x_B)^2/L_B^2] \sin[k_B(x - x_B)]$  where the parameters  $L_B, k_B$  and  $x_B$  characterize the profile of the fluctuation. We solve eqs.(1) and (2) by using a finite difference scheme.

We now present the computational results of eqs.(1) and (2). We first consider a magnetic fluctuation with  $k_B=3\text{cm}^{-1}, L_B=2\text{cm}$  and  $x_B = -10\text{cm}$ . In Fig.2, we show the wave profile of the magnetic fluctuation by a dotted line. The magnetic fluctuation is localized in a relatively narrow region in the vicinity of  $x_B = -10\text{cm}$ . In the figure, we also show the density profile  $n_0(x)$  by a dashed line and the wave profile ( $E_y(x)$ ) of the X mode caused by the cross polarization scattering at  $t = 4\text{ns}$  by a solid line. As the wave equations (1) and (2) are linear, the amplitude of the mode-converted X mode is proportional to the amplitude  $B_f$  of the magnetic fluctuations as well as the amplitude  $E_0$  of the incident O-mode pulse. However, at present we are concerned with not the amplitude of the mode-converted wave but the structure of the frequency spectrum. In Fig.3, we show the frequency-spectral signal of the mode-converted X mode ( $E_y(x)$ ) that is reflected and received at  $x = -60\text{cm}$  by using a fast Fourier transform(FFT). We see that the spectral signal consists of two frequency domains. The lower-frequency domain is located roughly from 10GHz to 15GHz and the higher one is located roughly from 20GHz to 24GHz. In order to seek the peak frequencies of the spectral signal more precisely, we show the frequency-spectral signal of the mode-converted X mode obtained by a maximum entropy method(MEM) in Fig.4. We see that the spectral signal by the MEM is more

sharply distributed than that by the FFT. From Fig.4, we find that the peak frequencies of the spectral signal are 12.4GHz and 22.5GHz.

We hereafter show that the spectral signal obtained in Fig.3 or 4 is caused by the cross polarization scattering based on the Bragg resonance condition with respect to the wave numbers among the O and X modes and the magnetic fluctuation. The local wave number  $k$  is a function of  $x$  and frequency  $\omega$ , as the density is non-uniform, and the wave number  $k_{fl}$  of the magnetic fluctuation is approximately given by  $k_{fl} = k_B$ . Let us assume that the cross polarization scattering from the O to X mode takes place at  $x_B = -10\text{cm}$ . There exist two types of the cross polarization scattering from the O to X mode. That is, one is the forward scattering and the other is the backward scattering. If we assume that the first peak of the spectral signal in Fig.4 is due to the backward scattering with the Bragg resonance condition of  $k_O(\omega_1, x_B) - k_{fl} = -k_X(\omega_1, x_B)$ , we obtain  $\omega_1/2\pi=12.3\text{GHz}$  from this Bragg condition. The value is very close to 12.4GHz obtained from Fig.4. Therefore, we conclude that the first peak of the spectral signal in Fig.4 is caused by the backward cross polarization scattering with the Bragg resonance condition of  $k_O - k_{fl} = -k_X$ . On the other hand, the second peak of the spectral signal in Fig.4 is supposed to be due to the forward scattering with the Bragg resonance condition of  $k_O(\omega_2, x_B) - k_{fl} = k_X(\omega_2, x_B)$  and we obtain  $\omega_2/2\pi=22.3\text{GHz}$ . This value is also very close to 22.5GHz obtained from Fig.4. In this case, the forward-scattered X mode is reflected by the right-hand cutoff  $\omega_R$ . Therefore, we also conclude that the second peak of the spectral in Fig.4 is caused by the forward cross polarization scattering with the Bragg resonance condition of  $k_O - k_{fl} = k_X$ .

We here note that the above arguments concerning with the cross polarization scat-

tering from the O to X mode can be easily explained by Fig.5, which determines the relationship between the frequencies  $\omega$  of the mode-converted waves and the wave number  $k_{fl}$  of the magnetic fluctuation. In Fig.5,  $k_O(\omega, x_B) + k_X(\omega, x_B)$  is expressed by solid lines,  $k_O(\omega, x_B) - k_X(\omega, x_B)$  by a dashed line and  $k_X(\omega, x_B) - k_O(\omega, x_B)$  by a chain line. As we have two branches for the X mode in the present plasma model, we see that there exist generally four processes in the cross polarization scattering for a given  $k_{fl}$ . From the figure, we see that at most of three processes can take place in the cross polarization scattering. In the case of  $k_{fl} = k_B = 3\text{cm}^{-1}$  shown in Fig.2, though we have the third solution  $\omega=18.2\text{GHz}$  in addition to  $\omega/2\pi=12.3\text{GHz}$  and  $22.3\text{GHz}$ , however, we find that the spectral signal of the mode-converted X mode does not exist near  $\omega/2\pi=18.2\text{GHz}$  as shown in Fig.3 and 4. This is because the mode-converted X mode with  $\omega/2\pi=18.2\text{GHz}$  is a forward scattered wave and is almost absorbed at the upper-hybrid resonance  $\omega_{UH}$  (In this case, there occurs no reflection of the X mode at the upper-hybrid resonance<sup>11)</sup> and the transmission coefficient of the X mode crossing the upper-hybrid resonance is very small as  $k_X\Delta \gg 1$ ,  $\Delta$  being the distance between the upper-hybrid resonance and the right-hand cutoff<sup>11)</sup>.) The hatched region shown in Fig.5 denotes the evanescent region (between  $\omega_{UH}$  and  $\omega_R$ ) of the X mode. Therefore, we see that the mode-converted X mode with  $\omega=18.2\text{GHz}$  is never observed at  $x = x_0$ .

To make clear the above arguments, we next calculate the case of  $k_{fl} = k_B = 9\text{cm}^{-1}$ ,  $L_B = 2\text{cm}$  and  $x_B = -10\text{cm}$ . From Fig.5, we suppose that in this case only one solution with  $\omega/2\pi = 26.0\text{GHz}$  among three solutions in the mode-converted X modes can be observed in the reflected-wave signal, and that other two solutions are almost absorbed



at the upper-hybrid resonance  $\omega_{UH}$  and are not observed. In Fig.6, we show that the frequency-spectral signal of the mode-converted X modes received at  $x = x_0$  by the MEM for the case of  $k_B = 9\text{cm}^{-1}$  with  $L_B = 2\text{cm}$  and  $x_B = -10\text{cm}$ . We find only one peak in the spectral signal of the reflected X mode as we already expected, and the peak frequency is  $\omega/2\pi = 25.7\text{GHz}$ . We see that it is very close to  $\omega/2\pi = 26.0\text{GHz}$  estimated from Fig.5 under the assumption of  $k_{fl} = k_B$ .

As the conclusion, we can say that the peak frequencies in the spectral signals of the mode-converted waves are determined from the Bragg resonance condition in the wave numbers among the O and X modes and the magnetic fluctuations for relatively short-wavelength localized magnetic fluctuations. However, for a case of long-wavelength global magnetic fluctuations, we find that the spectral signal of the mode-converted wave are seemed to be insensitive to the Bragg resonance condition in the wave number. In Fig.7, we show the wave profile ( $E_y(x)$ , solid line) of the X mode converted from the O mode at  $t = 4\text{ns}$  for the case of  $k_B = 0.3\text{cm}^{-1}$ ,  $L_B = 20\text{cm}$  and  $x_B = 0\text{cm}$ . In the figure, the density profile  $n_0(x)$  (dashed line) and the wave profile of the magnetic fluctuation (dotted line) are also shown. In Fig.8, we show the frequency-spectral signal of the mode-converted reflected X mode received at  $x = x_0$  by the FFT. In this case, we see that the spectral signal of the reflected X modes exists continuously up to 25GHz and we cannot find any sharp peaks in the spectral signal. (In this case, the MEM is also failed to yield any plausible results.) One reason for this is that the position at which the cross polarization scattering takes place does not become definite as the magnetic fluctuation is global.

Finally, we performed the simulation study on cross polarization scattering of ultrashort-

pulse electromagnetic waves due to magnetic fluctuations. We solved one-dimensional coupled wave equations for the O and X modes in an inhomogeneous cold plasma and investigated the cross polarization scattering process from the O to X modes due to magnetic fluctuations for incident sub-cycle O-mode pulses. We showed that the peak frequencies in the frequency-spectral signals of the mode-converted waves are determined from the Bragg resonance condition in the wave numbers among the O and X modes and the magnetic fluctuations for relatively short wavelength localized magnetic fluctuations.

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## 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, H. Hojo, M. Kobayashi, N. Oyama, L. G. Bruskin, E. J. Doyle, T. Tokuzawa, A. Itakura, M. Ichimura and T. Tamano: *Diagnostics for Experimental Thermonuclear Fusion Reactors*, ed. P. Stott et al. (1996,Plenum) p.153.
- 4) C. Laviron, P. Millot and R. Prentice: Plasma Phys. Control. Fusion **37** (1995) 975.
- 5) M. Nagatsu: J. Plasma Fusion Res. **71** (1995) 132; references cited therein.
- 6) A. Mase, T. Tokuzawa, N. Oyama, Y. Ito, A. Itakura, H. Hojo, M. Ichimura and T. Tamano : Rev. Sci. Instrum. **66** (1995) 821.
- 7) X. L. Zou, L. Colas, M. Paume, J. M. Chareau, L. Laurent, P. Devynck and D. Gresillon: Phys. Rev. Lett. **75** (1995) 1090.
- 8) C. W. Domier, N. C. Luhmann, Jr., A. E. Chou, W. M. Zhang and A. J. Romanowski: Rev. Sci. Instrum. **66** (1995) 399.
- 9) B. I. Cohen, B. B. Afeyan, A. E. Chou and N. C. Luhmann, Jr.: Plasma Phys. Control. Fusion **37** (1995) 329.
- 10) N. Katsuragawa, H. Hojo, H. Honda and A. Mase : *Proc. 7th Int. Symp. Laser-Aided Plasma Diagnostics* (Dec. 1995, Fukuoka) p.345.
- 11) T. H. Stix: *The Theory of Plasma Waves* (McGraw-Hill,1962) Chap.10.

## Figure Captions

- Fig.1: The schematic view of the simulation model, where the profiles of the right-hand cutoff  $\omega_R$  (dashed line), the upper-hybrid frequency  $\omega_{UH}$  (dotted line), the electron plasma frequency  $\omega_{pe}$  (solid line) and the left-hand cutoff  $\omega_L$  (chain line) are shown. The incident O-mode pulse (solid line) is localized at  $x = x_0 = -60$  cm.
- Fig.2: The wave profile ( $E_y$ , solid line) of the X mode converted from the O-mode ( $E_z$ ) by a localized magnetic fluctuation (dotted line) at  $t = 1$  ns, where  $k_B = 3\text{cm}^{-1}$ ,  $L_B = 2\text{cm}$  and  $x_B = -10\text{cm}$ . The density profile (dashed line) is also shown.
- Fig.3: The frequency-spectral signal of the mode-converted X mode ( $E_y$ ) received at  $x = -60\text{cm}$  by the FFT for the localized magnetic fluctuation of Fig.2.
- Fig.4: The frequency-spectral signal of the mode-converted X mode ( $E_y$ ) by the MEM for the localized magnetic fluctuation of Fig.2. The two peak frequencies are  $\omega/2\pi = 12.4$  and  $22.5\text{GHz}$ .
- Fig.5: The frequencies of the mode-converted X modes vs. the wave number of the magnetic fluctuation. For the Bragg resonance condition,  $k_X + k_O$  (solid line),  $k_O - k_X$  (dashed line) and  $k_X - k_O$  (chain line) at  $x = x_B = -10\text{cm}$  are shown. The hatched region is the evanescent region of the X mode.
- Fig.6: The frequency-spectral signal of the mode-converted X mode ( $E_y$ ) by the MEM for the magnetic fluctuation with  $k_B = 9\text{cm}^{-1}$ ,  $L_B = 2\text{cm}$  and  $x_B = -10\text{cm}$ . Only one peak frequency is observed at  $\omega/2\pi = 25.7\text{GHz}$ .

Fig.7: The wave profile ( $E_y$ , solid line) of the X mode converted from the O-mode ( $E_z$ ) by a global magnetic fluctuation (dotted line) at  $t = 4\text{ns}$ . where  $k_B = 0.3\text{cm}^{-1}$ ,  $L_B = 200\text{cm}$  and  $x_B = 0\text{cm}$ .

Fig.8: The frequency-spectral signal of the mode-converted X mode ( $E_y$ ) received at  $x = -60\text{cm}$  by the FFT for the global magnetic fluctuation of Fig.7.

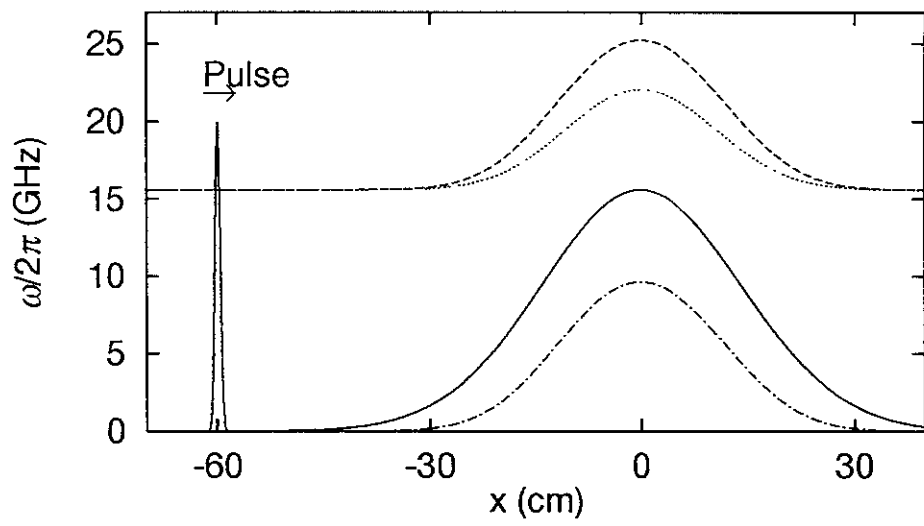


Fig.1

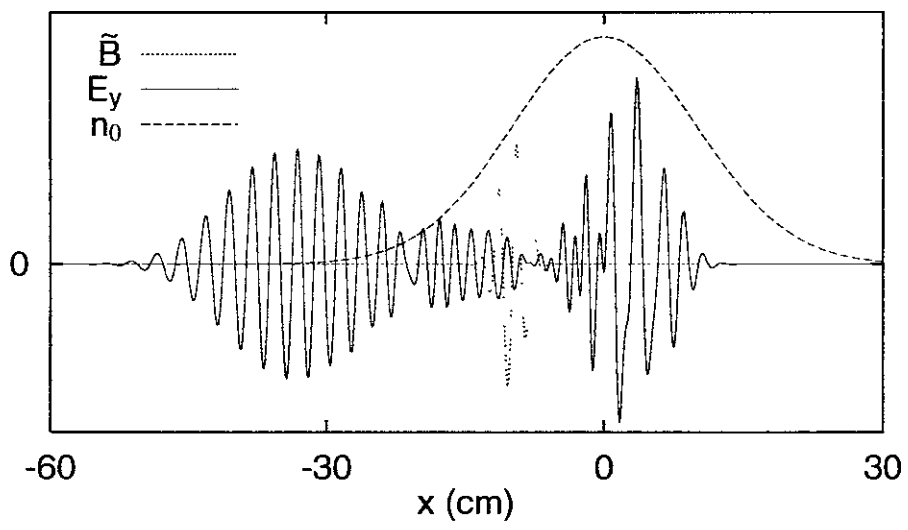


Fig.2

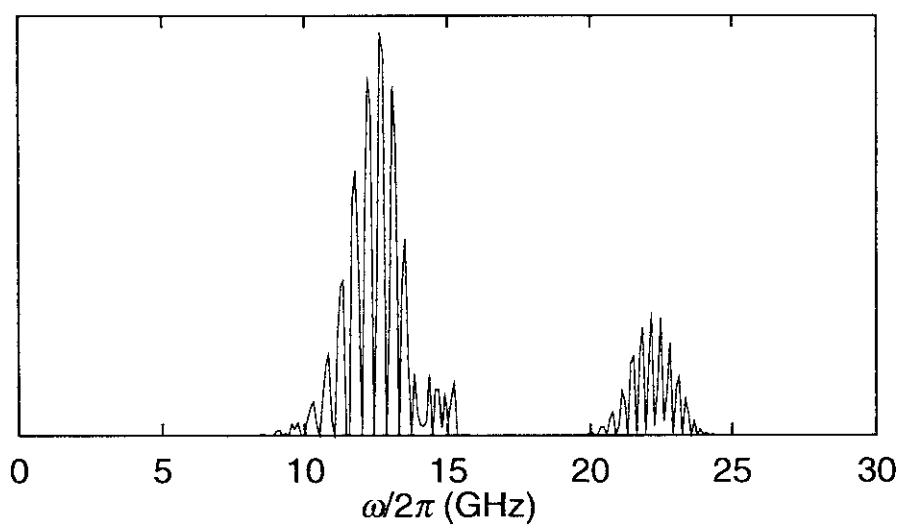


Fig.3



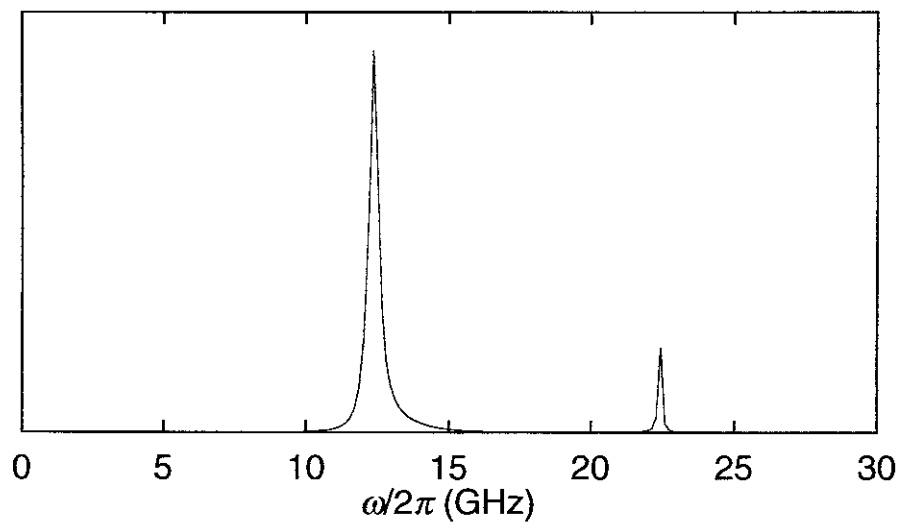


Fig.4

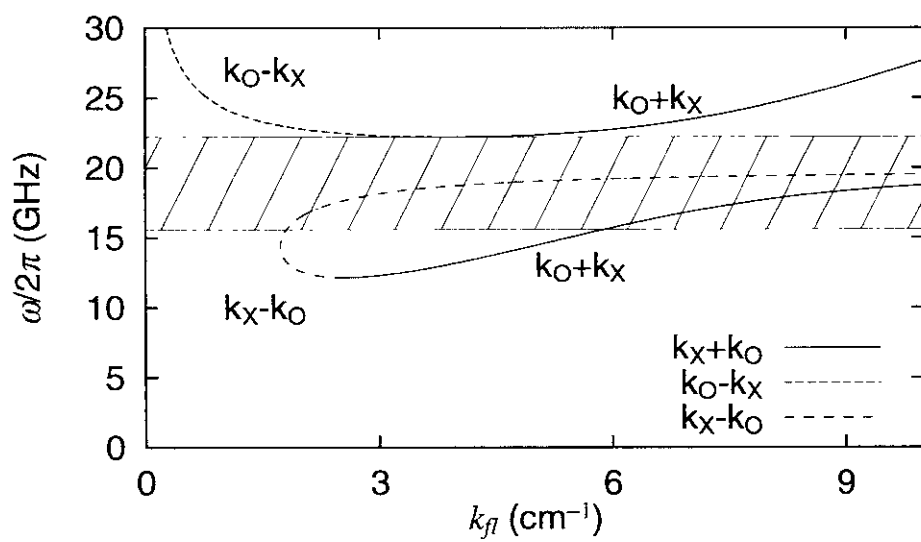


Fig.5

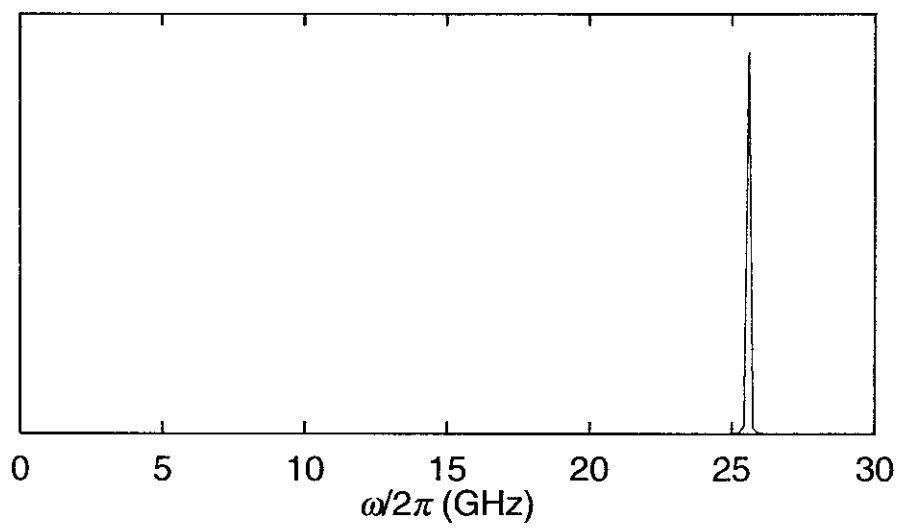


Fig.6

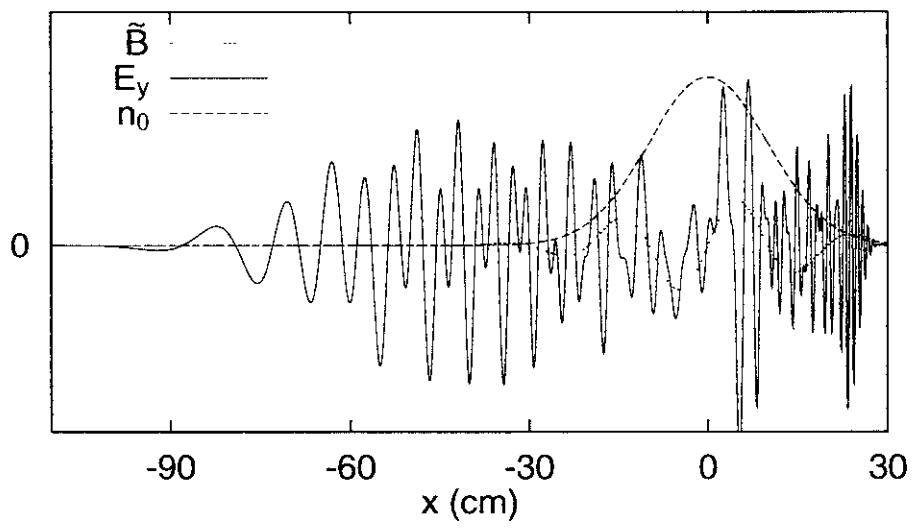


Fig.7

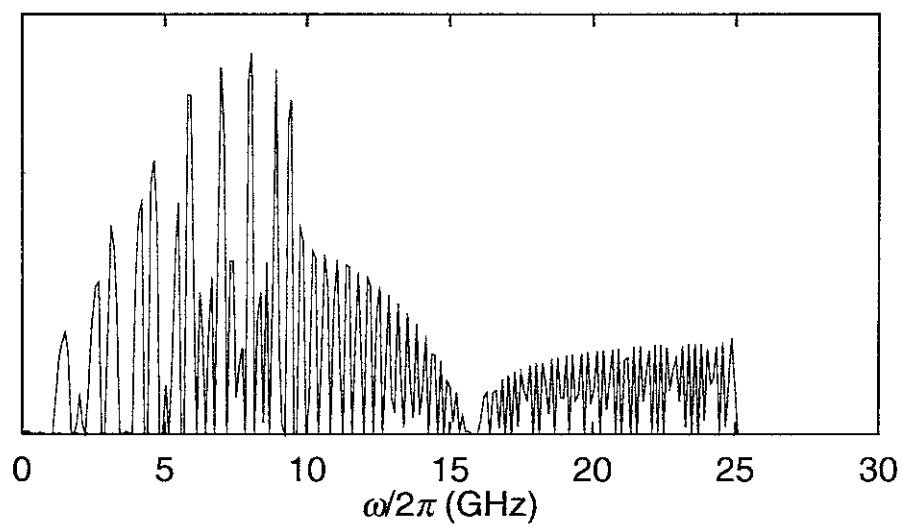


Fig.8

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*Development of Negative-Ion-Based Neutral Beam Injector for the Large Helical Device*; Sep. 1996 (IAEA-CN-64/GP-9)
- NIFS-442 K. Toi, K.N. Sato, Y. Hamada, S. Ohdachi, H. Sakakita, A. Nishizawa, A. Ejiri, K. Narihara, H. Kuramoto, Y. Kawasumi, S. Kubo, T. Seki, K. Kitachi, J. Xu, K. Ida, K. Kawahata, I. Nomura, K. Adachi, R. Akiyama, A. Fujisawa, J. Fujita, N. Hiraki, S. Hidekuma, S. Hirokura, H. Idei, T. Ido, H. Iguchi, K. Iwasaki, M.

Isobe, O. Kaneko, Y. Kano, M. Kojima, J. Koog, R. Kumazawa, T. Kuroda, J. Li, R. Liang, T. Minami, S. Morita, K. Ohkubo, Y. Oka, S. Okajima, M. Osakabe, Y. Sakawa, M. Sasao, K. Sato, T. Shimpō, T. Shoji, H. Sugai, T. Watari, I. Yamada and K. Yamauti,

*Studies of Perturbative Plasma Transport, Ice Pellet Ablation and Sawtooth Phenomena in the JIPP T-IIU Tokamak*; Sep. 1996 (IAEA-CN-64/A6-5)

- NIFS-443 Y. Todo, T. Sato and The Complexity Simulation Group,  
*Vlasov-MHD and Particle-MHD Simulations of the Toroidal Alfvén Eigenmode*; Sep. 1996 (IAEA-CN-64/D2-3)
- NIFS-444 A. Fujisawa, S. Kubo, H. Iguchi, H. Idei, T. Minami, H. Sanuki, K. Itoh, S. Okamura, K. Matsuoka, K. Tanaka, S. Lee, M. Kojima, T.P. Crowley, Y. Hamada, M. Iwase, H. Nagasaki, H. Suzuki, N. Inoue, R. Akiyama, M. Osakabe, S. Morita, C. Takahashi, S. Muto, A. Ejiri, K. Ida, S. Nishimura, K. Narihara, I. Yamada, K. Toi, S. Ohdachi, T. Ozaki, A. Komori, K. Nishimura, S. Hidekuma, K. Ohkubo, D.A. Rasmussen, J.B. Wilgen, M. Murakami, T. Watari and M. Fujiwara,  
*An Experimental Study of Plasma Confinement and Heating Efficiency through the Potential Profile Measurements with a Heavy Ion Beam Probe in the Compact Helical System*; Sep. 1996 (IAEA-CN-64/C1-5)
- NIFS-445 O. Motojima, N. Yanagi, S. Imagawa, K. Takahata, S. Yamada, A. Iwamoto, H. Chikaraishi, S. Kitagawa, R. Maekawa, S. Masuzaki, T. Mito, T. Morisaki, A. Nishimura, S. Sakakibara, S. Satoh, T. Satow, H. Tamura, S. Tanahashi, K. Watanabe, S. Yamaguchi, J. Yamamoto, M. Fujiwara and A. Iiyoshi,  
*Superconducting Magnet Design and Construction of LHD*; Sep. 1996 (IAEA-CN-64/G2-4)
- NIFS-446 S. Murakami, N. Nakajima, S. Okamura, M. Okamoto and U. Gasparino,  
Orbit Effects of Energetic Particles on the Reachable  $\beta$ -Value and the Radial Electric Field in NBI and ECR Heated Heliotron Plasmas; Sep. 1996 (IAEA-CN-64/CP -6) Sep. 1996
- NIFS-447 K. Yamazaki, A. Sagara, O. Motojima, M. Fujiwara, T. Amano, H. Chikaraishi, S. Imagawa, T. Muroga, N. Noda, N. Ohyabu, T. Satow, J.F. Wang, K.Y. Watanabe, J. Yamamoto, H. Yamanishi, A. Kohyama, H. Matsui, O. Mitarai, T. Noda, A.A. Shishkin, S. Tanaka and T. Terai  
*Design Assessment of Heliotron Reactor*; Sep. 1996 (IAEA-CN-64/G1-5)
- NIFS-448 M. Ozaki, T. Sato and the Complexity Simulation Group,  
*Interactions of Convecting Magnetic Loops and Arcades*; Sep. 1996
- NIFS-449 T. Aoki,  
*Interpolated Differential Operator (IDO) Scheme for Solving Partial Differential Equations*; Sep. 1996
- NIFS-450 D. Biskamp and T. Sato,  
*Partial Reconnection in the Sawtooth Collapse*; Sep. 1996



- NIFS-451 J. Li, X. Gong, L. Luo, F.X. Yin, N. Noda, B. Wan, W. Xu, X. Gao, F. Yin, J.G. Jiang, Z. Wu., J.Y. Zhao, M. Wu, S. Liu and Y. Han,  
*Effects of High Z Probe on Plasma Behavior in HT-6M Tokamak*; Sep. 1996
- NIFS-452 N. Nakajima, K. Ichiguchi, M. Okamoto and R.L. Dewar,  
*Ballooning Modes in Heliotrons/Torsatrons*; Sep. 1996 (IAEA-CN-64/D3-6)
- NIFS-453 A. Iiyoshi,  
*Overview of Helical Systems*; Sep. 1996 (IAEA-CN-64/O1-7)
- NIFS-454 S. Saito, Y. Nomura, K. Hirose and Y.H. Ichikawa,  
*Separatrix Reconnection and Periodic Orbit Annihilation in the Harper Map*; Oct. 1996
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*Topics on MHD Equilibrium and Stability in Heliotron / Torsatron*; Oct. 1996
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*Wrap, Tilt and Stretch of Vorticity Lines around a Strong Straight Vortex Tube in a Simple Shear Flow*; Oct. 1996
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*Turbulent Transport and Structural Transition in Confined Plasmas*; Oct. 1996
- NIFS-458 A. Kageyama and T. Sato,  
*Generation Mechanism of a Dipole Field by a Magnetohydrodynamic Dynamo*; Oct. 1996
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*The Non-axisymmetric Instability of the Wide-Gap Spherical Couette Flow*; Oct. 1996
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*A Tandem Parallel Plate Analyzer*; Nov. 1996
- NIFS-461 Y. Hamada, A. Nishizawa, Y. Kawasumi, A. Fujisawa, K. Narihara, K. Ida, A. Ejiri, S. Ohdachi, K. Kawahata, K. Toi, K. Sato, T. Seki, H. Iguchi, K. Adachi, S. Hidekuma, S. Hirokura, K. Iwasaki, T. Ido, M. Kojima, J. Koong, R. Kumazawa, H. Kuramoto, T. Minami, I. Nomura, H. Sakakita, M. Sasao, K.N. Sato, T. Tsuzuki, J. Xu, I. Yamada and T. Watari,  
*Density Fluctuation in JIPP T-IIU Tokamak Plasmas Measured by a Heavy Ion Beam Probe*; Nov. 1996
- NIFS-462 N. Katsuragawa, H. Hojo and A. Mase,  
*Simulation Study on Cross Polarization Scattering of Ultrashort-Pulse Electromagnetic Waves*; Nov. 1996