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Full-wave Analysis for Estimation of Microwave Beam Broadening by Turbulent Density Fluctuations in LHD

Ryoma Yanai[1], Toshiki Kinoshita[2], Kenji Tanaka[1,2], Hikona Sakai[2], Shin Kubo[3]
[1] National Institute for Fusion Science, [2] Kyushu University, [3] Chubu University
e-mail (speaker): yanai@nifs.ac.jp

Electron cyclotron heating (ECH) is an essential auxiliary heating method for magnetically confined fusion plasmas. A high-power microwave beam is used and the power is absorbed in plasma via electron cyclotron resonance. ECH realizes local high-power density heating by using a focused beam and is used for electron heating, plasma initiation, and current drive. Recent simulation and experiment studies suggested that the ECH microwave beam is scattered by turbulent density fluctuations in plasmas and the beam width is broadened.[1, 2] The important characteristics of ECH such as heating locality and the current drive efficiency can be deteriorated by beam width broadening caused by the turbulent density fluctuations. Therefore, it is necessary to investigate and evaluate the effect of the density fluctuations on the ECH beam quality. The Large Helical Device (LHD) has 1 MW-class ECH systems using 77 GHz and 154 GHz gyrotrons. A two-dimensional phase contrast imaging (PCI) system is in operation at the LHD[3] and can provide data on the absolute value of electron density fluctuations caused by ion-scale turbulence. This PCI system also provides the time evolution of the radial profile of the density fluctuations including the wavenumber spectrum. We carry out the electromagnetic simulation with a cold plasma model to analyze the effect of the density fluctuations on the 77 GHz microwave beam based on the ECH system in the LHD. Firstly, we conducted a two-dimensional simulation to investigate the influence of the scale of the density fluctuations by introducing a monochromatic wavenumber structure into the ambient electron density $n_{e0} = 3 \times 10^{19}$ m^{-3}. The amplitude of the density fluctuations is 2% of n_{e0}. Figure. 1 shows an example of the two-dimensional profile of electron density for the simulation and the wave electric field of a Gaussian beam propagating in a plasma model with a monochromatic density fluctuation, where the wavenumber of the fluctuation was set to one-tenth of that of a 77 GHz electromagnetic wave in free space ($k_{77\,\mathrm{GHz}}$). The wave electric field was distorted, and the profile deviated from the Gaussian profile by the density fluctuations. The simulation result showed that the wavenumber less than one-third of $k_{77\,\mathrm{GHz}}$ had relatively large influences on the beam quality. We will show the detail of the effect of the fluctuation size and the result using a precise model based on the experimental data of LHD plasma in the presentation.

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References

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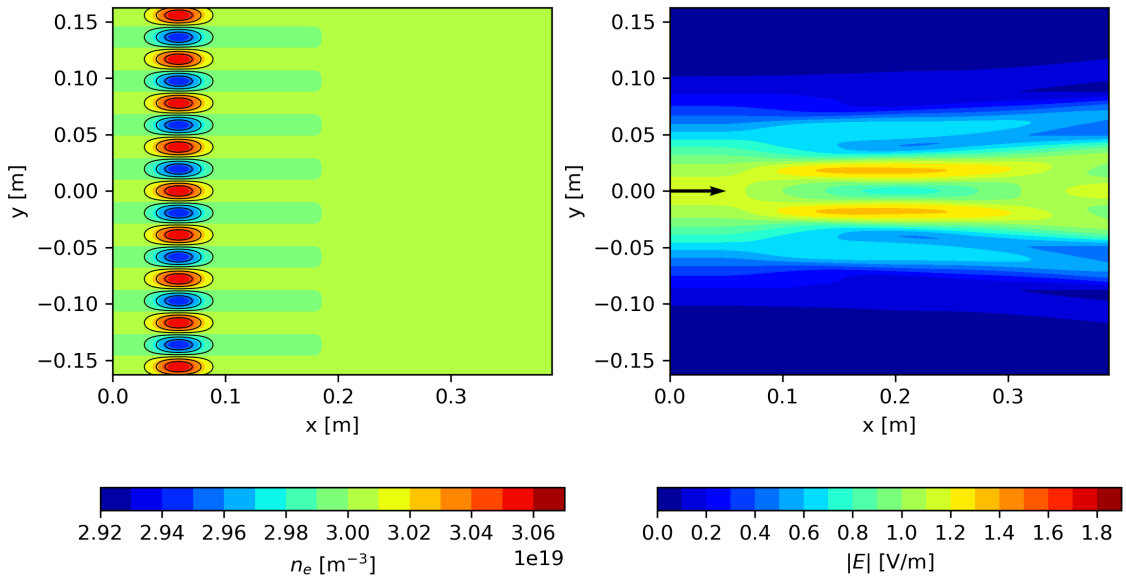

Figure. 1. Two-dimensional profile of electron density with monochromatic density fluctuations for full-wave simulation (left), and the absolute value of the wave electric field propagating in the positive x-direction from $x = 0$ m (right).