Finite Difference Time-Domain code CUWA

Maxwell’s equations and Plasma response (“cold” electron law of motion), First order finite difference discretization on staggered grids.

\[ \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \]

\[ c^2 \nabla \times \vec{B} = \frac{1}{\varepsilon_0} \frac{\partial \vec{E}}{\partial t} + \frac{\varepsilon_0}{\mu_0} \frac{\partial \vec{B}}{\partial t} \]

\[ \frac{\partial j}{\partial t} = \varepsilon_0 \omega^2 \mu_0 E_0 - j \times B_0 \]

Conversion efficiency in W7-X

The ECRH antennas setup in W7-X is shown schematically in the left figure. For the six steerable antennas (orange), a ray-tracing study gives 12 “WKB-optimal” rays. O-X conversion efficiency calculated with 3D full-wave for each of the 12 rays varying the steering angles (±2.5°±2.5°) around those predicted by the ray-tracing (indicated above each of the contour plots). The density length scale \( L_{\text{n},10^6} = 1/15 m \).

Optimized conversion scenario

Conversion happens when the “turning” points for both modes are “close”. The evanescent layer thickness varies within the beam due to equilibrium variation and beam k-spectrum. WKB provides an estimate for the thickness of the evanescent layer [8]. The crossing of the two surfaces is parameterized by \( N_\text{eff} \).

Conditions for efficient conversion:

\[ \omega_{\text{pe}} = \omega \]

\[ N_{\text{eff}} = 1 - \frac{\omega^2}{\omega^2 - \omega_{\text{pe}}^2} \]

Efficient conversion locations can be identified: The function representing the Gaussian-weighted gradient of the thickness of the evanescent layer on the cutoff surface is shown. A few minima of this function are marked with red dots.

Effect of turbulence on conversion efficiency

The effect of plasma turbulence on the conversion efficiency was noticed in the pioneering OXB experiments on W7-AS [9]. Their detrimental role was conjectured in that work. However, theoretical considerations presented in Ref. [10] suggest that plasma fluctuations most likely cannot be responsible for the low efficiency of OXB heating. We address this problem by direct numerical calculation of the O-X conversion in perturbed plasma.

Conclusion

The O-X conversion process defines efficiency of the entire OXB heating scheme, which is suitable for heating of overdense plasmas. In this work, we conducted a comprehensive study of the O-X conversion efficiency in realistic W7-X parameters.

For realistic W7-X equilibrium and ECRH parameters, the efficiency of the scheme is low and is not expected to exceed 50-60%.

However, we also demonstrated that a significant improvement of the conversion (~85%) could be achieved if the equilibrium is tailored in such a way that the conversion occurs at the location where the evanescent layer width weighted over the beam profile is minimized. It was also shown that the density fluctuations expected in W7-X should not have a significant effect (< 10%) on the O-X conversion efficiency.

References


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