PhD thesis topcis / Doktorarbeitsthemen:
Fullwave simulation of millimeter wave plasma diagnostics

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Introduction

Plasma turbulence is a major concern for the confinement of fusion plasmas. Among the available diagnostics, microwave scattering is used for measuring turbulent density fluctuations. Doppler reflectometry uses the reflection of the wave at the cutoff layer to localise the scattering volume. One of the main goals of Doppler reflectometry is the measurement of the perpendicular wavenumber spectrum of the plasma density fluctuations. The sensitivity to fluctuations and the spatial localisation are determined by the path of the probing beam. This path is different for each wavenumber, as is the diagnostic sensitivity (instrument function).

The fullwave code IPF-FD3D is used to implement a synthetic Doppler reflectometer on top of plasma turbulence simulations. These are carried out by collaborators at IPP Garching with the gyro-kinetic code GENE.

Experimental Doppler spectra and density spectra from turbulence simulations show marked differences in the position and shape of the inertial range of the turbulence. Fullwave simulations of the reflectometer show the non-linear scattering properties of the plasma at the observed density fluctuation levels and can explain these differences. These investigations were done for ASDEX Upgrade.

An important parameter is the amplitude of the density fluctuations, which are varied in the simulations by several orders of magnitude, yielding very different recovered spectra, even though the underlying density fluctuation spectrum is always the same. The 3% fluctuation amplitude in the GENE simulations are already far in the non-linear regime for X mdde.

The Simulation Code

IPF-FD3D is a 2D or 3D finite difference time domain code for cold magnetised plasmas. It contains sources and coherent receivers for Gaussian beams, and solvers for O and X mode, as well as mixed polarisations. It is written in C, with post-processing done in python.

The existing solvers work on a cartesian grid and are second order in time and space. Both E and H fields of the wave are considered, and the plasma currents are solved separately in a modified Crank-Nicolson scheme. They are parallelised with OpenMP. Since many applications require running one setup with many different turbulence fields as input, it is also trivially parallelised along these instances using MPI.

Time dependent plasma effects are treated by simulating “frozen” snapshots of the plasma state in sequence. Theoretically, the Doppler shift of the scattered wave should be recovered. In practice, this only works in simple slab geometry.

Scope of PhD Work

Improvement and extension of the existing code and application to new problems of Doppler reflectometry and other millimeter wave diagnostics. **A few of these would be enough for a thesis.**

Code development topics include

- development of new solvers of higher order in time and space (might be impossible to do simultaneously for EM fields and plasma currents, but still an improvement)
- adaptation to hexagonal grids to improve numerical dispersion
- optimisation of existing solvers for faster execution
- adaptation of kernels to vector computers (NEC SX-ACE)
- domain decomposition using MPI for large grids (e.g. in 3D)
- implementation of unidirectional sources
- add simple raytracing code for following the beam
- explore stability issues with X mode and large density gradients

Physics topics include

- effect of edge fluctuations when probing further inside (generic or applied to ASDEX Upgrade)
- general validation and verification
- effect of $v_\perp$ oscillations
- synthetic turbulence: find better synthetic fluctuations that mimic the actual structures seen in GENE simulations (elongated radial structures + shear effect)
- scaling of scattering results with turbulence strength
- investigate enhancement of scattering near UH resonance
- explain super-linear scaling at intermediate fluctuation strengths
- investigate forward scattering at high k, broader / shifted Doppler spectrum?
- impact of higher order scattering

Prerequisites

- Physics Master with at least 2.0 “gut” grade or equivalent
- good programming skills
- good knowledge of C
- good knowledge of python, numpy, scipy
- some familiarity with high performance computing and parallel environments
- some familiarity with plasma diagnostics, millimeter waves