Integration of core/edge plasmas in fullwave RF simulation

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Core/Edge integration for RF simulation

Motivation

Need of self consistent simulation with realistic 3D antenna and plasma geometries:

- Several physics issues require coupling of edge (antenna and SOL) and core simulations to be understood:
  - Edge losses
  - Antenna coupling in 3D geometries (stellarators, C-Mod, etc.)
  - Small device plasmas
  - Multiple-pass absorption regimes

Individually, good solvers for each region is available. However, extending such a solver to the other region is difficult.

This approach can be extended to other frequency ranges, such as HMFE in NSTX, Helicon in DIII-D, LHCD in C-Mod.

Spectral vs. FEM:

Spectral:
- Hot plasma formulation is apparent
- Availability of mature scientific codes e.g. TORIC, AORSA, TAE, EVE
- 2D, 3D by single toroidal mode analysis
- Handling of nearby geometrical features more difficult
- Dense matrices

FEM:
- Accurate geometry description (antenna, wall, SOL, ...)
- Cold plasma wave with collisions are straightforward
- Not easy to deal with cold plasma effects (Needs a wave branch specific technique such as an iterative approach in UHAPIC)
- Sparse matrices

The core spectral solver is integrated with edge FEM code.

The best of two worlds approach:
- Core:
  - Asymmetric flux surface regular grid
  - Hot plasma conductivity
  - Dense Matrix Solver
- Edge:
  - Unstructured mesh with complicated geometry (either 2D or 3D)
  - Cold plasma with collision.
- Boundary matching technique to build integrated solution

Demonstrated using TORIC ICRF solver + COMSOL FEM package

First ever TORIC ICRF simulation with realistic scrape-off layer

Cold plasma FEM solver using MFEM

Motivation

Solving whole 3D SOL could be a large problem

- Need to resolve the change of dielectric property in the (penumbra-like) scale length of SOL
- Slow wave excitation
- Nonlinear interaction would also rectify short wave length modes.
- Scalability to massively parallel computer will be required

MFEM library

A free, lightweight, scalable library for finite element methods (see http://mfem.org for details)

- Higher-order Finite-Element Spaces: H1, H2, H3, H0, H1/2-
  conforming spaces, and more
- Triangle, quadrilateral, tetrahedral and hexahedral elements
- Tightly integrated with hypre scalable solver library
- Multithreaded parallelism throughout the library
- Various examples including Measwell, etc. run out-of-box
- Written in C++

PymFEM: python wrapper for rapid physics implementation

PyMFEM: python wrapper for rapid physics implementation

Cold collisional plasma model ported to python

Frequency Domain EM physics layer

Solve inhomogeneous Maxwell eq. in 3D in frequency domain

Cartesian coordinate system

Time harmonics term follows the physics convention: “mz dt” Domain

- Uniform dielectric media
- Anisotropic (matrix) media
- External J

Boundary

- Perfect electric conductor (PEC)
- Perfect magnetic conductor (PMC)
- Waveside port (TE, TEM, coax)
- Periodic boundary
- Surface current
- Magnetic field
- Electric field
- Impedance Boundary (not yet)

Cold collisional plasma model ported to python

Summary

Core spectral and edge FEM coupling opens the possibility “from coarse to core” RF simulations

- This model will permit realistic antenna models for ICRF and LHR full- wave studies.
- With the addition of a triangular mesh for the vacuum region instead of the extended flux surface geometry now used, TORIC could model non-converging antenna placement, accurate limiter geometries and wave propagation in the scrape off layer.
- Possible application and extension includes...
  - Slow wave excitation
  - Grad-Shafranov solution and computation of diffusion model for density/temperature on open field lines.
  - Extensions to HMFE in NSTX, Helicon in DIII-D, LHCD in C-Mod
  - 3D antenna geometry
  - RF boundary conditions
  - First steps towards whole device model for RF

Large scale 3D application motivational to migrate present test cases to open source scalable MFEM library

Python wrapper (PymFEM) developed for rapid development of physics layer and other meshing cases such as complex number

GUi on tRISOPE

GUI is built on a core code style python data analysis system

- Test
- Devel
- User
- Project management
- Interface
- Message
- Graphs
- Databases

GUI is built on tRISOPE

- Some GUI solutions are based on python data analysis system
- Completed code for testing core solution using VTK based data analysis

GUI is built on tRISOPE

- Simple model code interface
- Accommodation of core and edge
- Support to lower VTK-based data system runtime to support core solver for data visualization using VTK-based data

UI gui launcher

- 3D stripped cold plasma model
- 8 wave guide with 80 deg phasing
- Linear density profile

Solution obtained using PymFEM is nearly identical to a cold plasma model used in COMSOL

Verifiacion

ICRF case for C-Mod

Full view field patterns in the core is very similar on left field code

TORIC/COMSOL

C-Mod requires full view field patterns

Next Step

- Integrate into TORIC-FEM workflow
- Start investigating 3D field

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