

# Development of a 3-D GPU-Assisted Maxwell Code for Synthetic Diagnostics on ITER



## Synthetic Diagnostics on ITER

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### Motivation

Electromagnetic wave propagation and scattering in magnetized plasmas are important diagnostics for high temperature plasmas. 1-D and 2-D full-wave codes are standard tools for measurements of the electron density profile and fluctuations; however, ray tracing results have shown that beam propagation in tokamak plasmas is inherently a 3-D problem.

### Objective

The goal of this project was to enlarge the current computational domain of a GPU-assisted Maxwell code. This synthetic diagnostic will be used to simulate beam propagation in the ITER edge plasma and will be compared against ray tracing results.

### Methods Overview

- Cold plasma approximation
- Yee Lattice used to stagger the the position of the field and current densities in both space and time
- Finite-Difference Time Domain method used for updating elements of magnetic and electric fields
- The current densities are solved for using the J-E convolution method

### Code Domain

- Previous code was limited by the 6 GB on-board GPU memory
  - Previous dimensions: 140x401x401
- Domain expanded via domain decomposition
  - New dimensions: 801x801x801
- Domain subdivided into 25 layers
- Number of time steps scales with x-dimension
  - Computational time will theoretically increase by a factor of 6 without any overhead
    - This estimate assumes no new code architecture
- Initial tests show an increase by a factor of 35
  - Due to new code structure and additional memory copies

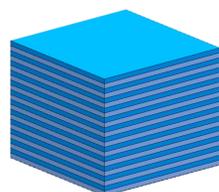


Fig 1 : A visual representation of the expanded domain with dimensions of 801x801x801. The subdomains are indicated by alternating colors.

### Code Architecture

- Code was written using NVIDIA's CUDA C extension
- Pinned memory was utilized to speed up transfer rates due to extensive memory transfers
- Subdomains were passed onto GPU from the host, modified on the GPU, and passed back

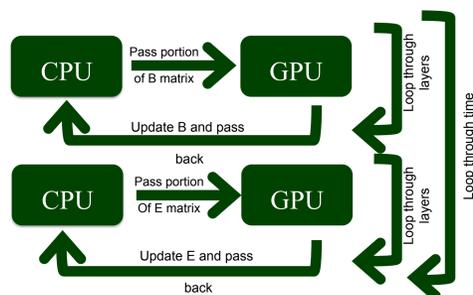


Fig 2 : Overview of the CUDA code. The magnetic and electric fields are updated for each section of the domain and then this process is repeated until the desired end time is reached.

- Courant-Fredrichs-Lewy stability limit restricts the time step due to the spatial discrete step size

$$\Delta t < \frac{1}{c} \left( \frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2} \right)^{-\frac{1}{2}}$$

### ITER LFSR

- The variation in plasma properties influences the beam propagation and antenna coupling
- Effects that need to be evaluated using simulation for the ITER low field side reflectometer (LFSR);
  - Beam drift
  - Linear mode conversion
  - Diffraction/scattering due to fluctuations
  - Time dependent sources and targets

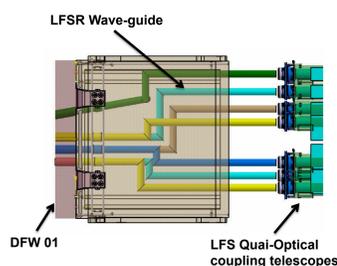


Fig 3 : View of the EP11 DSM-1 and quasi-optical relay telescopes in the port interspace. The LFSR antennas have a diameter of 63.5 mm.

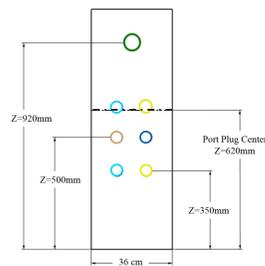


Fig 4 : View of the primary antenna locations on the EP11 DSM-1. All measurements are from the target midplane.

### Gaussian Beam

- Launched wave approximated by a Gaussian beam
  - Launched via corrugated circular waveguide
  - Launched from the DFW (diagnostic first wall) at R=844 cm
  - Wavelength HE11 mode couples to Gaussian beam with beam waist
    - $w_0 = 0.32 \cdot D = 1.6$  cm
  - D = 5 cm (diameter of the waveguide)

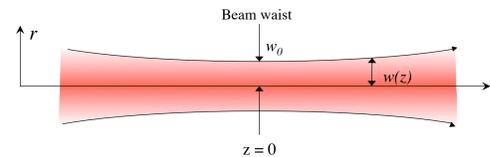


Fig 5 : An illustration of a Gaussian beam with a beam waist of  $w_0$ .

### ITER Target Plasma

- Full field ITER plasmas
  - 5.3 T toroidal field at vessel center
- 15 MA shots
- Launch frequency of 80 GHz (O-mode)
- Code domain under these conditions results in a cube of side length 15 cm

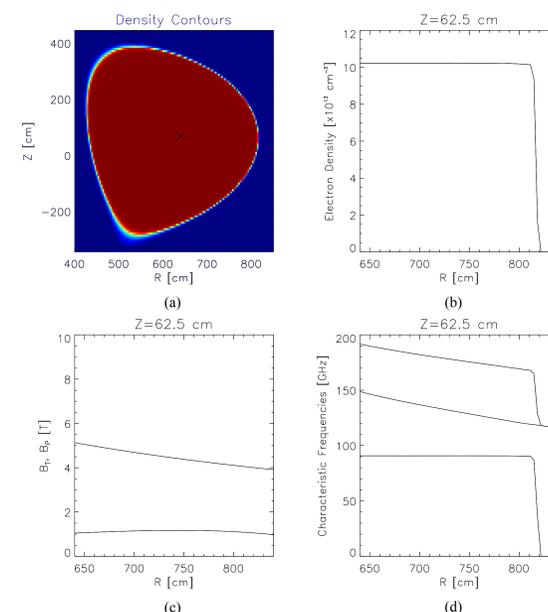


Fig 6 : Each plot is generated at plasma equilibrium. All plots except for plot (a) are fixed at a height of 62.5 cm. Plot (d) shows the relationship between the plasma's various characteristic frequencies. The lowest frequency is the O-mode cutoff, the middle is the electron cyclotron frequency, and the uppermost frequency is the X-mode cutoff.

### Ray Tracing

- Historically used to calculate the trajectory of waves through the plasma
- Beam is modeled by using a large number of individual rays
  - The WKB Assumption is made as well as a plane wave assumption

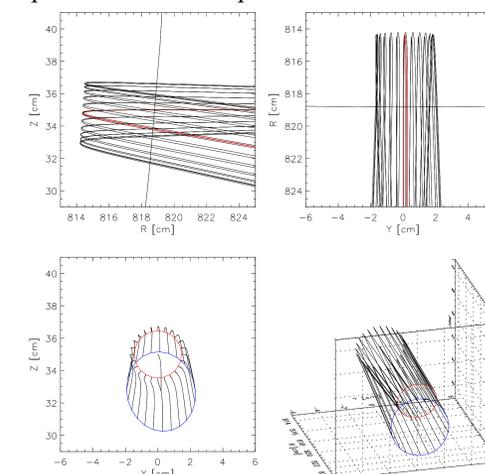


Fig 7 : Results from the ray tracing code. A pencil of rays at 1/e of the electric field were launched from a height of 35 cm and with a radius of 1.45 cm. Red indicates the initial rays that were launched and blue is the result after the rays were reflected at the cutoff layer.

- Cold plasma approximation used
- O-mode waves launched at 80 GHz
- Compared with full wave calculations where a Gaussian beam was launched at R=825 cm.
  - Results for both match at the reflection layer

### Conclusions

- Domain decomposition has been implemented
- Future work includes:
  - Verification and validation of implementation
  - Optimization for shorter run times

### References

- [1] D. Woodbury, et al., *Development of a GPU-Accelerated 3-D Full-Wave Code for Electromagnetic Wave Propagation in a Cold Plasma*. Poster JP8.00021, Presented at the 55th Annual Meeting of the APS Division of Plasma Physics, Oct. 27-31, 2014, New Orleans, LA
- [2] K.S. Reuther, et al., *Development of a GPU-Accelerated 3D Full-Wave Code for Reflectometry Simulations*. JP8.00017, Presented at the 54th Annual Meeting of the APS Division of Plasma Physics, Nov. 11-15, 2013, Denver, CO

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