A new FELICE release coupled to TOPICA code

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Introduction. The TOrino Polytechnic Ion Cyclotron Antenna (TOPICA) code is an advanced tool for the simulation of ion-cyclotron (IC) radio frequency antennas. This code uses an integral equation formulation with the method of moments (MoM) solution. It solves Maxwell's equations taking into account the entire geometry of the antenna and an approximate 1D plasma computed by the Finite ELements Ion Cyclotron Evaluation (FELICE) code.

The FELICE code, initially developed in the 90s and last updated in 2002, has been used along with TOPICA for the past twenty years. Written in Fortran 90 it has limitations by today's standards. For instance, it utilizes single-precision functions and lacks modern features and advanced functionality such as modules, derived data types, and traditional structures and loops such as "CASE" and "DO WHILE." Due to its age, it is challenging to incorporate new features and address issues that arise when developing new TOPICA upgrades.

This paper describes the work done to couple the current version of the FELICE code (dated 2023) to TOPICA and compares the standard TOPICA outputs obtained with the current and the previous version of the FELICE code.

FELICE-TOPICA. FELICE is a finite elements code that solves the full-wave equation in a plane stratified geometry with a semi-spectral method using the FLR (Finite Larmor Radius) equations [1]. To integrate FELICE with TOPICA, outward radiation conditions (equivalent to PML) are imposed as boundary conditions inside the plasma where the WKB is applicable. Furthermore, the code was adjusted to utilize a complex spectral mesh as input.

The FELICE output is a plasma 2x2 impedance matrix (1) with elements that are functions of $n_\perp$, $n_\parallel$ in the spectral domain where $\vec{n} = c\vec{k}/\omega$ and $\vec{k}$ has components y and z along the equivalent poloidal and toroidal directions [2].

$$\begin{pmatrix} E_y \\ E_z \end{pmatrix} = \widetilde{Z_p} \begin{pmatrix} H_y \\ H_z \end{pmatrix} \qquad (1)$$

This matrix is the input that represents the plasma contribution in TOPICA. Using an equivalent circuit, a plasma Green function can be described as a transmission line (see Figure 1), with the plasma expressed as the admittance $\widetilde{Y_p}$.

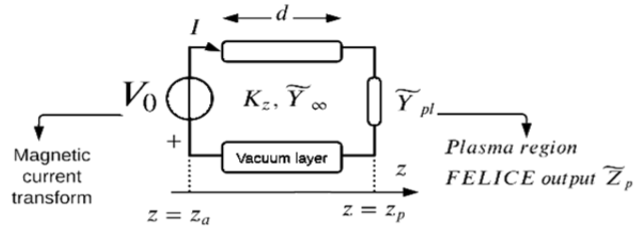

Figure 1: Circuit analog equivalent to the slab plasma geometry,

By applying the surface equivalence theorem, we can represent the entire system using magnetic and electric currents [3]. Then, using a hybrid spatial–spectral MoM, a reaction integral of the plasma is evaluated directly in the spectral domain to solve fields in the entire geometry (antenna-plasma) [3]. Finally, the antenna circuit parameters (impedance/scattering matrices), the radiated power, and the fields (at locations other than the chamber aperture) are then obtained.

Comparing FELICE's old and new versions, one can notice that the 2023 version offers several enhancements. It employs double precision functions in the LU decomposition routines and uses a full numerical input profile; moreover, the algorithm retains three waves: Fast, Shear Alfven, and Ion Bernstein. This modular version provides greater flexibility and maintains compatibility with both default use and TOPICA mode. Additionally, it is possible to compute the plasma electric and magnetic field at any point within the integration area and then compute the fields with the antenna in TOPICA.

Simulation methods and setup. Figure 2 shows a preliminary flat version of the three-strap antenna envisioned in DTT [4], which has been loaded in TOPICA and simulated at three working frequencies (60-75-90 MHz) with one plasma loading (see Figure 3, where DTT profile 2295 [5] is depicted) with two radial shifts at 0.7130 [m] and 0.7330 [m]. The two versions of FELICE code are first compared in terms of the standard code output, i.e., the plasma impedance matrix. Besides,

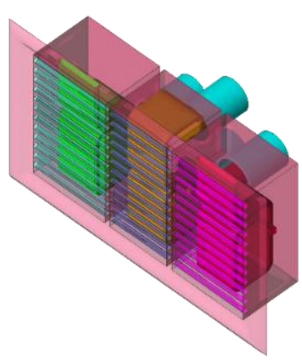

Figure 2 : Three-strap DTT flat antenna

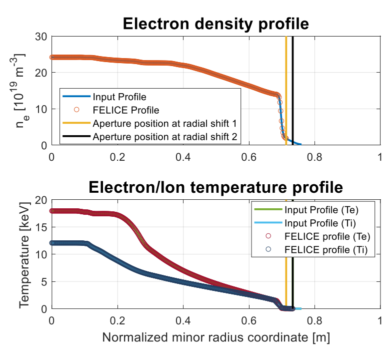

Figure 3: Electron density & temperature profile (2295) vs. Radius.

the effects of the new release are described by looking at typical TOPICA results, i.e. the antenna parameters, the power transferred to plasma, the electric currents and the electric fields in front of the IC launcher.

Results. The use of double precision functions in the LU decomposition routines improves the accuracy of the plasma impedance matrix compared to the single precision functions used in the previous version, as demonstrated in Figure 4 by the impedance matrix computed at 0.7130 m with 60 MHz

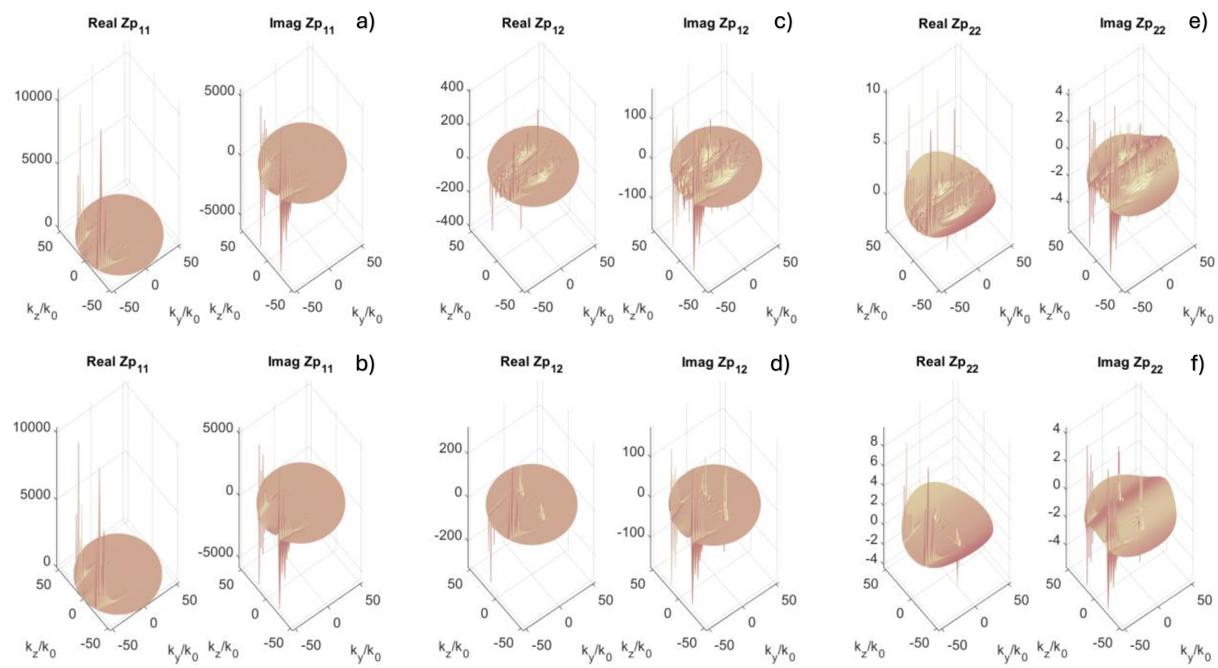

Figure 4 : Plasma impedance matrix in radial shift 1 at 60 MHz a) Fast-wave old FELICE, b) Fast-wave new FELICE, c) Mix-term old FELICE, d) Mix-term new FELICE, e) Slow-wave old FELICE, f) Slow-Wave new FELICE.

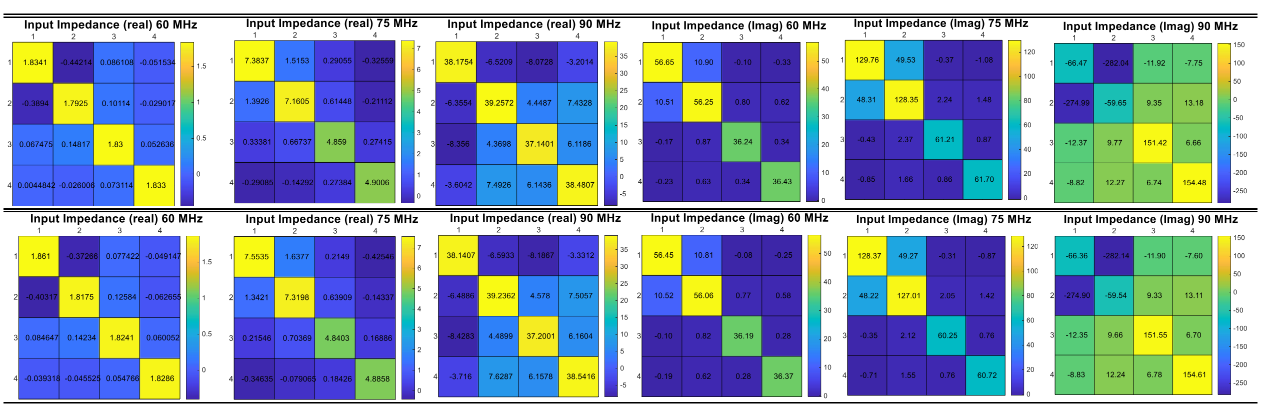

*Figure 5**:** Antenna input impedance: Up) Old FELICE plasma profile at 0.7130 m, down) New FELICE plasma profile at 0.7130 m*

In terms of input impedance, the difference is small for self-terms and it increases for non-diagonal terms, as documented by Figure 5. In terms of radiated fields, the two versions of FELICE slightly differ at 60MHz (see Figure 6a/b), while they are basically identical at 90MHz (see Figure 6c/d).

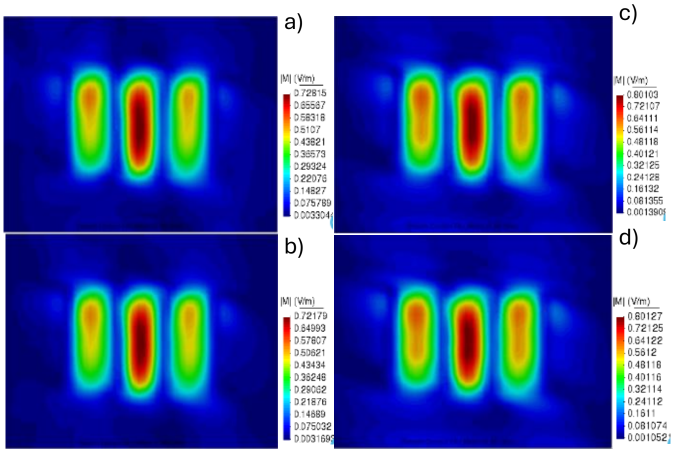

Figure 6: Magnetic Current (V/m) in aperture at 0.7130 a) old FELICE 60 MHz, b) new FELICE 60 MHz, c) old FELICE 90 MHz, d) new FELICE 90 MHz.

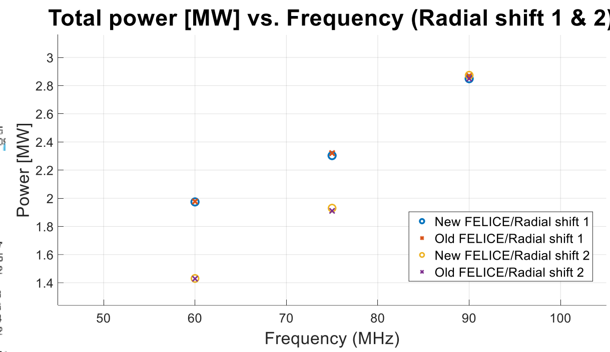

Figure 7: Total power vs. Frequency at 60,75,90 MHz with aperture at 0.7130 m, 0.7330 m.

Eventually, in terms of coupled power, the difference between the two versions of FELICE increases with the frequency, even though it remains negligible, as seen in Figure 7.

Conclusions. The new FELICE code is now integrated with TOPICA, reducing the complexity of the code in terms of writing and organization. This improvement will make future developments more efficient and accessible. With respect to simulation results, i.e. testing with different frequencies and plasma profiles, the results obtained with the new version of FELICE are very similar to those obtained with the old version. Currently, the updated version of the code is being used to evaluate real antenna plasma scenarios, and new features for TOPICA are under development.

References

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