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Radio Frequency Plasma Heating in the Divertor Test Tokamak experiment

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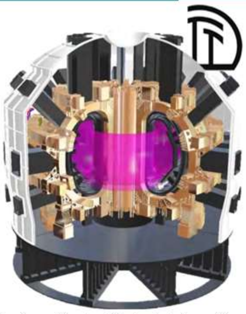
Research context and motivation

TOKAMAKs are experiments for arriving at controlled nuclear fusion energy generation**.** TOKAMAKs require a powerful plasma heating system operated through the coupling of electromagnetic waves ("radio frequency"). Antennas are critical components of RF heating systems, charged with the task of handling and delivering high power to the plasma while at the same time operating in prohibitive conditions of thermal and mechanical stresses. In this challenging scenario, predicting the antenna performances in coupling electromagnetic energy to the plasma becomes of utmost importance in designing heating systems and, more generally, fusion experiments.


https://www.dtt-project.it/index.php/science/dtt-project.html

TOPICA code (Torino Polytechnic Ion Cyclotron Antenna) is used by most of the scientific community to simulate plasma-facing antennas in Tokamak experiments. This code solves Maxwell equations considering an approximate plasma (yet with "finite temperature" effects) and the full geometry of the antenna; it employs the integral equation formulation with the method of moments (MOM) solution. At present, it is the only code able to:
- Handle the realistic geometry of these antennas
- Correctly account for the plasma loading conditions.

Addressed research questions/problems

Due to the complex environment of these systems, there are many design constraints.

➢ **Geometry:**
- × Mechanical constraints (mechanical, thermal, and nuclear stresses).
- × Limited space available on the machines. For strap type antenna $L\_strap= \lambda/2$.
- × (Loop-type) The resonance loop perimeter is $L\_loop \approx \lambda$.

➢ **Electrical properties :**
- × High power to be delivered to the plasma.
- × High voltage is dangerous, causing arcs and driving RF potentials that can eventually damage the entire system.
- × Frequency operation f-work= 60MHz to 90MHz.

A critical problem in improving Ion Cyclotron Resonance Heating Antenna for nuclear fusion systems is the impossibility of testing them in real systems.

➢ **TOPICA simulation code**
- × Slab approximation – **Radial plasma component.**
- × Numerical instability at low densities (Lower Hybrid resonance).
- × Solution time.

How do we improve Ion Cyclotron Resonance Heating Antenna designs?

Antenna concepts for enhanced performance

☺ New antenna concept L-Type antenna $L\_L \approx \lambda/4$, Inverted F- Type Antenna $L\_F \approx \lambda/4$.

Simulation for design

☺ Real antenna – plasma approximation Axisymmetric approximation - **Toroidal plasma component.**

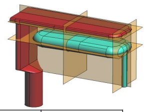
☺ Fast solver.

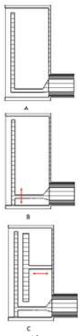
Submitted and published works

- A Self-Resonant Plug-In IC Antenna for DTT – D. Milanesio et Al. - Proceedings of the 24th Topical Conference on Radio-frequency Power in Plasma - 2022

Novel contributions

- **Design a resonant antenna**
  - ✓ New antenna concept resonant tunable DTT



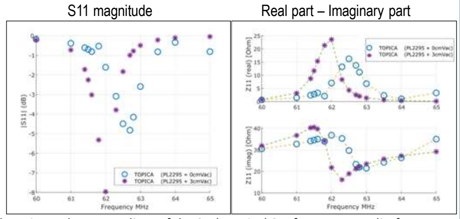


➢ **Short**

➢ **Tap point**
Control the value of the impedance at resonance.

➢ **Tuning element**
Move the resonance in frequency.

Without Vacuum	Resonance= 62.8MHz	S11 = -4.8dB	469kW coupled per port
+ 3cm Vacuum	Resonance= 62MHz	S11 = -7.96dB	679kW coupled per port

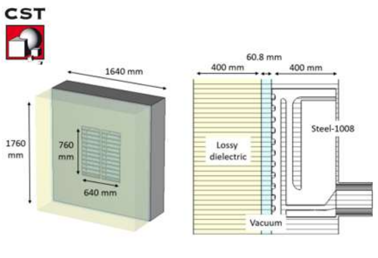


A Self-Resonant Plug-In IC Antenna for DTT – D. Milanesio et Al. - Proceedings of the 24th Topical Conference on Radio-frequency Power in Plasma - 2022

Adopted methodologies

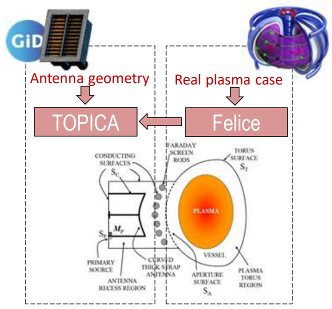
- **Simulations for Antenna Optimization**

➢ Approximate effect of plasma simulated by a high-permittivity lossy dielectric to allow use of a commercial simulator for standard antennas



A Self-Resonant Plug-In IC Antenna for DTT – D. Milanesio et Al. - Proceedings of the 24th Topical Conference on Radio-frequency Power in Plasma - 2022

➢ Verification of designed antenna with TOPICA code (plasma effect)



V. Lancellotti *et al* 2006 *Nucl. Fusion* **46** S476

Future work

- New antenna improved power handling reduction of the max E field
- Integration of axisymmetric plasma (REAL ANTENNA – PLASMA APPROXIMATION)
- Improve TOPICA solver in terms of velocity (*FAST SOLVERS)

Acknowledgments

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DTT DIVERTOR TOKAMAK TEST facility

List of attended classes

- 02SFURV Programmazione scientifica avanzata in matlab 21/04/2022, 6 credits.
- 01RPVKG Plasma physics 08/04/2022, 6 credits.
- 01DOBRV Mathematical-physical theory of electromagnetism 03/082022, 3 credits.
- 01RGBRV Optimization methods for engineering problems 07/06/2022, 6 credits.
- 01UIZRV Microwave sensing and imaging for innovative applications in the health and food industry 22/03/2022, 4 credits.
- 01NDLRV Lingua italiana I livello 17/02/2022, 3 credits.
- ESoA course 2022 - ADVANCED COMPUTATIONAL EM (MCSA COMPETE) 23/09/2022.

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering