3D/1D analysis of ICRF antennas

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3D/1D Analysis of ICRF Antennas

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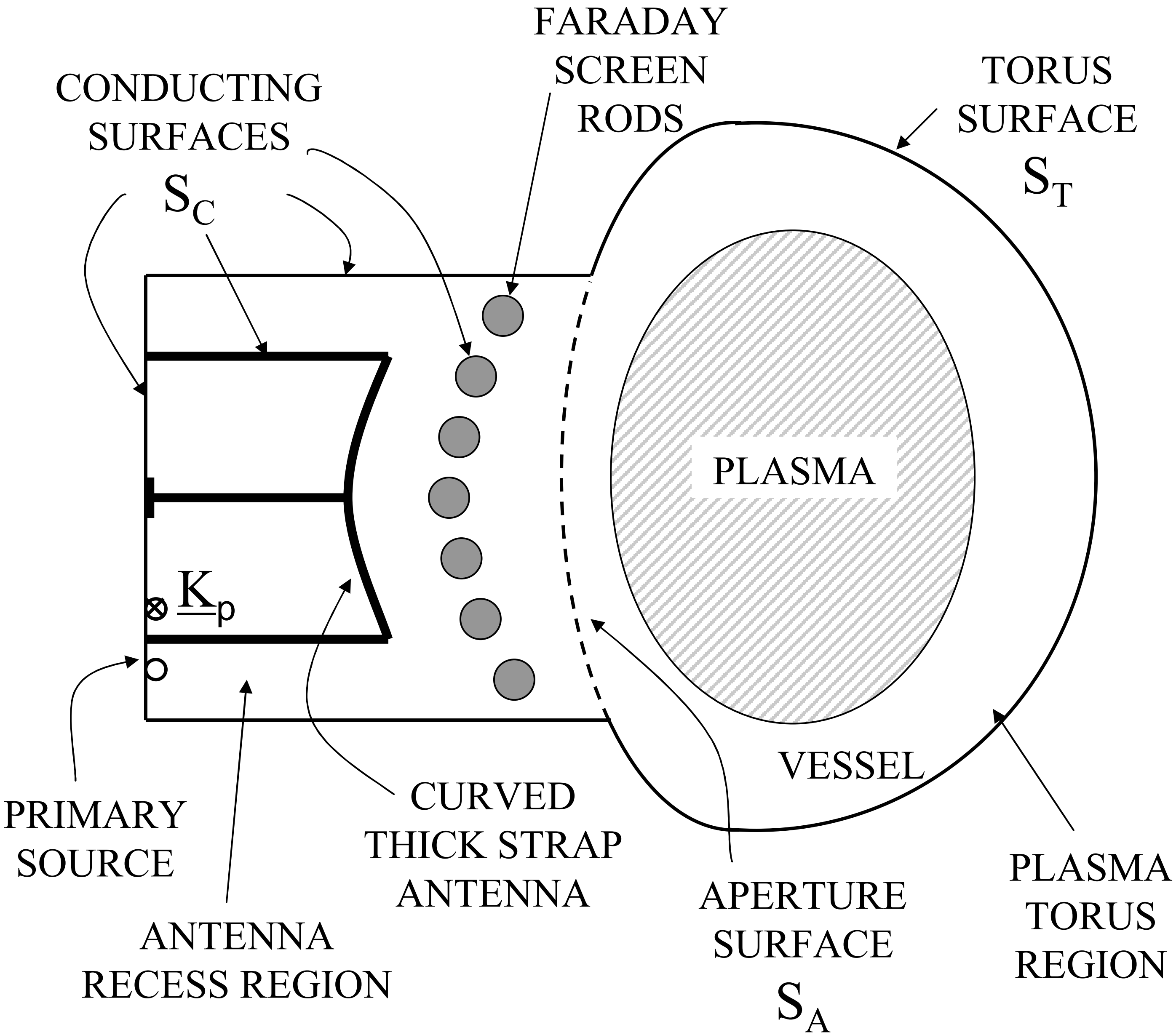
Objectives

- To study a **realistic antenna** with a high level of geometric details (solid, rounded edges, etc.) and within a reasonable CPU time

- To include an accurate and **realistic plasma** description into the model

- To get reliable information about:
  - **antenna input parameters (Z and S matrices, SWR)** which allow an accurate design of *tuning & matching* control system
  - **electric field distribution** everywhere (breakdown, hot spots)
  - **behaviour during ELM**

Typical Configuration

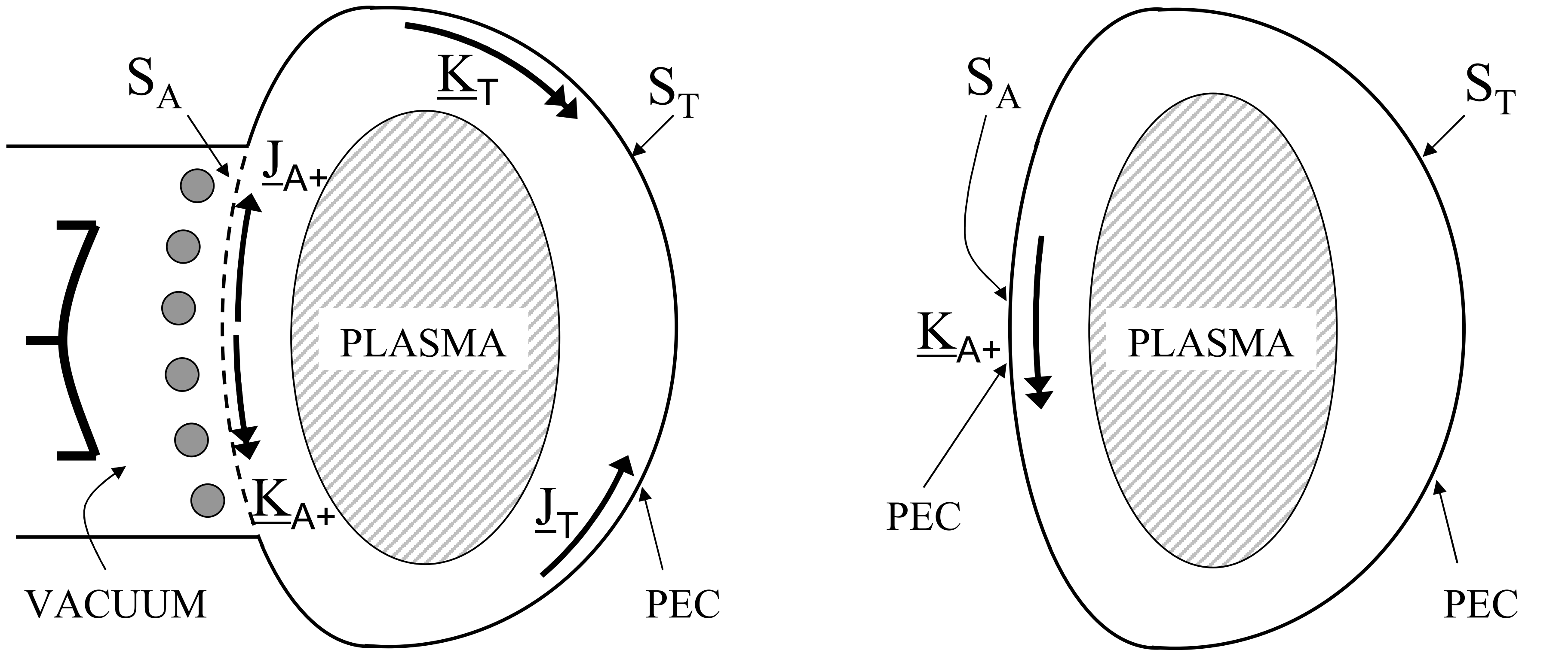


Innovative Idea

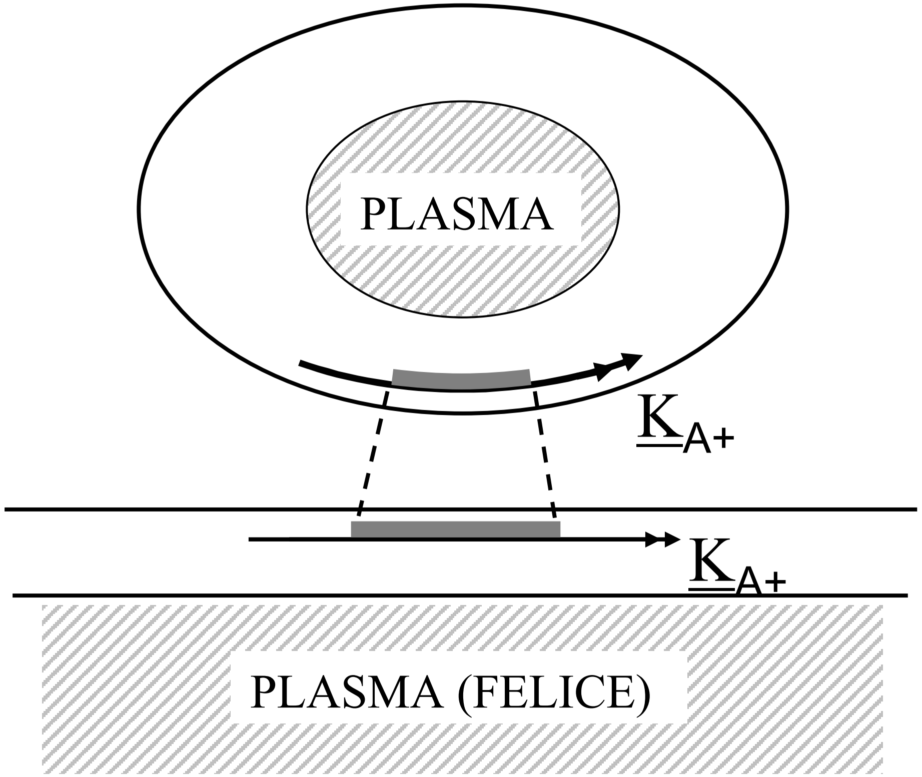
To formulate the boundary value problem:

- Keeping **self-consistency**
- **Maximizing separation** between:
  - complex **antenna geometry**: inside recess box (at least the same accuracy as commercial codes)
  - complex **plasma conditions**: in vacuum vessel (link to existing physics-based plasma codes)
- This yields to two coupled integral equations (for further discussion or documentation see authors at **POSTER SESSION VIII, THURSDAY AFTERNOON**)

Problem Formulation: Plasma



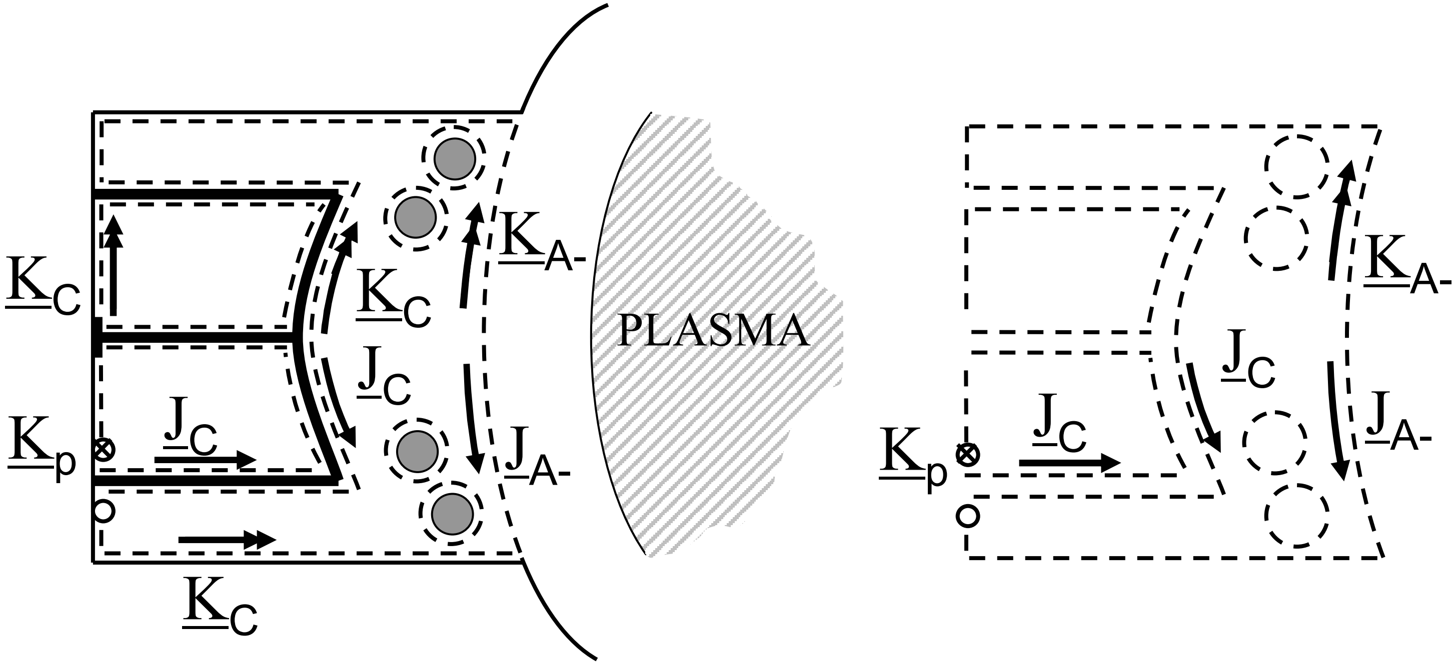
Plasma Model



- Projection of surface/flat plasma description (FELICE formulation) to our curved aperture ("1.5D" approximation)

- Waiting to couple to 2D plasma description (TORIC, EMIR, ...)

Problem Formulation: Antenna



Moment Method Solution

- The unknown are expressed as a superposition of linear interpolating vector functions (RWG) defined over **triangular facets**

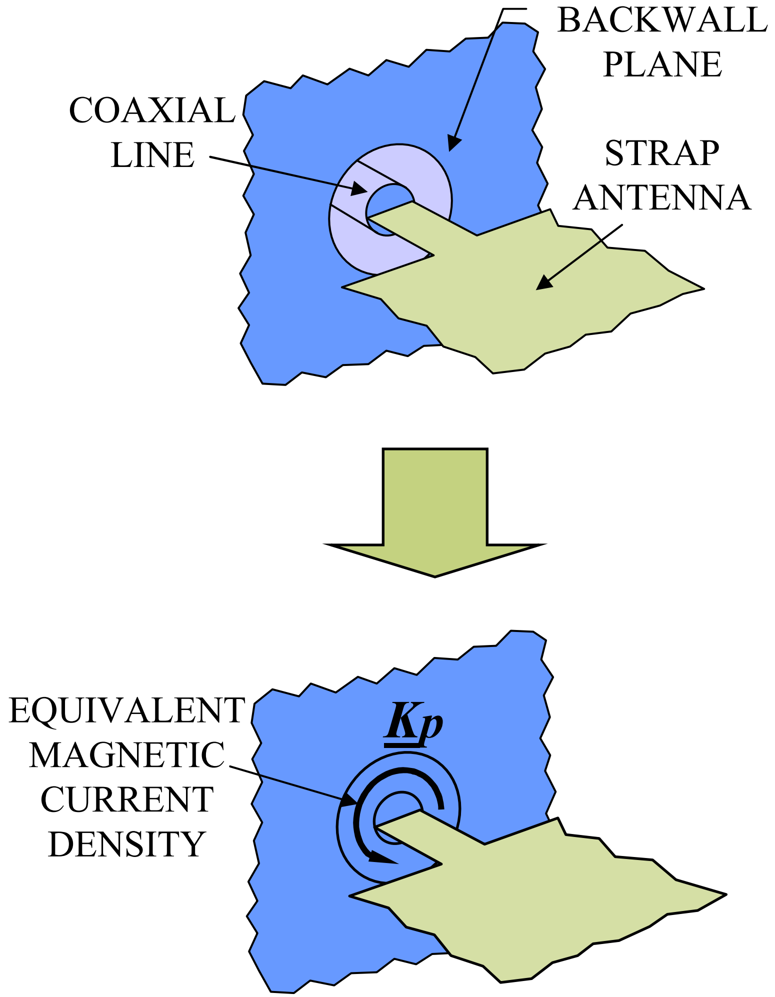
$$\underline{J}_C = \sum_{n=1}^{N} I_n \underline{f}_n \qquad \underline{K}_{A-} = -\underline{K}_{A+} = \sum_{q=1}^{Q} M_q \underline{g}_q$$

- Standard testing procedure yields the final algebraic system:

$$\begin{bmatrix} -G_{JJ} & G_{JK} - T_B \\ \left(G_{JK} - T_B\right)^T & G_{KK} - Y_p \end{bmatrix} \begin{bmatrix} \sqrt{Z_0} I \\ -\sqrt{Y_0} M \end{bmatrix} = \begin{bmatrix} \sqrt{Y_0} V_0 \\ \sqrt{Z_0} I_0 \end{bmatrix}$$

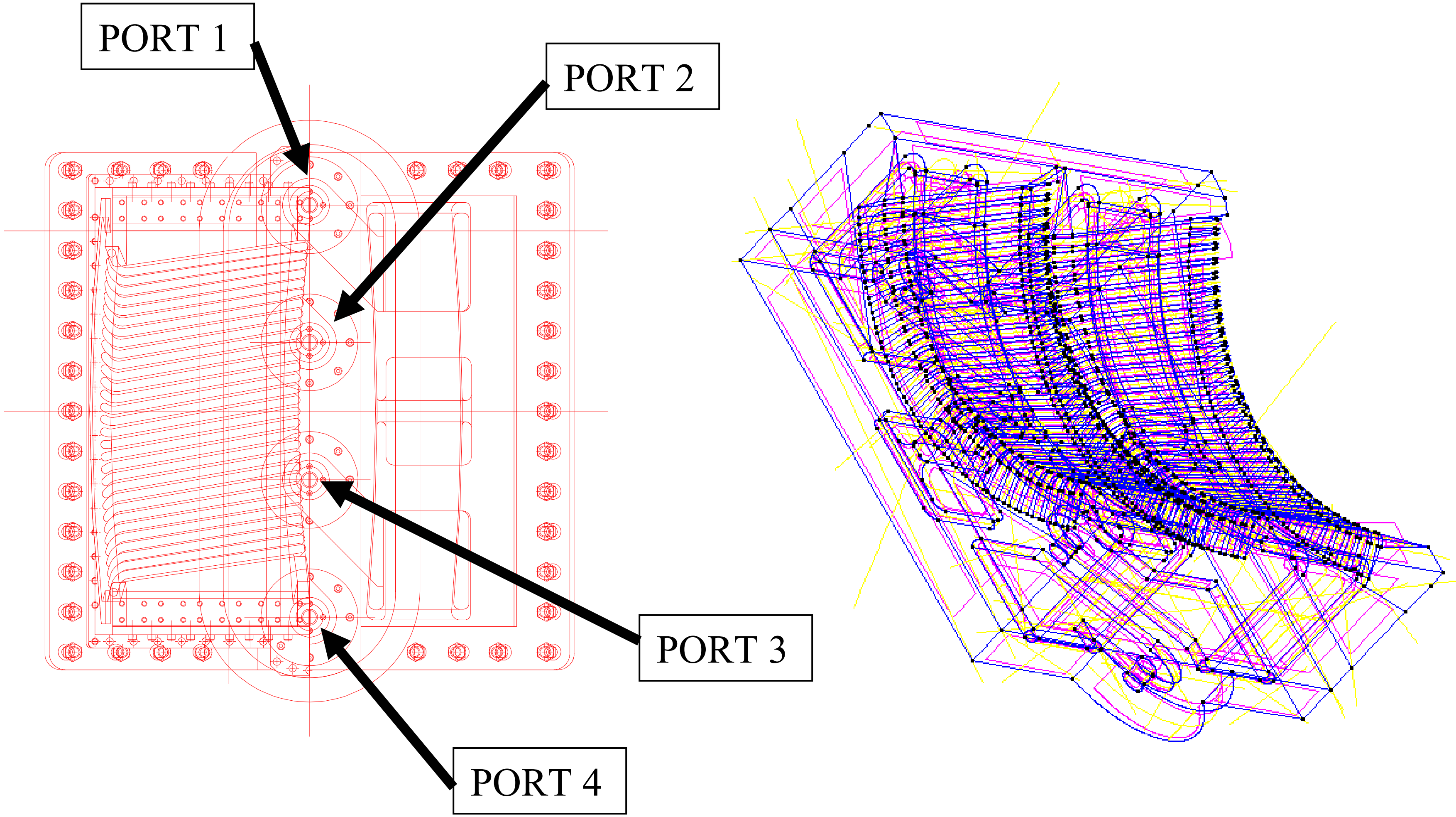
Source Modeling

- The antenna is fed by a **coaxial line** truncated at the back wall section

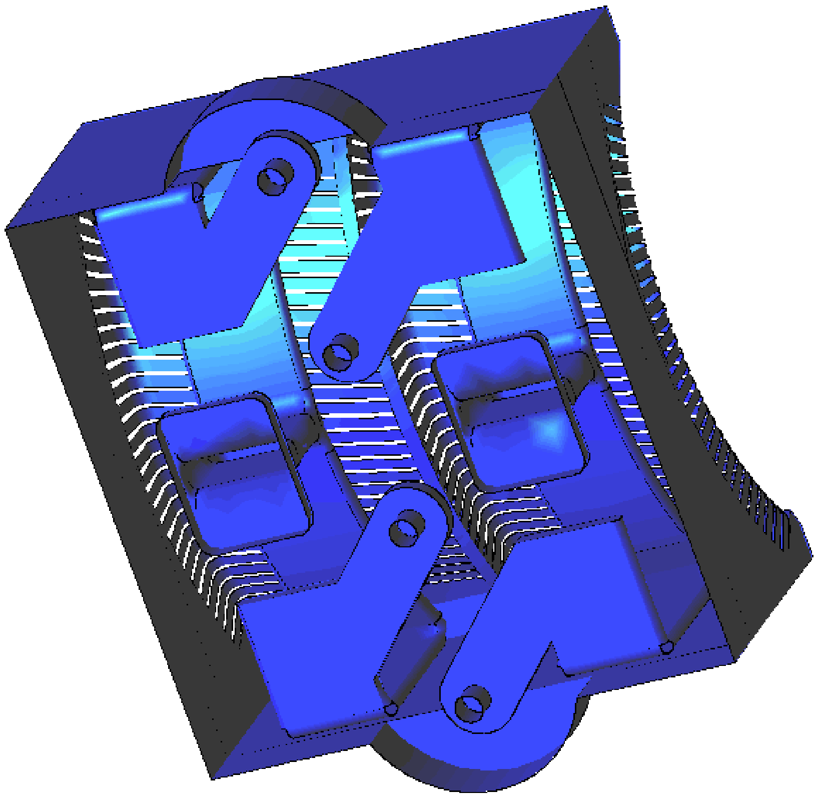


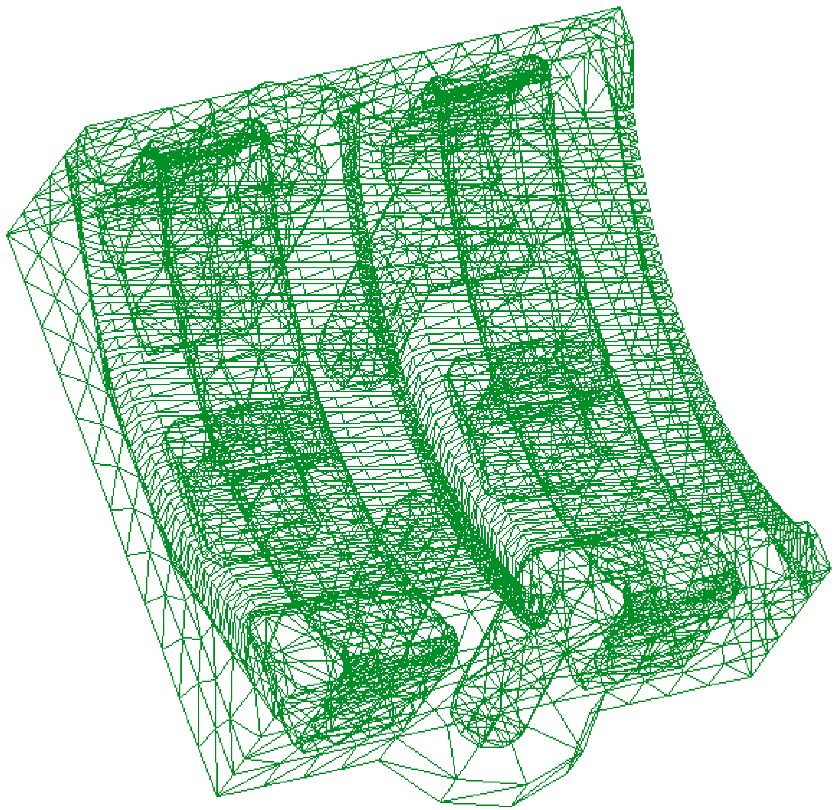
- Equivalence theorem is invoked to replace the coax with a surface **magnetic current**

From CAD to 3D Model

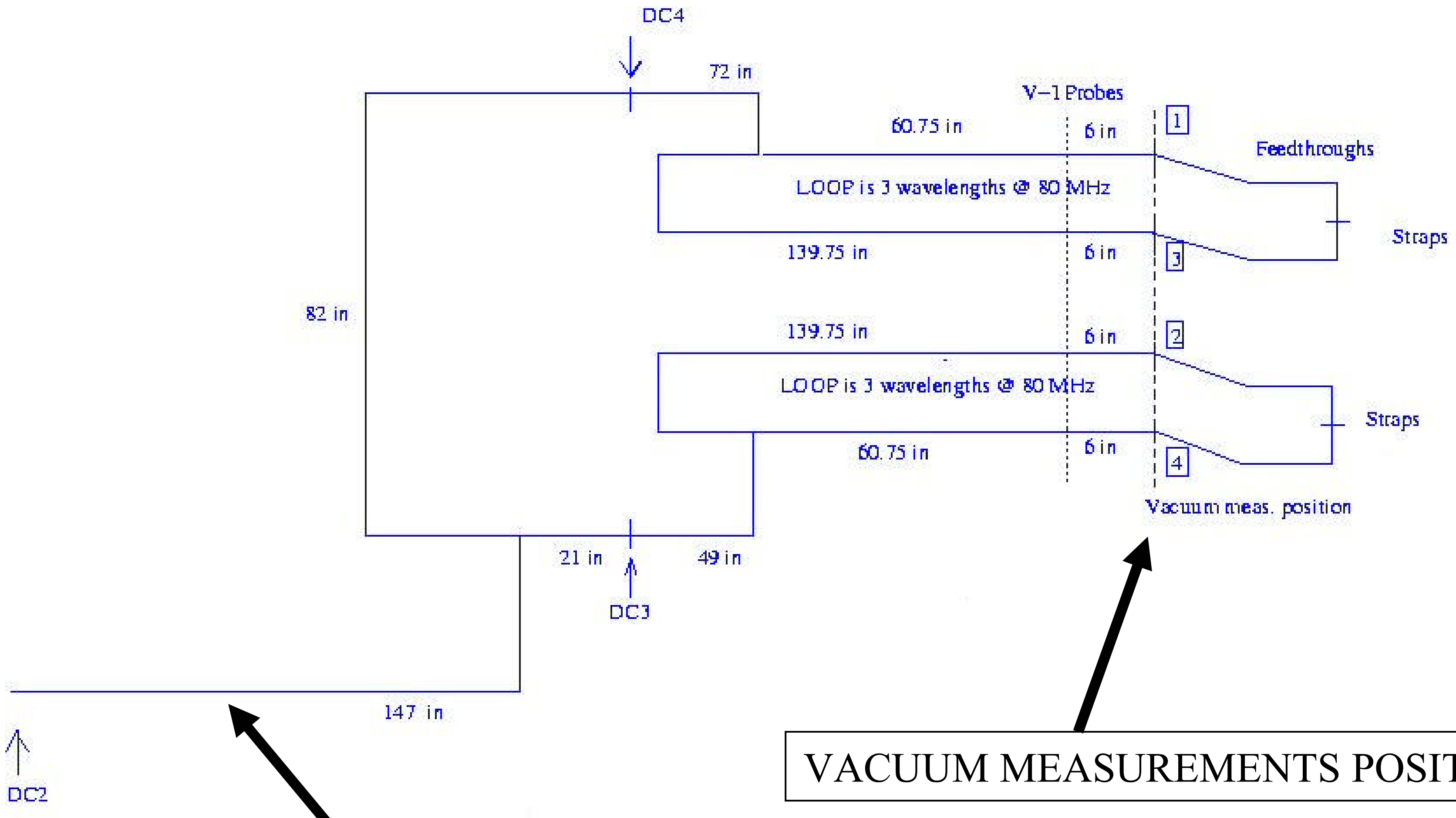


From 3D Model to Meshing





Feeding System



VACUUM MEASUREMENTS POSITION

$$R_C = \frac{V_{max}^2}{2P} = \frac{Z_0}{SWR}$$

PLASMA MEASUREMENTS POSITION

Alcator C-mod D antenna in Vacuo

The data used in the following simulations are courtesy of Alcator C-mod Group @ MIT, Cambridge, MA (USA)

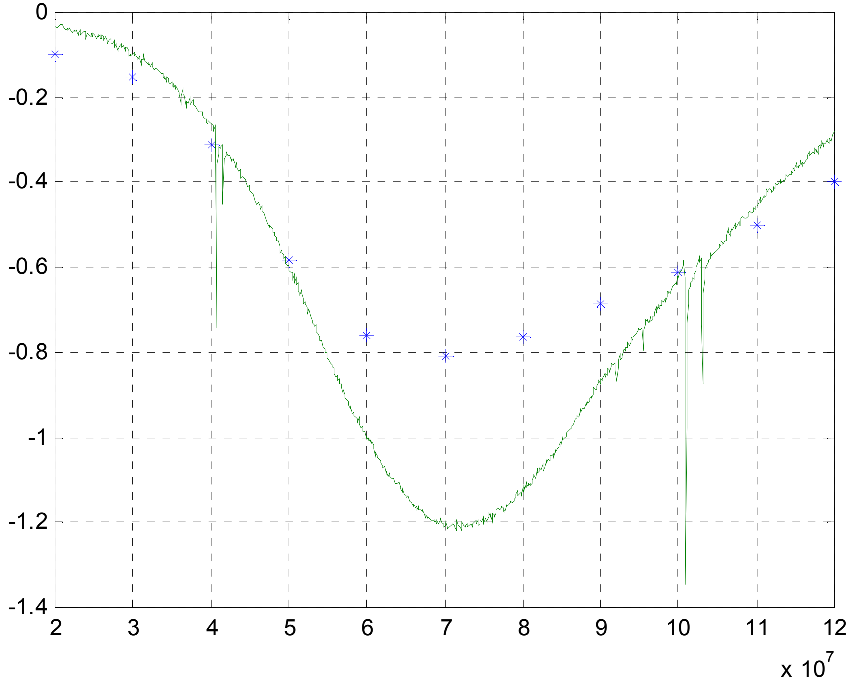
Measurement (-) conditions:

1. Antenna radiating in real torus
2. Some details changed
3. Lossy conductors

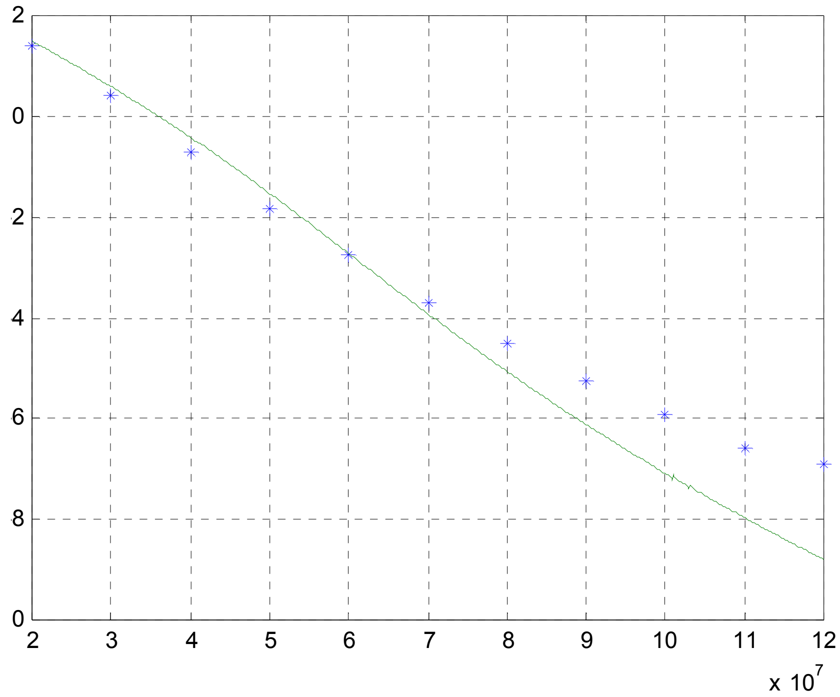
Simulation (*) conditions:

1. Antenna model to be refined
2. Voltage gap excitation
3. Antenna radiating in free space
4. Perfect electric conductors

S11 (~S33) [dB, rad]

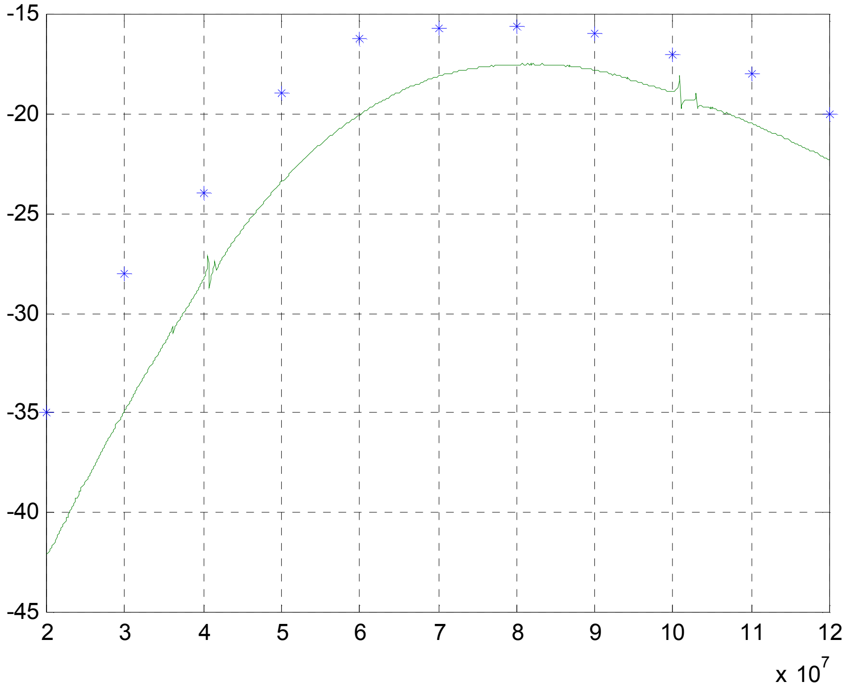


Frequency [Hz]

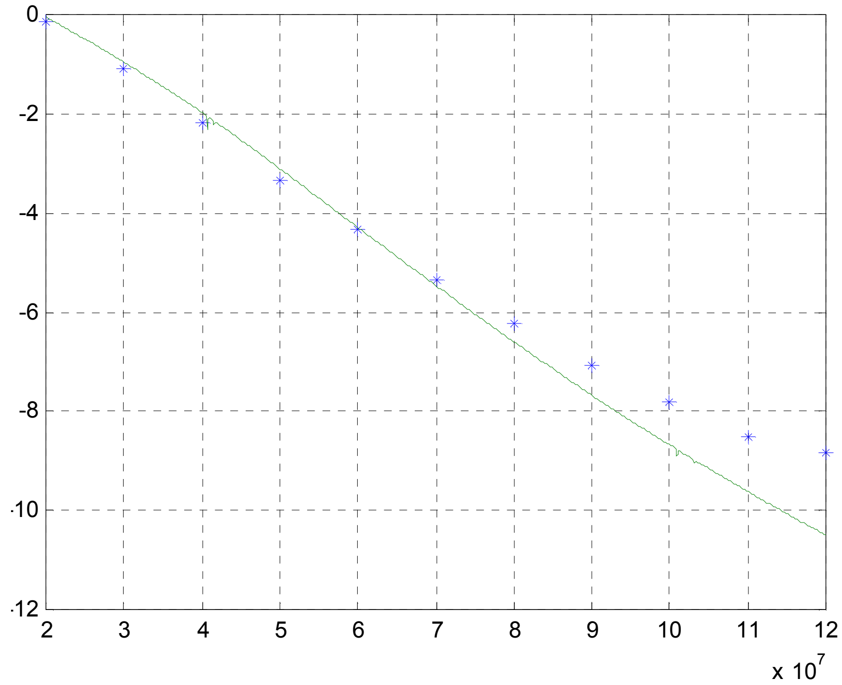


Frequency [Hz]

S12 (~S34) [dB, rad]

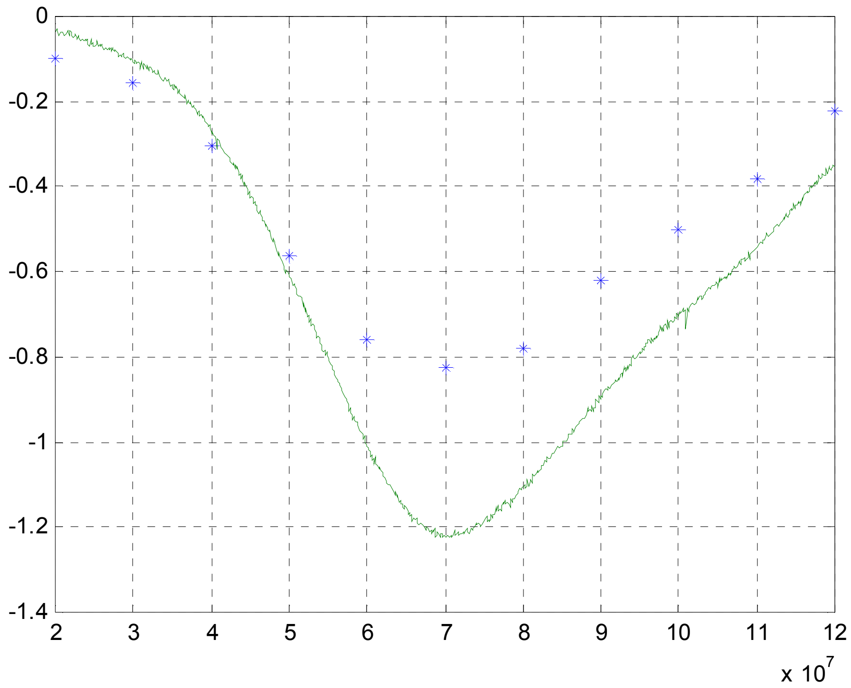


Frequency [Hz]

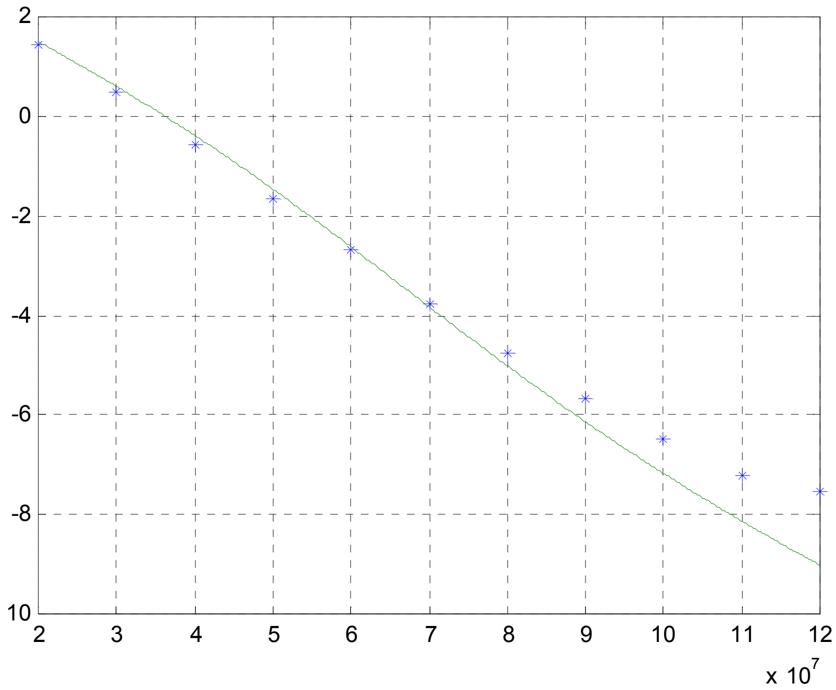


Frequency [Hz]

S22 (~S44) [dB, rad]

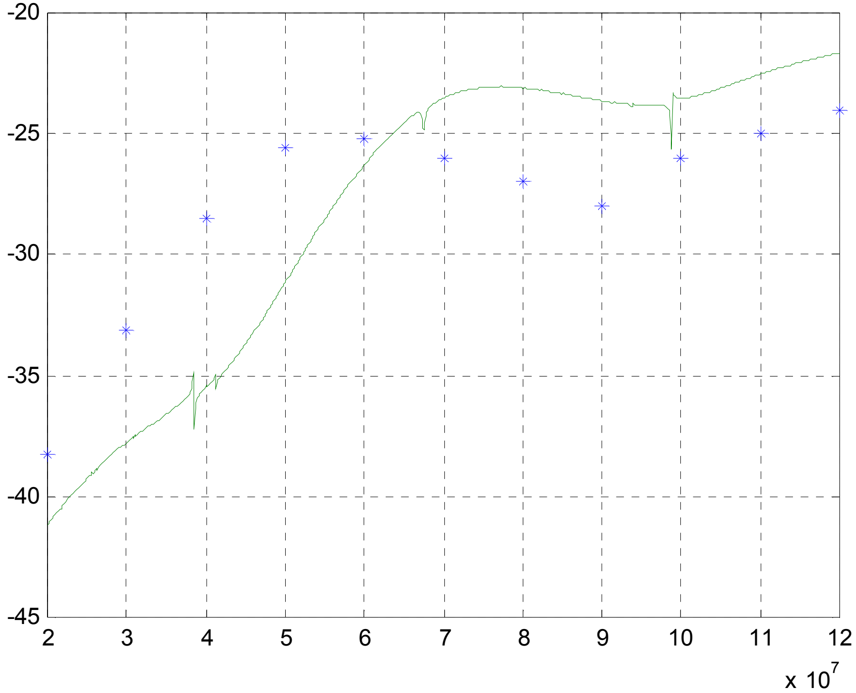


Frequency [Hz]

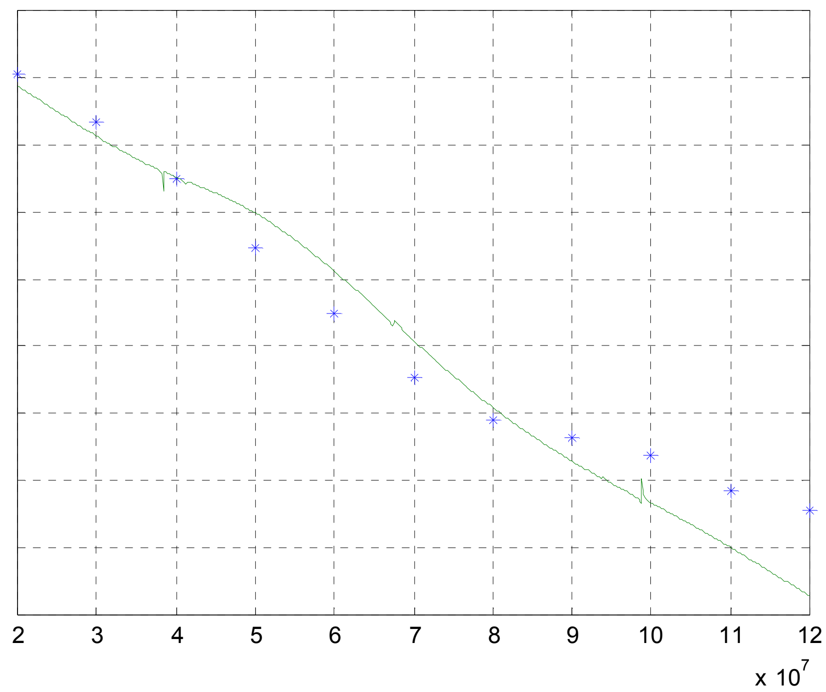


Frequency [Hz]

S23 (~S14) [dB, rad]

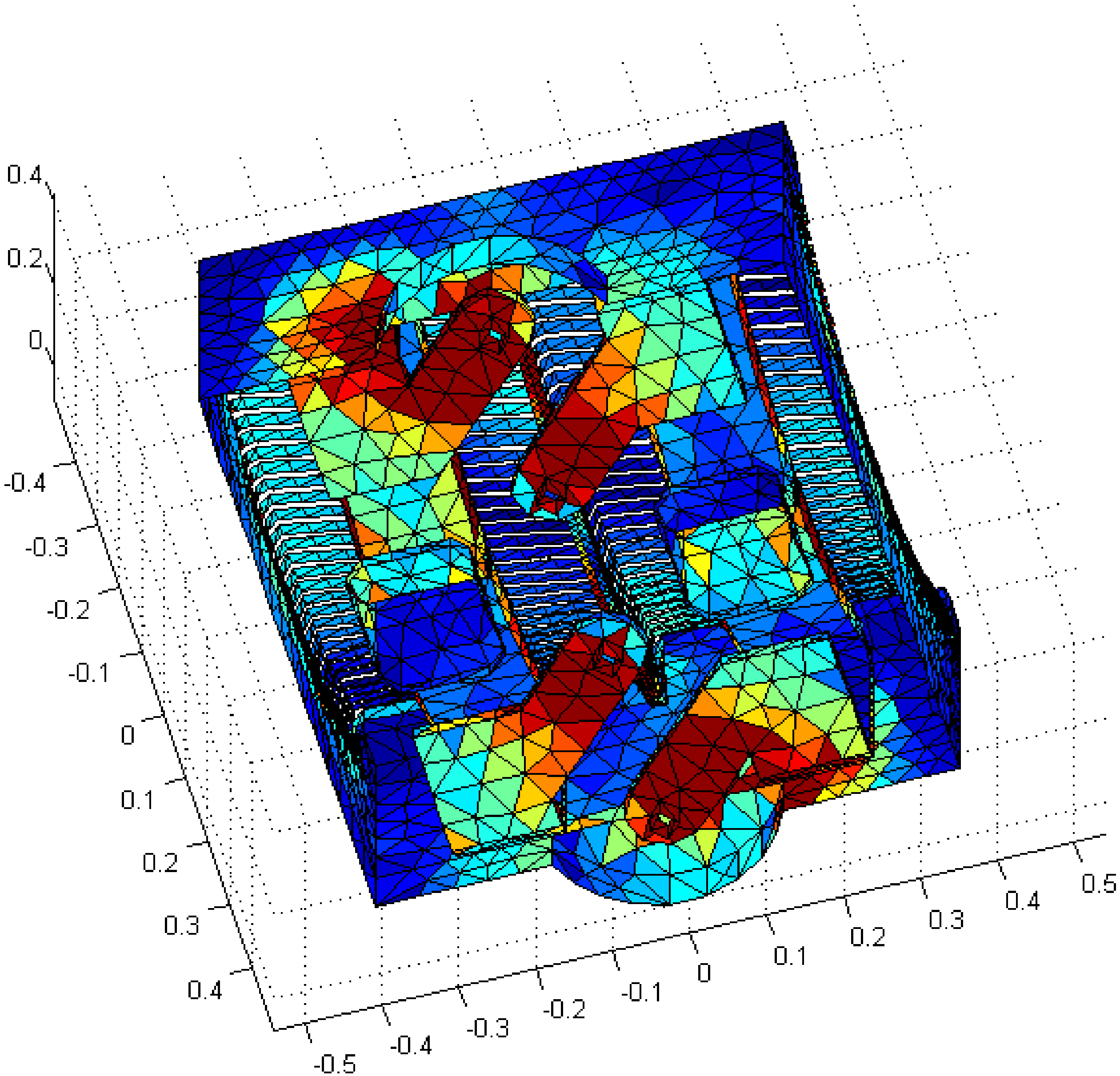


Frequency [Hz]



Frequency [Hz]

Current Distribution at 110 MHz



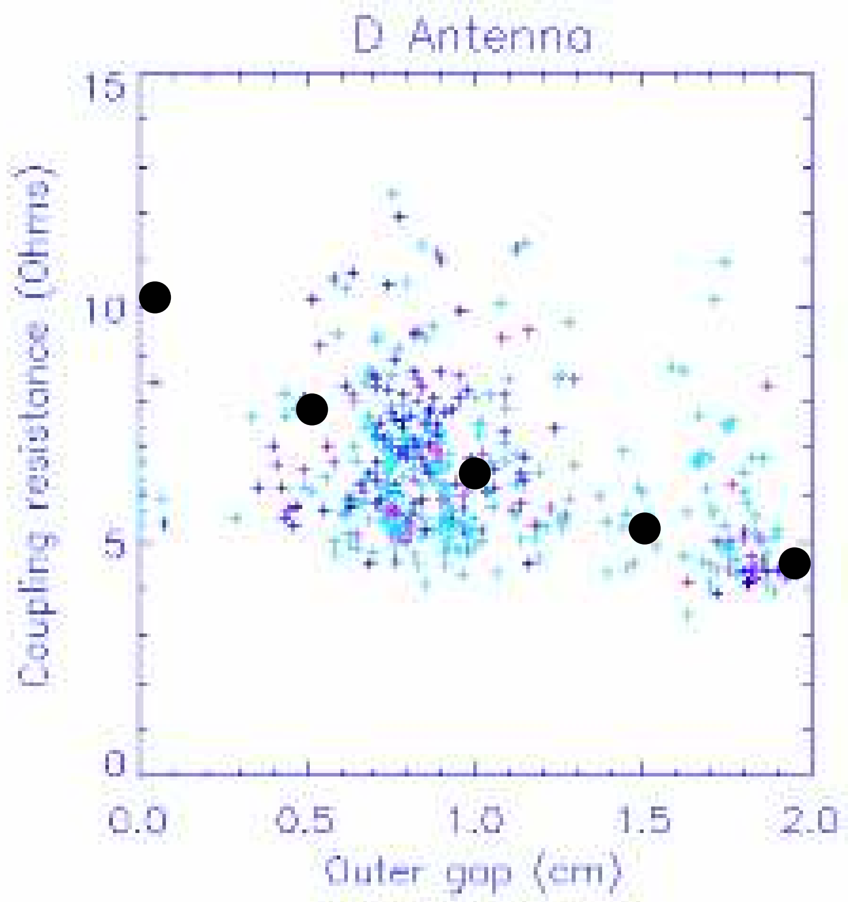
Alcator C-mod D antenna with Plasma

The data used in the following simulations are courtesy of Alcator C-mod Group @ MIT, Cambridge, MA (USA)

Plasma characteristics:

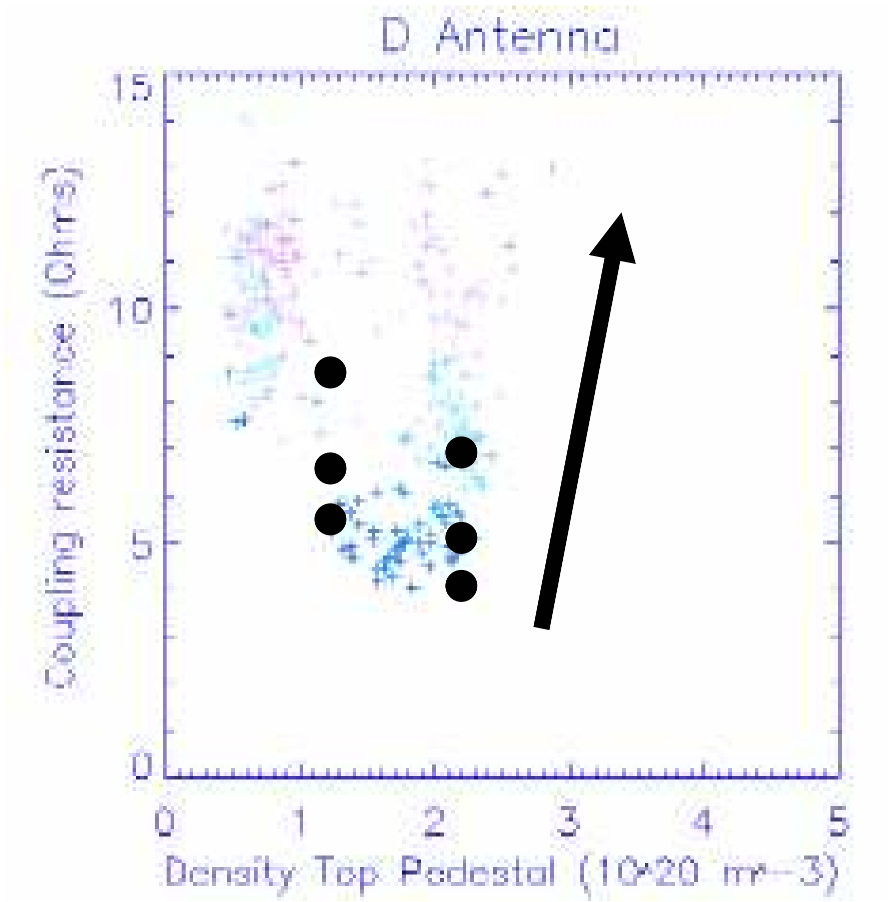
BZERO = 5.3, toroidal magnetic field on axis (T)
RTORUS = 67.5, toroidal plasma radius (cm)
RPLASM = 22.3, poloidal plasma radius (cm)
RVERT = 34.3, vertical plasma radius (cm)
DENC = 1.2E14, central electron density (/m^3)
DNEDGE = 0.75E14, edge electron density
GLDN = 0.8, density decay length in SOL (cm)
EDGLEN = 3.2, width of the scrape off layer (cm)
TEMPEC = 5.0, central electron temperature (KeV)
TEEDGE = 0.20, edge electron temperature
GLTE = 2.0, temperature decay length in SOL (cm)
NSPEC = 2, number of ion species
ACONC(1) = 0.98, concentrations N(j)/N(e)...
ACONC(2) = 0.02,
FREQCY = 80.0E6, transmitter frequency (Hz)
...

Outer gap



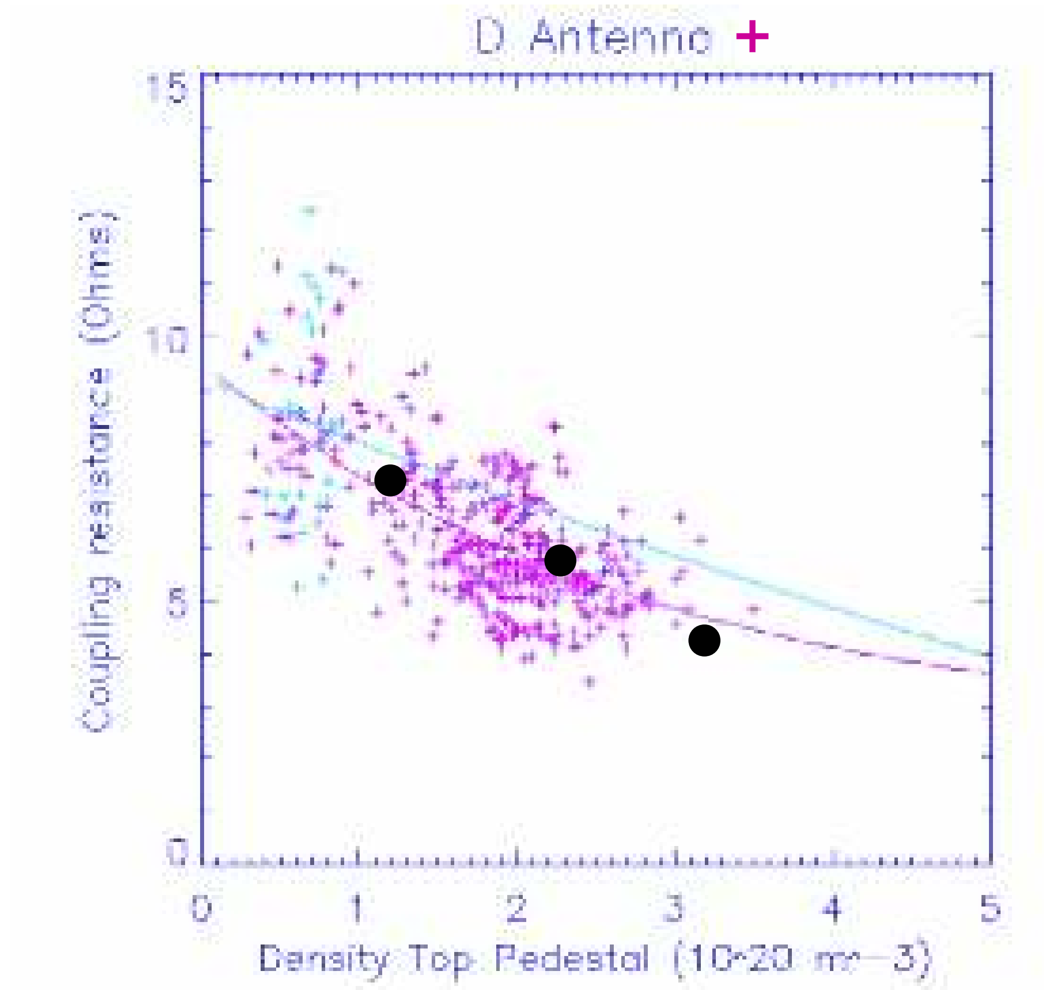
Different color represent different minority fraction H/D: no dependance is found both experimentally and in simulations

SOL density



Different color represent different position averaged density in SOL

Density top pedestal



Conclusions

TOPICA© simulation suite:

- 3D solid antenna structure model (including FS, box, …)
- "1.5D" plasma, non-homogeneous, FLR, absorption (FELICE plasma model)
- Structure geometry drawn in CAD and imported into TOPICA core
- Multi-port (typical: 4 ports) circuit parameters (Z, Y, S matrices) calculation
- Coax, Voltage and current excitation of strap ports
- Computes current, fields, and voltage everywhere around antenna and housing
- High efficiency, controllable convergence, affordable CPU times (**8000 basis function takes 8 hours on a PC with a 2.66 MHz CPU and 1Gbyte RAM**)

NEXT STEP: coupling with 2D plasma model (TORIC, EMIR, …)