An automatic matching system for the ICRF antenna at TOMAS

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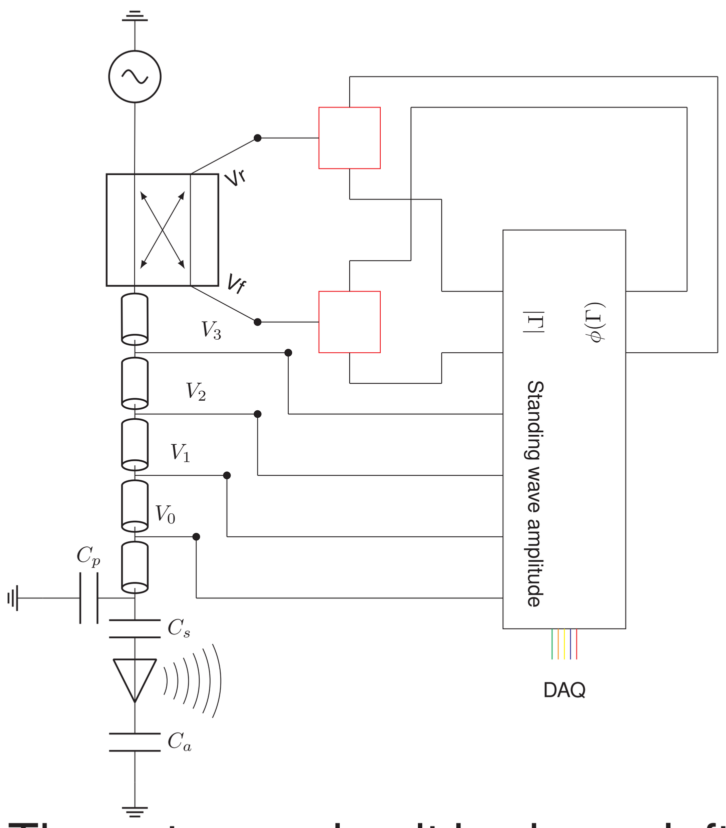
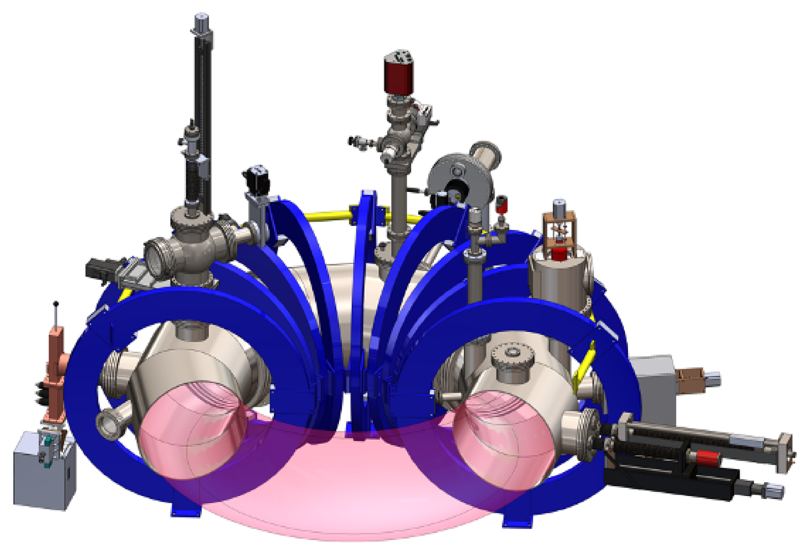
Introduction

The TOMAS (TOroidal Magnetized System) device is a small machine located in Forschungszentrum Jülich, Germany [1]. The small machine has various wall conditioning systems used in big machines such as Glow Discharge (GD), Electron Cyclotron Wall Conditioning (ECWC) and, the focus of this poster, an Ion Cyclotron Resonance Frequency (ICRF) antenna capable of Ion Cyclotron Wall Conditioning (ICWC). This antenna needs to be tuned to the plasma, for which we need an algorithm.





The antenna circuit is shown left, if we imagine the power to flow from top (the AC symbol/amplifier output) to bottom then it goes from the amplifier through a directional coupler, making it possible to measure the forward and reflected standing voltages, after which it goes through a coaxial line with embedded voltage meters. The signal then gets to a T capacitor matching section (i.e the C_p and C_s variable capacitors), after which it goes to the antenna, part of which may couple to the plasma, and then finally we have the pre-matching capacitor C_a. If the system is not perfectly "matched", meaning that not all the power was deposited in the plasma, then a part may return back up the chain to the amplifier which dumps the power in a dummy load (a power absorbing system).

Derivation

Transmission line theory:

$$V_i = V_0^+(e^{i\beta l_i} + \Gamma_L e^{-i\beta l_i}) \tag{1}$$

$$\frac{|V_i|^2}{|V^+|^2} = 1 + u^2 + v^2 + 2u\cos(2\beta l_i) + 2v\sin(2\beta l_i) \tag{2}$$

Where $\Gamma_L := u + iv$. Using the absolute voltage measurements at the points along the line $|V_{0-3}|$ and the measured forward standing wave voltage $|V^+|$, we can solve for u and v using 3 of the 4 voltage probes. Now that we have Γ_L we can transform it to find that the admittance is given by

$$Y_L = \frac{1-\Gamma_L}{1+\Gamma_L} = \frac{1-u^2-v^2}{(1+u)^2+v^2} - i\frac{2v}{(1+u)^2+v^2} := g + ib \tag{3}$$

RF matching (i.e no reflection) occurs when $\Re\{Y_L\} := g = 1$ and $\Im\{Y_L\} := b = 0$. So, we'll introduce the error variables

$$\epsilon_b = \frac{2v}{(1+u)^2+v^2} \quad \text{and} \quad \epsilon_g = 1 - \frac{1-u^2-v^2}{(1+u)^2+v^2} \tag{4}$$

To match the system, the change in capacitances will have to vary as:

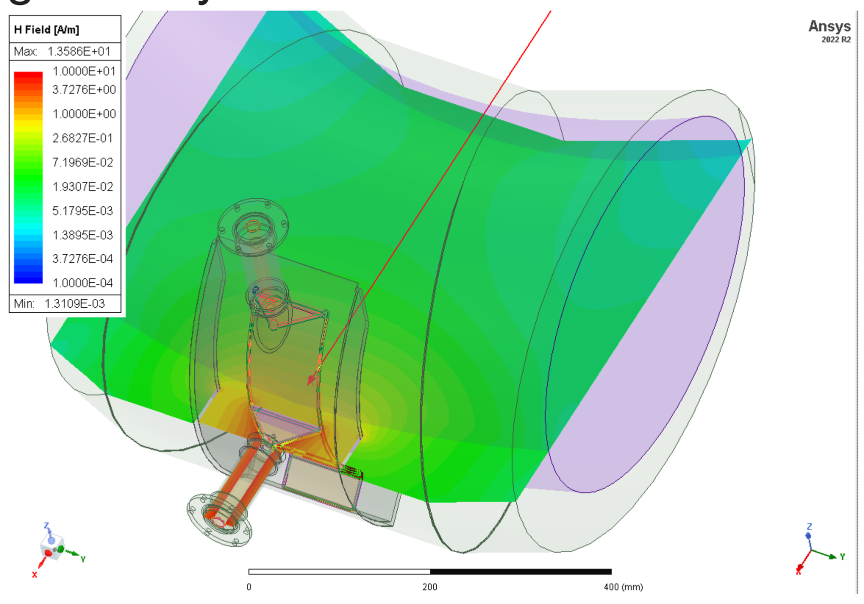
$$\delta C_s \propto \epsilon_g \cos\phi + \epsilon_b \sin\phi \tag{5}$$

$$\delta C_p \propto \epsilon_b \cos\phi - \epsilon_g \sin\phi \tag{6}$$

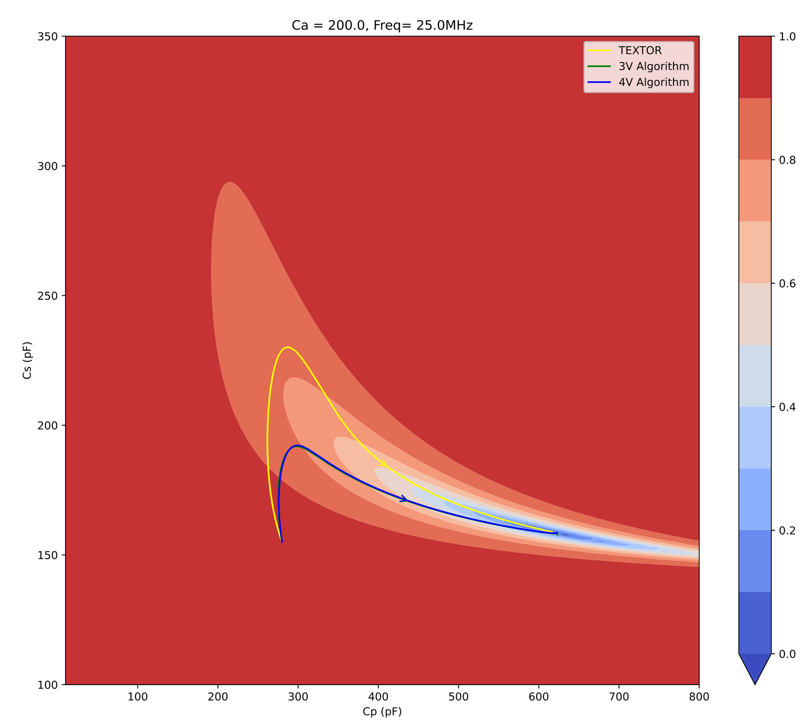
With ϕ the phase of Γ, i.e $\Delta\vec{C} \propto \vec{\epsilon} \cdot R(-\phi(\Gamma))$.

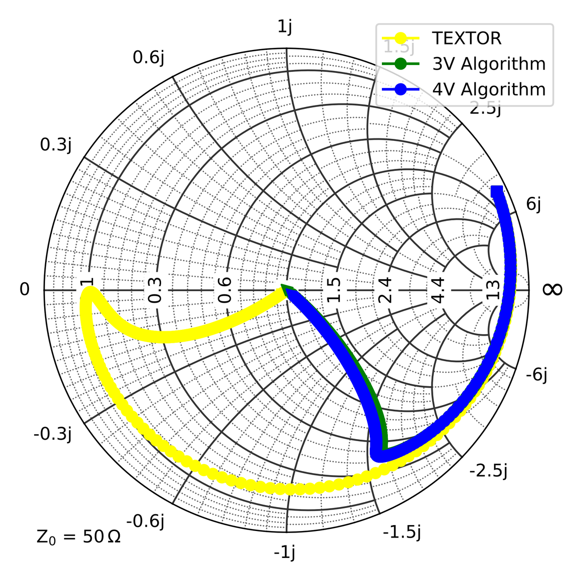
Simulation

To simulate the circuit we needed the S-matrices of all the components, the most important of which being the antenna in a plasma. This was simulated using HFSS making use of a realistic plasma dielectric in a simplified TOMAS geometry as shown below at the left

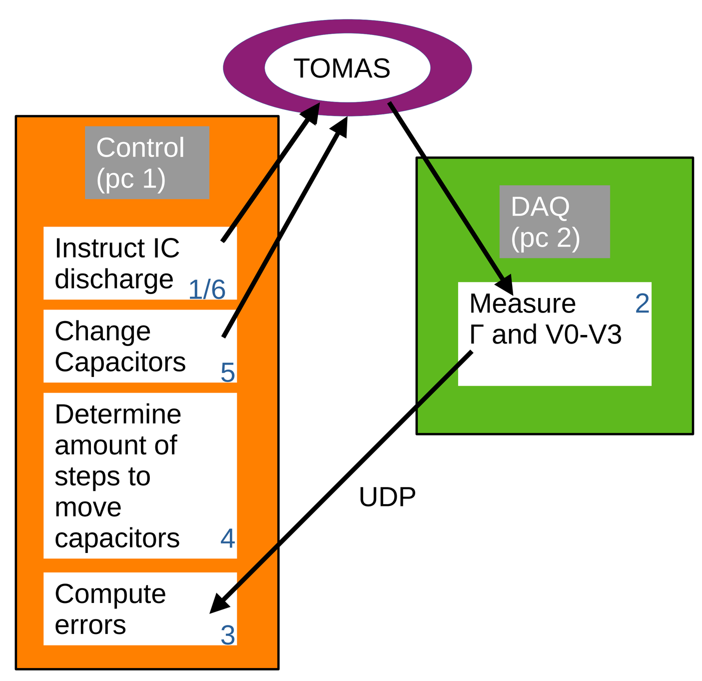


After this, using the open source tool pyRFtk, the complete circuit was put together. Now that we had a virtual TOMAS IC system, it was possible to test out the newly derived algorithm by evolving the system from an initial C_a,C_s,C_p position of which the results (3V and 4V algorithm) are shown below both in capacitor space (left) with the colors indicating $|\Gamma|$ and admittance space (right).

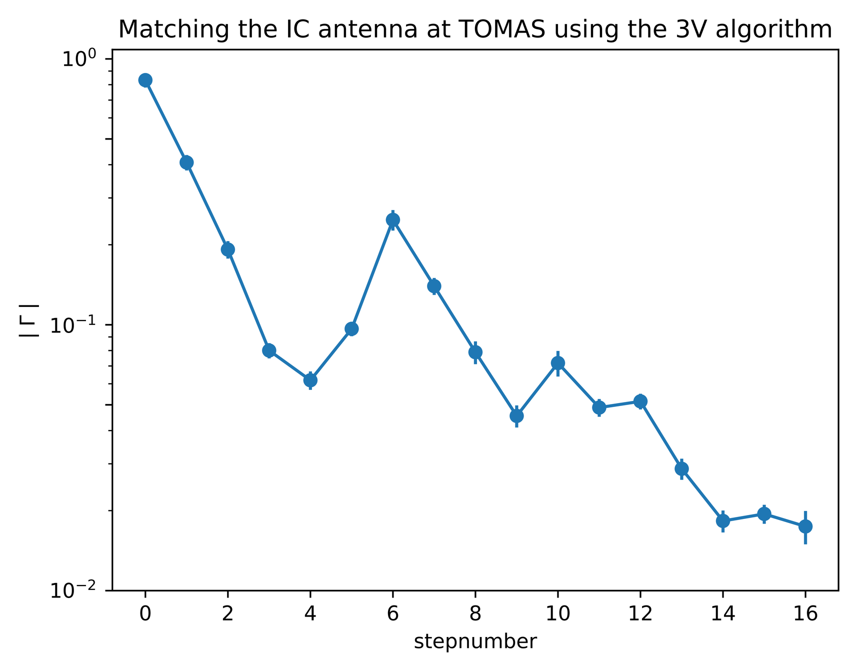


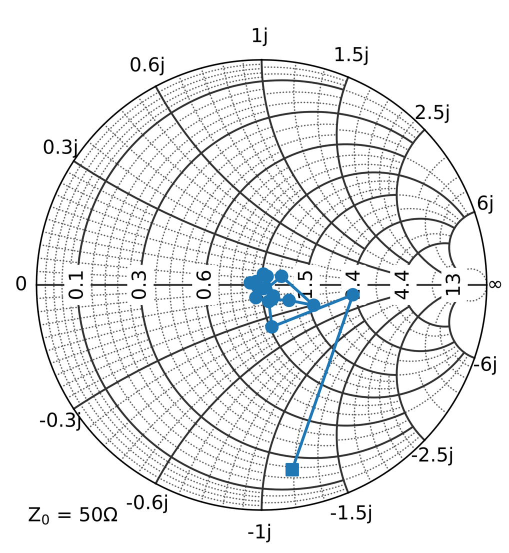


Testing on the actual machine



The control pc (pc1) instructs an IC discharge, either whilst using EC or with a short EC discharge beforehand (to create a plasma). It also triggers the DAQ (pc2) to collect data, pc2 collects the needed measurements and sends it over to pc1 via UDP, pc1 then goes trough the steps of the algorithm and moves the capacitors accordingly. Then it repeats the process. A test of this algorithm on the machine is shown below.





KEY REFERENCES

[1] A. Goriaev et al. The upgraded TOMAS device: A toroidal plasma facility for wall conditioning, plasma production, and plasma–surface interaction studies. *Review of Scientific Instruments*, 92(2):023506, 02 2021.

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