Advances in the modeling of the front face of the ITER ICRF antenna

F. Louche, A. Messiaen, P. Dumortier & F. Durodié

Laboratory for Plasma Physics - Association "Euratom-Belgian State", Trilateral Euregio Cluster, Ecole Royale Militaire - Koninklijke Militaire School, B-1000 Brussels, Belgium

Introduction

Ion cyclotron resonance heating (ICRH) is one the auxiliary heating schemes considered for ITER. The antenna designed for this task is made of 24 radiating straps grouped in 8 triplets by means of 4-port junctions. It is designed to deliver 20 MW to the plasma with low strap voltages. The orginal design has been significantly optimized during the last couple of years [1], notably with the help of electromagnetic simulations performed with the commercial code CST Microwave Studio® (MWS) [2]. An issue which still needs to be clarified is the necessity to align the front face of the antenna with the plasma separatrix. The present geometry of the antenna is flat in the toroidal direction, and "V-shaped" in the poloidal direction. Due to the toroidal curvature of the plasma in front of the antenna it is expected that the loading by individual straps will vary significantly due to varying strap-plasma distance. Straps in the outer columns are further from the load and this will have an impact on the total coupling. We present here a study of some possible solutions to this problem.

Modeling

In order to obtain accurate predictions of the antenna properties and optimize its geometry, it is necessary to get a model as close as possible to the actual mechanical design. Unfortunately no model of the antenna in a format that can directly be imported from CATIA into MWS and allows for easy modifications and optimization was available. Therefore a fully parametrized model of the front face has been re-built for this work, based on the reference CATIA design, featuring most of the geometrical details of the actual antenna. Only the Faraday screen is not included in our model and the poloidal asymmetry of the array is neglected: the poloidal inclination angle of the straps is 9.5 degrees for the eight triplets. The poloidal shape of the plasma must be taken from some realistic ITER equilibrium, and for the purpose of this exercise we have chosen the so-called "Scen2_2003_SOF_li085" equilibrium shown in figure 1. MWS unfortunately does not feature any model of a magnetized plasma. It has nevertheless been shown [3] that a dielectric slab with large permittivity can adequately reproduce the main features of wave reflection and refraction at the interface between vacuum and a H-mode plasma. The main slab dielectric approximating the plasma has $\varepsilon_r = 1000$. A scrape-off layer (SOL) is also defined in front of the separatrix. For the moment we consider an exponentially decreasing density (or permittivity) profile with a characteristic length $\lambda_{SOL} = 24$ mm. To evaluate the global power capability of the system, we use a procedure described in [4]. The scattering matrix of the 24 straps array S_{24X24} is included in a circuit model including the eight 4-port junctions as well as the matching and decoupling network. The imposition of appropriate anti-nodes voltage distribution (amplitude and phase) over specific locations in the feeding lines can precisely control the antenna wave spectrum. Such a procedure allows to generate the response of the system for various toroidal and poloidal phasings in terms of the minimum conductance G_{min2} which is proportional to the maximum power coupled to the plasma for a given maximum voltage: $P_{MAX} = 1/2 G_{min2} V_{MAX}{}^2$.

Results

The introduction of the real plasma curvature is expected to have a strong influence on the strap-plasma distance. For the geometry considered in this work this distance can vary by 4 cm within the array due to poloidal and toroidal shape of the plasma. Therefore the usual approximation of a slab load parallel to the front face of the straps can lead to significant discrepancies when compared with the more realistic geometry. We made the comparison between both geometries and computed G_{min2} in function of the frequency for various phasings: see figure 2. We see that a flat load under-estimates coupling by $\sim 30\%$.

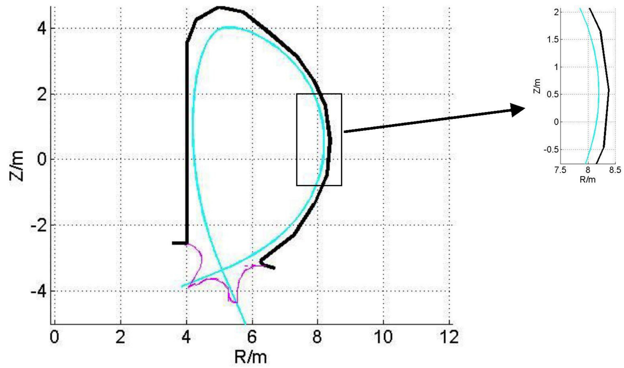

Figure 1: Left: considered equilibrium (antenna region is zoomed), right: perspective view of the full model (including the 4-port junctions)

The toroidal circular curvature of the plasma plays also an important role in the coupling anisotropy: the straps from the inner column are approximately 2 cm closer to the load than straps from the outer column. An effective segmentation should correct this difference and two solutions are considered in the present work. On the one hand we consider a toroidal "V-shape" antenna where the straps are aligned with the tangent to the separatrix drawn at the toroidal center in each half-antenna. On the other hand each strap column is aligned with the local tangent to the separatrix. These geometries are referred to as "two-segment" and "four-segment" respectively and are schematically depicted in figure 3. Numerical values are all given in the

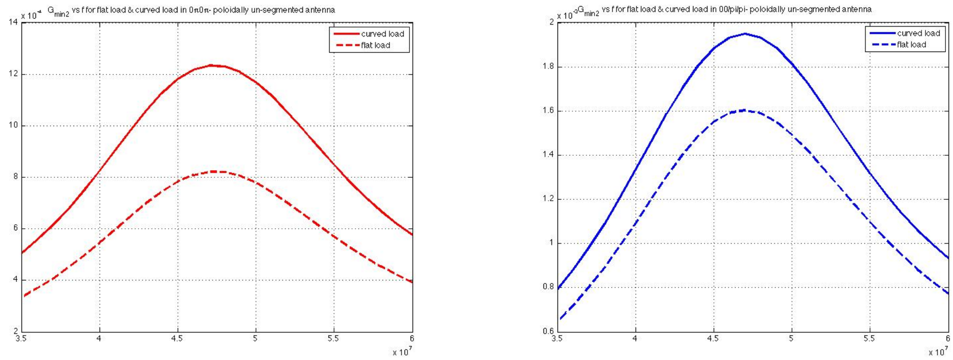

Figure 2: Coupling performance of the ITER antenna: comparison flat/curved load for $0\pi0\pi$ (left) and $00\pi\pi$ toroidal phasing (right).

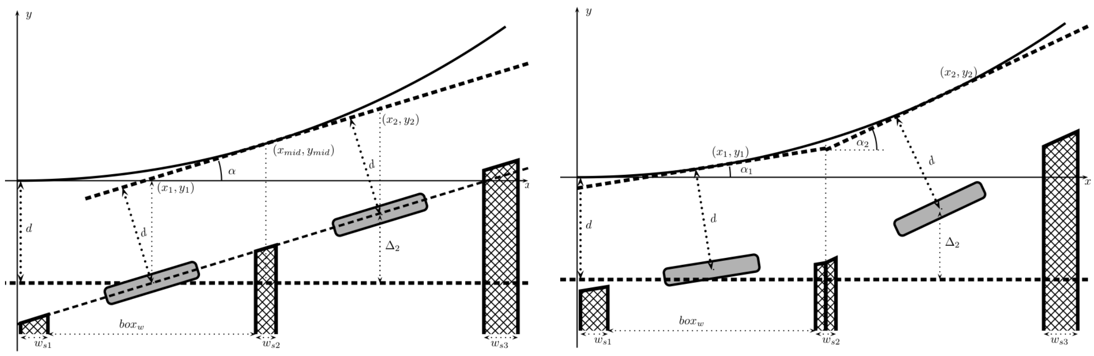

Figure 3: Schematics of the two segmentations proposed to align the straps to the separatrix in the toroidal direction. Left: two-segment ($x_{mid} = 395$ mm, $y_{mid} = 9.52$ mm, $\alpha = 2.8$, $\Delta_1 = 0.3$ mm, $\Delta_2 = 18.2$ mm); right: four-segment ($x_1 = 210$ mm, $y_1 = 2.69$ mm, $x_2 = 580$ mm, $y_2 = 20.54$ mm, $\alpha_1 = 1.5$, $\alpha_2 = 4.1$, $\Delta_1 = 2.6$ mm, $\Delta_2 = 19.9$ mm). Please note that the curvature of the plasma has been significantly increased for the sake of clarity.

legend of the figure. We see that the outer straps should be moved 18.2 mm forwards and rotated by 2.8 degrees in the two-segment case, while the inner and outer straps must be moved 2.6 and 19.9 mm forwards and rotated by 1.5 and 4.1 degrees respectively for the 4-segment case.

To assess the impact of the proposed geometry modifications we have considered the 4 classical toroidal phasings of the strap currents, and $[0\ \pi/2]$ poloidal phasing and computed for each of them the respective G_{min2}: see figure 4 where two cases are represented. We can see that the two-segment approximation leads to a substantial increase of coupling, while the four-segment only slightly improves the coupling. The reduction of coupling when reducing the number of segments can be read in table 1 for midband frequency and for each phasing case and confirms that going from four to two segments is not likely to significantly decrease the coupled power.

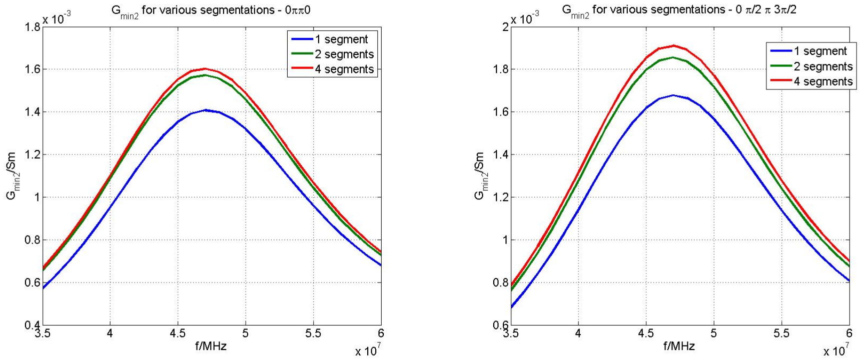

Figure 4: Power capability of the ITER IC array: the three segmentation cases are compared for each phasing.Left: $0\pi\pi0$; right: current drive $0\ \pi/2\ \pi\ 3\pi/2$

	$00\pi\pi$	$0\pi0\pi$	$0\pi\pi0$	$\pi/2$
Δ_{41}	-12%	-15%	-12%	-12%
Δ_{42}	-4%	-3%	-2%	-3%

Table 1: Relative reduction of coupling with respect to the 4-segment case when considering respectively one segment and two segments. Frequency is 47.5 MHz.

Conclusion

Based on the MWS model redrawn from the CATIA design, we have studied various approximations of the front face toroidal shaping. We have considered one poloidal plasma equilibrium. With this information, we have shown that the antenna must follow the toroidal curvature of the plasma: at least two straight-line segments should be considered. The loading is not significantly affected by the four segments option when compared with two segments.

References

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[4] A. Messiaen et al. *Nucl. Fusion*, **49** (2009) 055004.