*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.133 (2004)*

Three-dimensional Modelling of the ITER ICRF External Matching System

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1 Introduction

The problem of the coupling and tuning of the ICRH antenna array of ITER to the generator is of primary importance. A solution for this problem has been presented in [1] where a matching circuit located outside the vessel is considered. This presents the major advantage of avoiding remotely operated parts and ceramics inside the vessel. The 24 straps of the radiating array are grouped in 4 conjugate-T circuits in order to provide the highly load resilient matching needed in presence of ELMy discharges. Accurate simulations of this device are needed to estimate the expectations of the effects of the coupling between the straps. The maxima of the electric field amplitude and their location must be accurately determined. Moreover, the poloidal currents must be as uniform as possible. This must be checked before the installation of the antenna array on ITER. In this work, we present the first results of the modelling of this external matching system with the commercial code CST Microwave Studio® (MWS) [2]. This code considers all the features of the actual design, notably the curvature of the geometry and the thickness of the straps, but does not allow for a magnetized plasma. In our simulations, the antenna is located in front of a high-permittivity equivalent dielectric that mimics single-pass wave launch. Moreover, a scaled mockup of the system has been developed and salted water has been used as a load. We present a comparison between the first measurements and the predictions of our model.

2 Models and first simulation results

The first component that we have modeled is the 4-port junction which connects a set of three straps to one arm of the conjugate-T. It is constituted by a line of variable shape evolving from a stripline shape at one side to a circular coaxial line at the other side. This stripline shape allows an easy connection to the three 60 Ω sections (more details in [1]). The 4-port junction has to distribute equally its input power among the three fed straps. This is made more complicated by the curvature (8.5 degrees in the poloidal direction) of the junction imposed by the constraint that the straps have to lie at approximately the same distance from the separatrix.

The MWS model for this component is shown in figure 1-a (the ports are labeled from 1 to 4): the perfectly conducting junction itself is surrounded by a metallic box (not represented on the figure) whose thickness is tailored in such a way that the characteristic impedance all along the junction is approximately 20 Ω. We have computed the elements of the scattering matrix $\mathbf{S}$ and studied the effect of the asymmetry of the junction. Figure 2 shows the elements of $\mathbf{S}$ related to the input port 1 in function of the generator frequency. In the frequency domain of interest (40-60 MHz), we see that the mutual terms S_{21} and S_{41} are almost identical, but the S_{31} element is slightly higher. The importance

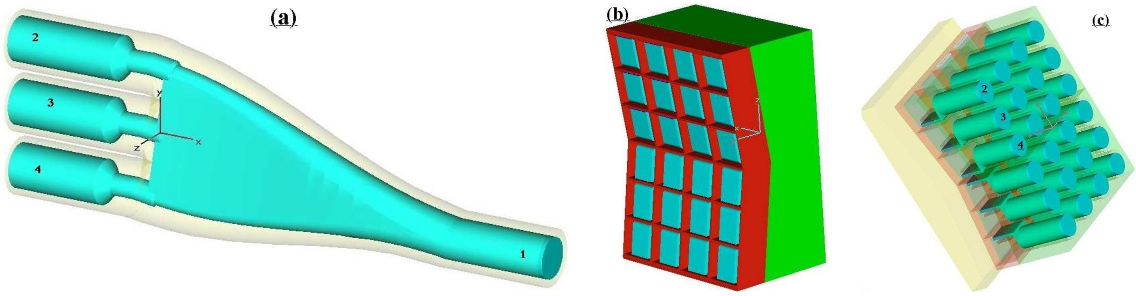

Figure 1: (a) - MWS model of the 4-port junction (b) & (c)- MWS model of the launcher (resp. front and rear view)

of this result on the repartition of the input current on the straps will be investigated further in this section. A model of the full 6×4 straps launcher (see figure 1-b) has also been developed with MWS. The 'quasi-rectangular' features of the device are beneficial for meshing. To avoid the full simulation of the 24 ports, the presence of 2 planes of symmetry is exploited and the 24×24 impedance matrix is obtained from four 6-port simulations of one quarter of the structure. Open boundary conditions are used, to have zero reflection, in all directions but the rear plane (see figure 1-c). Furthermore, the launcher is put in front of an equivalent dielectric medium characterized by a large dielectric constant. This is a good description of the loading properties of an ICRH antenna by a plasma with steep edge [3].

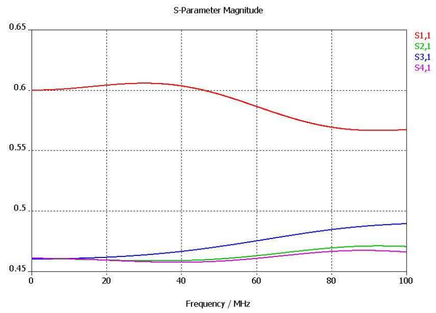

Figure 2: Scattering terms obtained by MWS for the 4-port junction. The reference Z_0 is 20 Ω.

A crucial point of the design study is to be sure that for a given input power, the power (and current) repartition among the straps is balanced. It is possible to exploit the impedance matrices previously obtained for each separate component and to couple the results with the help of circuit theory. Let us define:

- $\mathbf{Z}$, the 4×4 impedance matrix of the 4-port junction: $\mathbf{Z}_{ij} = V_i/I_j$, where V_i and I_j are respectively the voltage at port i and the current at port j of the junction, and
- $\mathbf{Z}'$, the 3×3 impedance matrix of a subset of 1 poloidal triplet of straps: $\mathbf{Z'}_{ij} = V'_i/I'_j$, where V'_i and I'_j are respectively the voltage at port i and the current at port j of a 3 straps array (see figure 1-c).

The $\mathbf{Z}$ matrix can be recast into the form :

$$\mathbf{Z} = \begin{pmatrix} Z_{11} & \ldots \\ (\vec{Z}_1) & (\mathbf{Z_{3\times 3}}) \end{pmatrix}$$

where

$$\left(\vec{Z}_1\right) = \begin{pmatrix} Z_{21} \\ Z_{31} \\ Z_{41} \end{pmatrix} \text{ and } (\mathbf{Z_{3\times3}})_{ij} = \mathbf{Z}_{ij} \text{ for } i,j = 2,3,4.$$

We can now match the voltages at the output ports $V_i = \sum_{j=1}^{4} Z_{ji} I_j$ (i= 2, 3,4) of the junction with the corresponding voltages at the input ports of the laucher $V_i' = \sum_{j=2}^{4} Z_{ji}' I_j'$. The currents being always incoming in each MWS model, we have $\vec{I} = -\vec{I}'$. If I_0 is the (arbitrary) input current, and $\vec{I}$ the vector of the currents on the straps, we obtain:

$$\vec{I} = -I_0 \left(\mathbf{Z_{3\times3}} + \mathbf{Z}'\right)^{-1} \cdot \vec{Z}_1.$$

Figure 3 shows the value of the external straps currents normalized to the central strap current. A maximal discrepancy of 2 % can be expected, which leads to a very small difference of 4 % for the power values. We also see that the currents are in phase: the largest $\Delta\Phi$ to be expected is approximately $4\ 10^{-3}$. Figure 4 shows the amplitude of the surface current density at 50 MHz. We see notably that a significant fraction of the current flows on the lateral sides of the straps, and that there is larger current density flowing on the back side of the straps than on the front side (compare figures 4-(a) and 4-(b)).

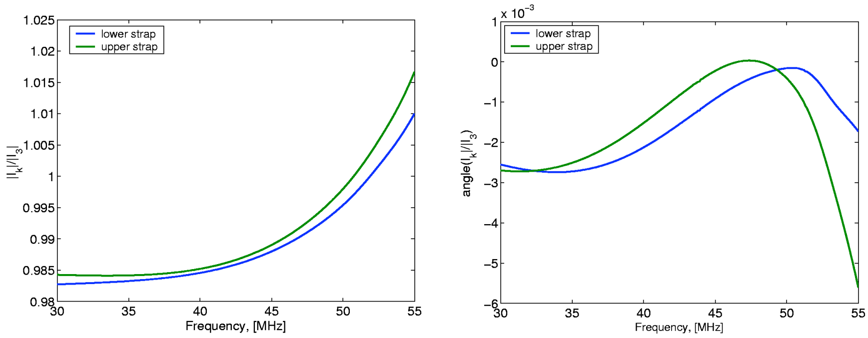

Figure 3: Repartition of the input current on the straps: external currents divided by central current - left: amplitude - right: phase

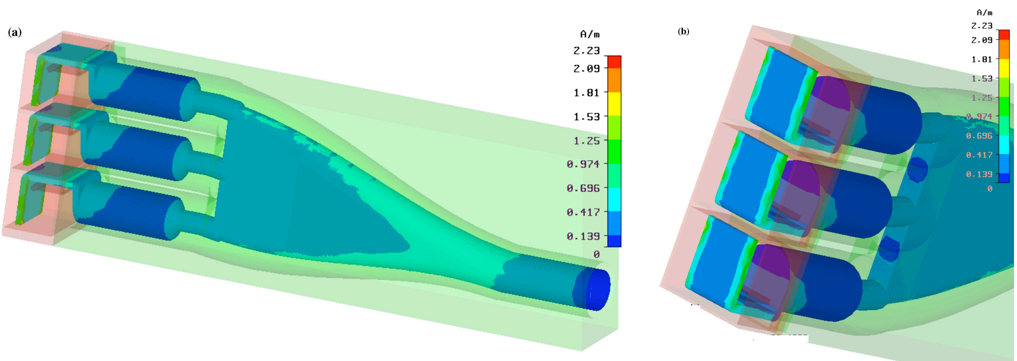

Figure 4: (a)-Amplitude of surface current density at 50 MHz. (b)- Zoom of the amplitude of surface current density on the strap in front of the dielectric

3 Comparison with experimental measurements

A scaled (factor 1/5) mock-up of the antenna array and of the 4-port feeding junction has been constructed. The plasma load is simulated by a tank containing salted water. The addition of salt provides large water absorption on a short distance and allows a proper adjustment of the loading properties [3]. In practice, an electrolyte conductivity of 0.5 S/m (corresponding to an imaginary part of the dielectric tensor $\epsilon'' \approx 40$) is obtained by adding 6 g of NaCl per liter H_2O. Measurements in the frequency range 200-275 MHz provides identical impedance matrix as the full scale system between 40 and 55 MHz and can be directly compared with our modeling. The first results are very encouraging. The reflection coefficient S_{11} has been measured and a fair agreement (see figure 5) between experiment and MWS modeling is obtained. The difference can be explained by some inaccuracy in the knowledge of the dielectric characteristics of the different media (salted water and glass wall).

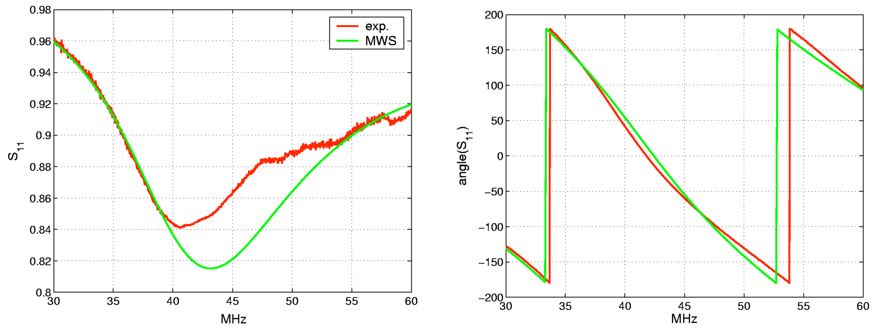

Figure 5: S_{11} obtained on the mockup compared with MWS modeling (amplitude & phase). The reference Z_0 is 20 Ω.

4 Conclusions

Some components of the ITER external matching system have been modeled with a high level of geometrical detail. Important issues such as the effect of the poloidal asymmetry of the 4-port junction on the current balance have been treated and the results show very small discrepancies. The agreement between modeling and the first experimental measurements on a scaled mockup is very fair. Forthcoming modeling will include toroidal coupling studies and effect of the load/antenna distance.

References

[1] P. Dumortier *et al.* Final Report on Task FU05-CT 2002 00094 (EFDA/02-675), *LPP-ERM/KMS Int. Rep. 121*, A. Messiaen *et al.* 30th EPS Conf. Contr. Fus. Plasma Phys., Europhysics Conf. Abstracts, 27A (2003) P-3.216

[2] CST MICROWAVE STUDIO® User Manual, Version 5.0, CST GmbH, Germany, 2003

[3] A. Messiaen *et al.* (2004) *LPP-ERM/KMS Int. Rep. 123*