Assessment of the RF field and current levels on the ITER blanket modules and of possible grounding solutions for the ICRF antenna

F. Louche*, P. U. Lamalle*, F. Durodié* and A. Borthwick†

*Laboratory for Plasma Physics - Association "Euratom-Belgian State", Trilateral Euregio Cluster
Ecole Royale Militaire - Koninklijke Militaire School, B-1000 Brussels, Belgium
†EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon OX14 3DB, UK

Abstract. We present the results of a numerical investigation of the interaction between the ITER ICRF antenna plug (external matching option) and the surrounding wall blanket modules with the commercial software CST Microwave Studio (MWS). In particular we study the RF currents circulating on and between these modules with a simplified rectangular model of the antenna and the blanket. Large currents can circulate on the plug and concentrate on the elements connecting the tiles to the first wall. We consider different grounding configurations (short-circuits and capacitors) aiming at decreasing the amplitude of the currents on the modules connectors. We observe a significant reduction of the RF currents on the connectors as well as a suppression of the propagative modes on the plug.

Keywords: ITER, antenna array, ICRH, external matching, modeling
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1. INTRODUCTION

In this work we study the interaction between the ITER ICRF antenna plug (external matching option) and the surrounding wall blanket modules with CST Microwave Studio (MWS) [1]. It is of prime importance to assess the levels of RF electric fields, currents and voltages on the ITER antenna plug. Consequently the design of a proper grounding solution for the plug has to be considered and in a first approach we present two possible solutions: on the one hand simple metallic connectors, on the other hand retractible capacitors.

2. MODELING ASSUMPTIONS

The simplified model we are using follows the geometry and the dimensions defined in [2] and is shown on figure 1-(a). The model is symmetric and neglects tokamak curvature. The antenna plug is surrounded by a set of modules which constitute the blanket. Normally each module is itself made of four tiles [3], but in a first approach we model each module with an homogeneous brick disregarding the inner tiles. The gap between the modules is 20 mm. The small connectors between the tiles and the first wall are modeled by cylinders with a diameter of 30 mm, and a length of 60 mm. These connectors have been numbered from 1 to 6 as shown on figure 1-(b). The antenna is

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loaded by a series of piled dielectric slabs. The main slab has $\varepsilon_r = 2000$, while additional slabs with decreasing ε_r mimicking the scrape-off layer are defined via an automatized procedure inside MWS (see [2]). All the results presented here are normalized for a strap loading resistance of 4 Ω/m.

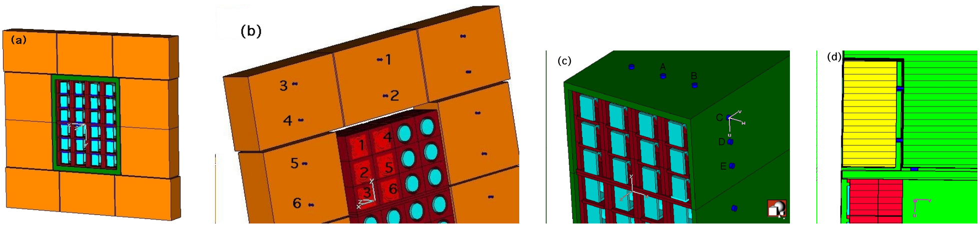

FIGURE 1. MWS model of the ITER antenna plug: (a) front view of the array surrounded by its blanket; (b) back view (the plug and first wall are hidden) with the labels of the connectors and the port numbers; (c) ITER antenna plug surrounded by grounding cylindrical short-circuits; (d) Cut view of the model with short-circuits.

3. UNGROUNDED CASE

In all this work we consider different toroidal phasing configurations: $00\pi\pi$, $0\pi0\pi$, $0\pi\pi0$ and monopole, even if this latter case has not been retained for ITER operation (disruptive effect in JET). The currents are poloidally in phase. The simulations (more details are found in [4]) show that large currents can propagate on and between the tiles, in particular in monopole and $0\pi\pi0$ phasing where the poloidally and toroidally in phase currents flow back to the wall and can in turn excite non-TEM modes on the antenna plug which is acting as a short-circuited waveguide. In particular we have identified the propagative TE_{01} mode of the rectangular coaxial line. This mode has a cutoff at 39 MHz which makes it likely to propagate on the ITER plug in the frequency range considered for the ICRH antenna. On the other hand the other phasing configurations are likely to excite other non-TEM modes buth the latter are evanescent in the frequency range of consideration. Furthermore, large amplitude RF currents concentrate on the connectors between the tiles and the first wall, as can be seen in table 1. The simulations predict currents one order of magnitude larger for the monopole case as compared with the three other configurations. The largest current magnitude in $0\pi\pi0$ phasing is about 110 A on connector 1. The peak voltages observed at the corner of the plug are estimated between 3 and 7 kV.

TABLE 1. Amplitude of the currents (in A peak) circulating on the elements connecting the blanket modules to the first wall for each phasing configuration.

Phasing	Connector					
	1	2	3	4	5	6
$0\pi0\pi$	0	0	18.6	16.1	10.6	14.
$00\pi\pi$	0	0	49.9	21.2	15.8	18.7
$0\pi\pi0$	107.3	52.4	34.8	4.	21.4	8.1
0000	1842	616.5	780.2	2.8	658	96.4

4. EFFECT OF GROUNDING ELEMENTS

As a first attempt to decrease the current density on the plug and on the connectors, the MWS model has been modified by adding cylindrical connectors between the plug and the first wall to ground the antenna plug. The center of the cylinders is located at 10 cm from the first wall (see figure 1-(c) & (d)). The diameter of the connectors is 30 mm. The influence of a larger diameter is also considered.

As a consequence of this grounding, the non-TEM modes which propagate in monopole and $0\pi\pi0$ phasings are avoided [4]. Furthermore, the short-circuits decrease the RF currents on the connectors where large currents were previously observed (see table 2). We also see that for most of the cases represented, doubling the diameter contributes to a slight decrease of the currents on the connectors. A few connectors see their current increase, depending on the array phasing (for instance on connector 1 in $0\pi\pi0$). Another consequence is the significant decrease of the peak voltages at the corners of the plug: in monopole phasing the peak value is about 15 kV while it stays below 4 kV for the other phasing cases.

TABLE 2. Influence of the short-circuits: amplitude of the currents (in A) circulating on the elements connecting the blanket modules to the first wall for each phasing configuration.

Phasing	Connector (30 mm)					Connector (60 mm)				
	1	2	3	4	5	1	2	3	4	5
$0\pi0\pi$	0	0	17.4	8.1	12.8	0	0	7.6	6.8	9.7
$00\pi\pi$	0	0	35.9	15.3	19	0	0	36.9	14.4	20.1
$0\pi\pi0$	15.5	44.3	8.5	12.3	23.3	29.3	35.3	5.0	2.4	6.8
0000	237.2	507.9	162.1	120.5	29.7	159.6	305.2	104.5	77.6	20.3

We have also considered non-symmetric phasing configurations: the $\pi/2$ phasing required for current drive operation, and the monopole operation of only one half of the antenna (left or right). This latter case could occur in case of a failure of one generator during dipole operation. The largest currents in $\pi/2$ phasing are of the order of 30 A and should not be considered as a problem. On the other hand, in half-monopole the currents can reach 250 A on the connector 3 and 170 A on connector 4. The grounding of the plug decreases these peak values to 80 A and 145 A respectively (see [4] for more details).

5. USING ARRAYS OF CAPACITORS AS RF GROUND

Now we discuss more realistic configurations ensuring the RF grounding of the ITER antenna plug. A sketch of an RF ground for the ITER ICRF antenna has been proposed (see figure 2): an array of capacitors built in to the antenna side walls provides an RF link but DC break. We have developed a MWS model of the capacitors from this design. This model has been fully parametrized in MWS to allow easy modifications and parameters scans. Three different models are tested here, differing by the number of capacitors and the diameter of the cylinders (30 mm for 1, 60 mm for 2 & 3, see figure 2). The results [4] can be read in table 3: we obtain a better grounding of the plug with larger capacitance but the currents are nevertheless larger than with the metallic short-circuits (section 4) by a factor 2 to 3. Let us add that our computations have not shown any significant influence of the number of capacitors: we have added a second row of capacitors (see model 3 in figure 2) and only a slight reduction of the RF currents in the two dipole cases has been observed.

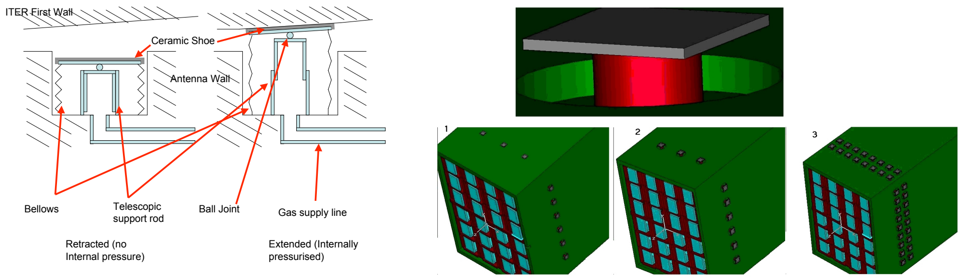

FIGURE 2. Schematic view of the RF grounding capacitor (retracted and in contact with the first wall) and MWS models used here. The ceramic has $\varepsilon_r = 10$.

TABLE 3. Influence of the capacitors: amplitude of the currents (in A) circulating on the elements connecting the blanket modules to the first wall for each phasing configuration.Only one row of capacitors is modeled here (see models 1 & 2 in figure 2).

Phasing	Capacitors (30 mm)					Capacitors (60 mm)				
	1	2	3	4	5	1	2	3	4	5
$0\pi0\pi$	0	0	21.5	11.6	7.4	0	0	27.1	11.9	22.3
$00\pi\pi$	0	0	50	25.6	13.9	0	0	63.7	31.0	45.0
$0\pi\pi0$	59.1	64.0	19.5	6.5	18.9	35.9	48.4	7.9	3.9	4.6
0000	482.9	565.6	102.4	84.7	112.3	250.2	482.2	108.3	103	33.2

6. CONCLUSIONS

In this work we have presented 3D simulations of the full ITER ICRH antenna array, including its plug and the surrounding blanket modules. The mains results of our analysis can be summarized as follows: high levels of RF currents are likely to circulate on the front face of the blanket and between the tiles depending on the phasing configuration, and the connectors of the tiles to the first wall are susceptible to support very large currents (up to 100 A in $0\pi\pi0$ phasing). Nevertheless, grounding the plug to the first wall helps to significantly reduce the levels of RF currents and voltages. A proper design of the grounding capacitors is therefore necessary to optimize this grounding and we recommend to properly short-circuit the plug to the first wall.

REFERENCES

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