Benchmark between antenna code TOPICA and Petra-M for the JET ITER-like antenna

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Plasma heating and non-inductive current drive in the ion cyclotron range of frequency (ICRF) will play a crucial role in the ignition and sustainment of burning plasmas in ITER. ITER will use 20 MW of ICRF heating. At this RF power level in long pulses, the interactions of IC waves and the SOL plasma together with the wall can be potentially a substantial plasma material interactions (PMI) driver, resulting in impurity generation and plasma facing component damage. For this reason, both modeling and experimental efforts to better understand the interaction of the IC waves with the edge of the plasma currently constitute an important research topic in RF community. In this work, we employ the Petra-M code [1, 2], which is a recently developed electromagnetic simulation tool for modeling RF wave propagation based on MFEM [http://mfem.org]. This code can potentially overcome some limitations of the current state-of-the-art RF SOL/antenna simulation such as relatively small volume in front of the antenna and stratifying antenna strap structure. Furthermore, with the self-consistent core-edge coupling [3], the model built on Petra-M can be applicable to a broad range of experimental conditions even where the core heating efficiency is not strong enough. This condition is indeed beyond the validity range of most

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existing simulation models. However, the Petra-M code verification and validation are still missing. For this reason, this paper reports a benchmark between the well tested antenna code TOPICA [4,5] and Petra-M for the JET ITER-like antenna (ILA) [6] assuming a flat model with both a flat and a curved plasma-vacuum interface.

Figure 1 shows the JET ILA antenna geometry generated in Petra-M directly from a CAD file and the two vacuum-plasma interfaces used in the simulations. In this work, a flat model of the JET ILA antenna is employed [7]. However, all main antenna features are considered. In terms of plasma model, in Petra-M we assume a cold plasma with artificial collision. The electron density profile is shown in Figure 2. This density profile is from JET shot # 90454 as used in [7]. It is important to note that the minimum density is set above the resonance S = 0 [8] to avoid the slow mode with a very short wavelength. The magnetic field at the antenna is 1.82 T and is tilted 12.5 degree with respect to the toroidal direction. The wave frequency is 42 MHz and we assume vacuum in the antenna region and 40 cm plasma region (see Figure 1(b)), when plasma is considered. The quantity that we have compared between TOPICA and Petra-M is the RF scattering matrix (S-matrix). The S-matrix relates the voltage waves incident on the antenna ports to those reflected from the ports, in other words, $b_i = S_{ij}\, a_j$ where a_j is the incident amplitude on port j in a *n*-port system and b_i is the reflected amplitude of port *i* as a result of the incident wave at port j. These quantities can be expressed for a generic port *l* in terms of the reference admittance of the port (Y_{rl}) and the incident/reflected voltages ($V_{+,l}$ and $V_{-,l}$, respectively) as follows $a_l = sqrt(Y_{rl})V_{+,l}$ $b_l = sqrt(Y_{rl})V_{-,l}$. Since the JET ILA antenna has 8 ports (see Figure 1(b)), the S-matrix is a 8 x 8 matrix. Three cases are presented in this paper: (i) vacuum case, (ii) plasma case with flat vacuum-plasma interface, and plasma case with curved vacuum-plasma interface. A very good agreement of the absolute value of the S-matrix elements is found for all three cases as shown, in figures (3), (4), and (5), respectively. In particular, the agreement of the S-matrix elements is within two/three digits as similarly shown in a benchmark activity between RAPLICASOL and TOPICA [9]. In the vacuum case, one can see that the S-matrix is symmetric as expected (Figure (3)). Moreover, unlike the vacuum case, for the flat interface, slightly smaller off-diagonal values are obtained from Petra-M with respect to TOPICA. However, in the curved vacuum-plasma interface case, both Petra-M and TOPICA has smaller off-diagonal values with respect to the flat vacuum-plasma interface.

Petra-M simulations of the curved model of the JET ILA antenna will be performed in order to further investigate the discrepancies found between experimental observations and simulations done so far and not yet fully clarified [7, 10, 11].

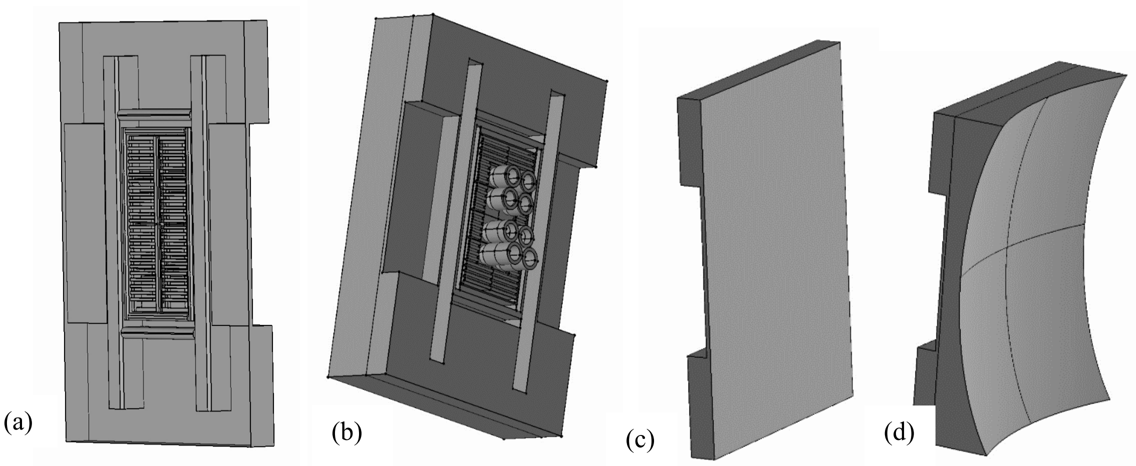

Figure 1. Front (fig. a) and back (fig. b) face of the JET ITER-like antenna assuming a flat geometry. Two vacuum-plasma interfaces are employed in this benchmark activity: flat (fig. (c)) and curved (fig. (d)) interface.

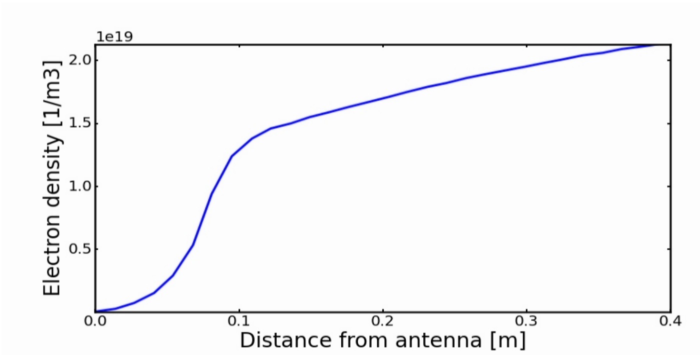

Figure 2. Electron density as a function of the distance from the antenna. This profile was obtained from Ref. [7] and it corresponds to the JET shot # 90454.

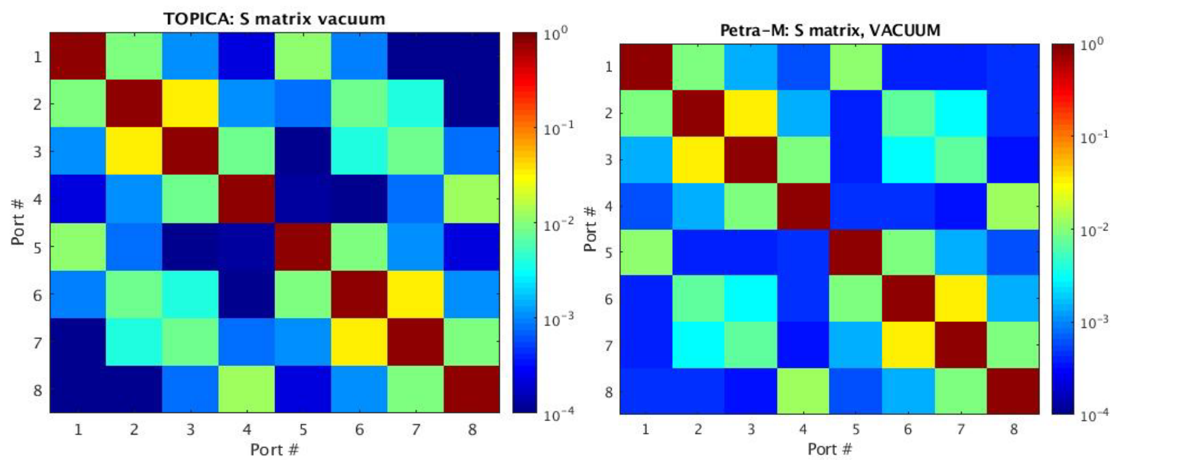

Figure 3. Comparison of the absolute value of the S-matrix (8 x 8) elements for the vacuum case between TOPICA (left figure) and Petra-M (right figure).

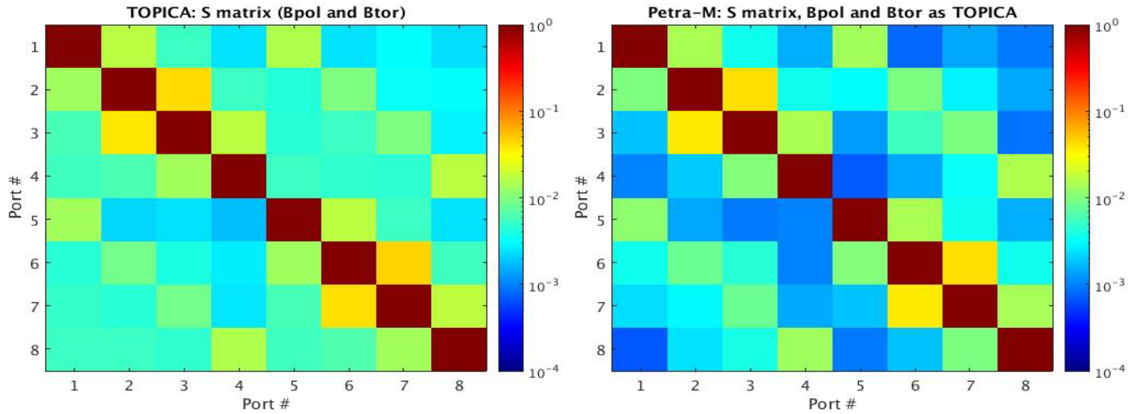

Figure 4. Comparison of the absolute value of the S-matrix (8 x 8) elements for the plasma case between TOPICA (left figure) and Petra-M (right figure) assuming a flat vacuum-plasma interface.

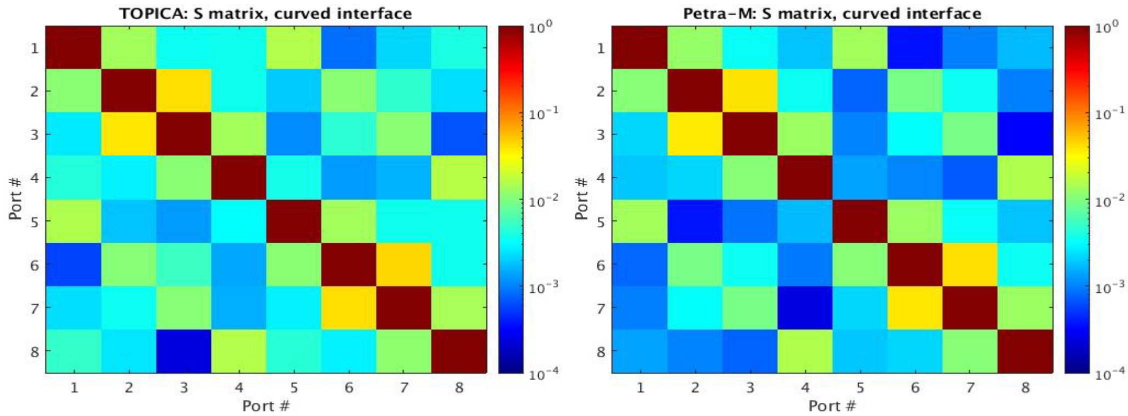

Figure 5. Comparison of the absolute value of the S-matrix (8 x 8) elements for the plasma case between TOPICA (left figure) and Petra-M (right figure) assuming a curved vacuum-plasma interface.

Acknowledgments
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