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# 3D full wave fast wave modeling with realistic HHFW antenna geometry and SOL plasma in NSTX-U

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A significant advancement of RF modeling was achieved by realizing for the first time the entire 3D full torus plasma simulation with detailed 3D realistic antenna and SOL plasma. Many experiments in different fast wave (FW) heating regimes, such as hydrogen minority heating and high harmonic fast waves (HHFW), have found strong interactions between RF waves and the SOL region. In a fusion device powered significantly by RF, however, the loss of RF power in the SOL can be a real plasma material interaction (PMI) issue for possible RF impurity generations and plasma facing component damage besides reducing the RF core performance. A significant interaction between FW and energetic ions generated by neutral beam injection (NBI), also, plays an important role in the current experiments and with fusion alphas for future experiments such as ITER. Commonly, previous RF simulations in the plasma core are neglecting the SOL plasma and they compute the RF field in a 2D domain assuming one single toroidal wave number. State-of-art RF SOL/antenna simulation is yet limited to a relatively small volume in front of the antenna, and it involves significant physics simplification such as stratifying antenna strap structure and/or treating the antenna front volume as vacuum. This paper, instead, examines the full 3D device geometry including realistic antenna geometry in order to capture the experimental situation including the 3D effects and the antenna plasma interaction in the SOL plasma and, at the same time, the core wave propagation. In particular, in this work we employ the Petra-M code (1, 2), which is a newly developed state-of-the-art generic electromagnetic simulation tool for modeling RF wave propagation based on MFEM [http://mfem.org], open source scalable C++ finite element method library. Furthermore, we report for the first time the interaction between FW and fast ions in a 3D geometry including both the SOL plasma and the full-orbit effects, which are very important for NSTX-U and future experiments such as ITER by using the wave field evaluated by Petra-M in the SPIRAL full-orbit following particle code (3).

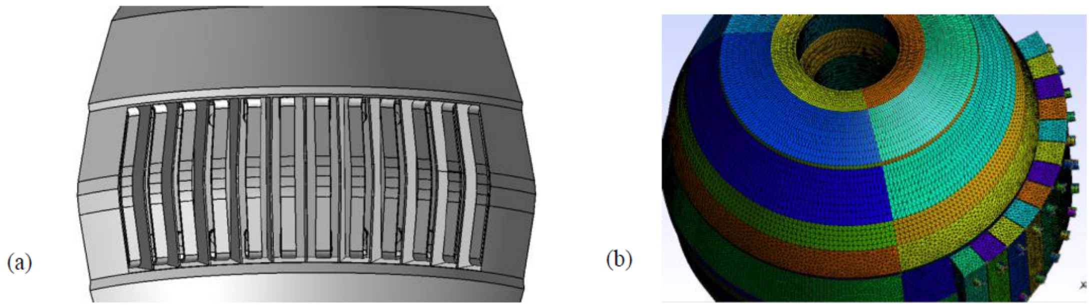


Figure 1: HHFW antenna (a) and the 3D mesh (plasma + HHFW antenna) for NSTX-U.

3D full wave simulations of HHFW regime in NSTX-U plasmas are analyzed (4). In Figure 1, one can see the realistic geometry employed in the simulations: the HHFW antenna geometry (figure (a)) and the 3D mesh for NSTX-U (figure (b)). Unlike the 2D simulations where a single wave number is employed, the 3D simulations allow us to study the 3D effects of the realistic antenna geometry and the role of the antenna spectrum, which can be modified by employing different antenna phasing between straps as done experimentally. Unlike the previous 2D full wave simulations (5, 6, 7, 8), 3D full wave simulations do not show strong cavity modes in the SOL plasma emphasizing the need to consider the 3D geometry. A scan of the antenna phasing shows a strong interaction between FWs and the SOL plasma for lower antenna phasing, which is consistent with previous NSTX HHFW experimental observations (9) (see Figure 2). This strong interaction for lower antenna phasing can lead to a potential RF power loss in the SOL plasma. Figure 2 shows also that (i) the wave field tends to propagate in the toroidal direction more that the radial direction when the antenna phasing is increased. This is expected because the ratio of the parallel and perpendicular group velocity goes like the parallel refractive index ($N_{\parallel}$), namely, for higher $N_{\parallel}$ the waves should travel toroidally more; (ii) some wave field propagation appears on the planes above and below the mid-plane for all antenna phasing. Finally, the effect of the 3D wave field on the fast ion population from both the radial and tangential NBI beams in NSTX-U is quantified by using the 3D field obtained from the Petra-M simulations in the SPIRAL full-orbit following particle code. Figure 3 shows the $E_z$ component of the wave electric field in a toroidal cross-section on the mid-plane of NSTX-U overlaid with a single fast ion orbit as obtained by SPIRAL. From this figure it is clear that the fast ions should be affected mainly in the region in front of the antenna where the wave electric field is strong. In order to show this point we used an ensemble of 40k particles in SPIRAL assuming an initial Maxwellian distribution with a fast ion temperature $T_{\rm FI} \sim 25$ keV and a central fast ions density of $n_{\rm FI} \sim 2 \times 10^{18}$ m$^{-3}$. At the same time, we used the three components of the wave electric field evaluated by Petra-M in the geometry shown in Figure 1 as a perturbation of the equilibrium field in the Lorentz equation. Figure 3 shows the contour plot of the fast ions power deposition evaluated by SPIRAL including the full 3D RF wave field evaluated by Petra-M. It clearly appears that the interaction between fast waves and fast ions occurs mainly in front of the antenna, as expected. This result demonstrates how 3D effects are important in these simulations for fast ions studies in which RF is included. Generally, a 2D wave field obtained with only a single toroidal wave number is used assuming toroidal symmetry. This approximation results in acceleration/deceleration of the fast ion due to RF everywhere in the torus and not only in the region where the RF wave field is localized. Further studies with realistic fast ion distribution functions from the NBI beams in NSTX-U will be discussed.

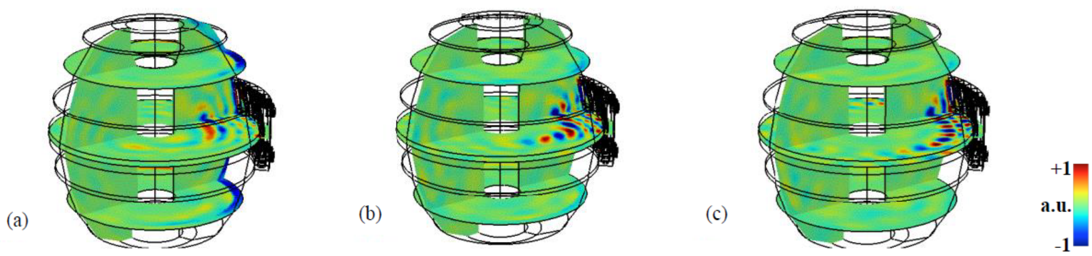


Figure 2: $E_z$ component of the wave electric field evaluated by Petra-M for the full 3D NSTX-U torus including the HHFW antenna and three different antenna phasing: 30° (figure (a)), 90° (figure (b)), 150° (figure (c)). Cold plasma approximation and plasma collision are used.

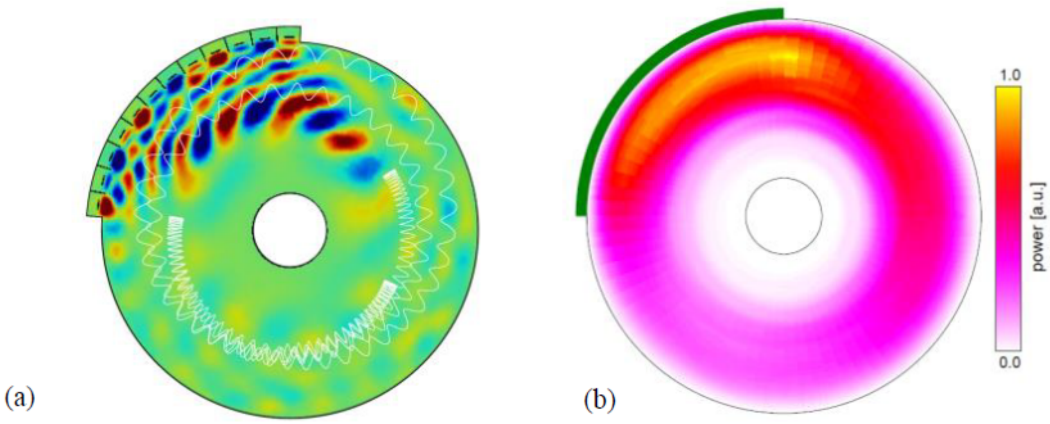


Figure 3: $E_z$ component of the wave electric field in the toroidal cross-section (on the mid-plane) for 90° antenna phasing with a single fast ion orbit in white; (b) Contour plot of the fast ions power deposition evaluated by SPIRAL including the RF wave field from Petra-M.

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**References**


(1) S. Shiraiwa et al., EPJ Web of Conferences 157, 03048 (2017).

(2) S. Shiraiwa et al., this conference.

(3) G. J. Kramer et al., Plasma Phys. Control. Fusion 55, 025013 (2013).

(4) N. Bertelli et al., Invited talk at the 23rd RF Power in Plasmas Conference (China, 2019). Accepted to be published in AIP Conf. Proceeding (2019).

(5) D. Green et al., Phys. Rev. Lett. 107, 145001 (2011)

(6) N. Bertelli et al., Nucl. Fusion 54, 083004 (2014).

(7) N. Bertelli et al., Nucl. Fusion 56, 016019 (2016).
(8) E.-H. Kim et al., Phys. Plasmas 26, 062501 (2019).
(9) J. C. Hosea and et al., Phys. Plasmas 15, 056104 (2008).

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