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Self-Consistent Modeling of Radio-Frequency Sheaths: Comparison with Tore Supra Measurements and Predictability for Future Machines

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In magnetic Fusion devices, non-linear wave-plasma interactions in the plasma edge often set operational limits for Radio-Frequency (RF) heating systems, due to impurity production or excessive heat loads. Understanding these interactions is key for reliable high-power Ion Cyclotron (IC) wave launch over long pulses in all-metal devices. Edge IC losses are attributed to a Direct Current (DC) biasing of the Scrape-Off Layer (SOL) plasma by RF sheath rectification. This paper presents a first step towards self-consistent modelling of RF wave penetration and the edge plasma DC biasing. A wave equation propagates the Slow magnetosonic mode from a map of the parallel RF electric field imposed at the outer boundary of the simulation domain. The local DC plasma potential VDC is governed by the continuity equation for DC currents in presence of anisotropic DC conductivity. The RF and DC modules are coupled by non-linear RF and DC sheath boundary conditions at the lateral boundaries of the simulation domain. The code is implemented with COMSOL, presently in 2 dimensions (radial/toroidal), with boundaries either parallel or normal to the confinement magnetic field. This approach could reproduce qualitative observations about heat loads and probe potentials measured in the vicinity of Tore Supra antennas that were hardly compatible with earlier models. For example asymmetric strap excitation led to left/right sheath asymmetry between the two extremities of the same field lines. Biasing of the free SOL has to rely on VDC diffusion from the private SOL due to the transport of DC current. This mechanism is qualitatively consistent with DC current flows measured in the vicinity of active antennas. The relative simplicity of the present model, its sensitivity to SOL parameters (density, temperature) and the large uncertainty on SOL transport coefficients make quantitative RF-sheath predictions challenging. Poloidal distributions of sheath potentials and relative comparisons between antennas look more robust for predictive assessment. This was assessed by comparing two Faraday screen types on Tore Supra and was subsequently applied to estimate sheath effects for the ITER antenna with different strap phasings. Finally a roadmap is proposed for testing the present model further against existing experiments, and for improving it towards full-wave propagation and shaped walls.

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