Full-Wave Simulations of the O–X–B Mode Conversion in a Realistic Experimental Geometry in the RFX-mod Device

Alf Köhn, Roberto Bilato, Francesco Volpe, and Roberto Paccagnella

***Abstract*—A full-wave code has been used to model the O–X–B mode-conversion process in RFX-mod. Parameter scans were performed to find the optimum launching condition for the microwave beam. Vacuum walls play an important role in the overall conversion efficiency, which is a key parameter for the success of the experiment. This is nicely illustrated in simulations.**

***Index Terms*—Finite difference methods, microwave propagation, plasma simulation, plasma waves.**

MICROWAVES are commonly used to generate and heat plasmas. In magnetic confinement fusion plasmas, the process of electron cyclotron resonance heating can heat electrons gyrating around a magnetic field line with the same frequency $\omega_{\rm ce}$ as microwave ω_0 [1]. If the plasma becomes overdense, the electron cyclotron resonance layer is shielded by cutoffs (and the microwave is reflected by these cutoffs), and alternative ways of transferring the microwave energy to the plasma need to be explored. One possibility that is used in fusion plasmas is heating at higher harmonics of $\omega_{\rm ce}$ [1]. However, for efficient heating, high electron temperatures in the kiloelectronvolt regime are necessary. Another approach is to use electron Bernstein waves (EBWs): These waves do not suffer from shielding by cutoffs and are very well absorbed at any electron cyclotron harmonic. The EBWs are electrostatic waves that cannot propagate in vacuum. Hence, they must be excited via mode-conversion processes. A candidate is the O–X–B mode-conversion process: An O-mode is injected at an optimal angle into the plasma and converted into an X-mode at the plasma cutoff layer. This X-mode then propagates outward until it reaches the upper hybrid resonance layer, where it is converted into an inward propagating EBW (for details, see [2]). The simulation of the O–X–B process for RFX-mod will be discussed in the following.

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A. Köhn is with the Institut für Plasmaforschung, Universität Stuttgart, 70569 Stuttgart, Germany (e-mail: koehn@ipf.uni-stuttgart.de).

R. Bilato is with the Max-Planck-Institut für Plasmaphysik, European Atomic Energy Community (EURATOM) Association, 85748 Garching, Germany.

F. Volpe is with the Department of Engineering Physics, University of Wisconsin-Madison, Madison, WI 53706 USA.

R. Paccagnella is with Consorzio RFX, European Atomic Energy Community (EURATOM) Association–European Nuclear Energy Agency (ENEA) sulla Fusione, 35127 Padova, Italy.

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RFX-mod is a reversed-field pinch experiment located in Padua, Italy. In a previous feasibility study, the potential of EBW heating by O–X–B mode conversion was analyzed [3] using the full-wave code Institut für Plasmaforschung—Finite Difference Code for Mode Conversion (IPF-FDMC). The code is based on the cold plasma approximation and described in more detail in [4]. It was found that the mode-conversion efficiency can achieve a maximum value of 58% for a specific injection angle. The nonconverted power is reflected and leaves the plasma without further interaction. However, in an actual experiment, the reflected microwave would hit the vessel walls. Therefore, the geometry of the vacuum vessel of RFX-mod was included in the simulations to investigate its contribution to the mode-conversion efficiency at the optimum launching condition. The walls are modeled as perfectly conducting material in the code, which is justified by negligible losses at the graphite-covered walls in RFX for a frequency of $f_0 = 28$ GHz.

Fig. 1 shows four plots of the simulation, taken at successive time steps, the exact value of which is given in the plots in units of oscillation periods. Plotted is the root-mean-square (RMS) value of the wave electric field. The microwave beam is injected from port 2. As illustrated, the microwave has not yet reached the plasma after ten oscillation periods. After 30 oscillation periods, it has arrived at the plasma boundary, and the conversion has started. It is also visible how the nonconverted power is reflected back toward the walls of port 2. In the next plot, taken after 100 oscillation periods, the microwave is partly reflected and guided between the plasma and the vessel wall toward ports 1 and 3. After 350 oscillation periods, steady state is achieved, and an enhancement of the wave electric field in the conversion region can be clearly seen. Obviously, this process takes a finite amount of time to occur [5]. In contrast to the previous results without the inclusion of the walls, the conversion efficiency has increased to 70%. However, 27% of the injected power is reflected directly back into the antenna port. This might constitute a severe danger for the port. The remaining 3% of the power leaves the computational plane at ports 1 and 3.

In conclusion, it has been demonstrated that the geometry of the vacuum vessel wall plays an important role in the overall conversion efficiency and, thus, the heating efficiency. Furthermore, the simulations revealed a considerable amount of power being reflected directly back into the antenna port,

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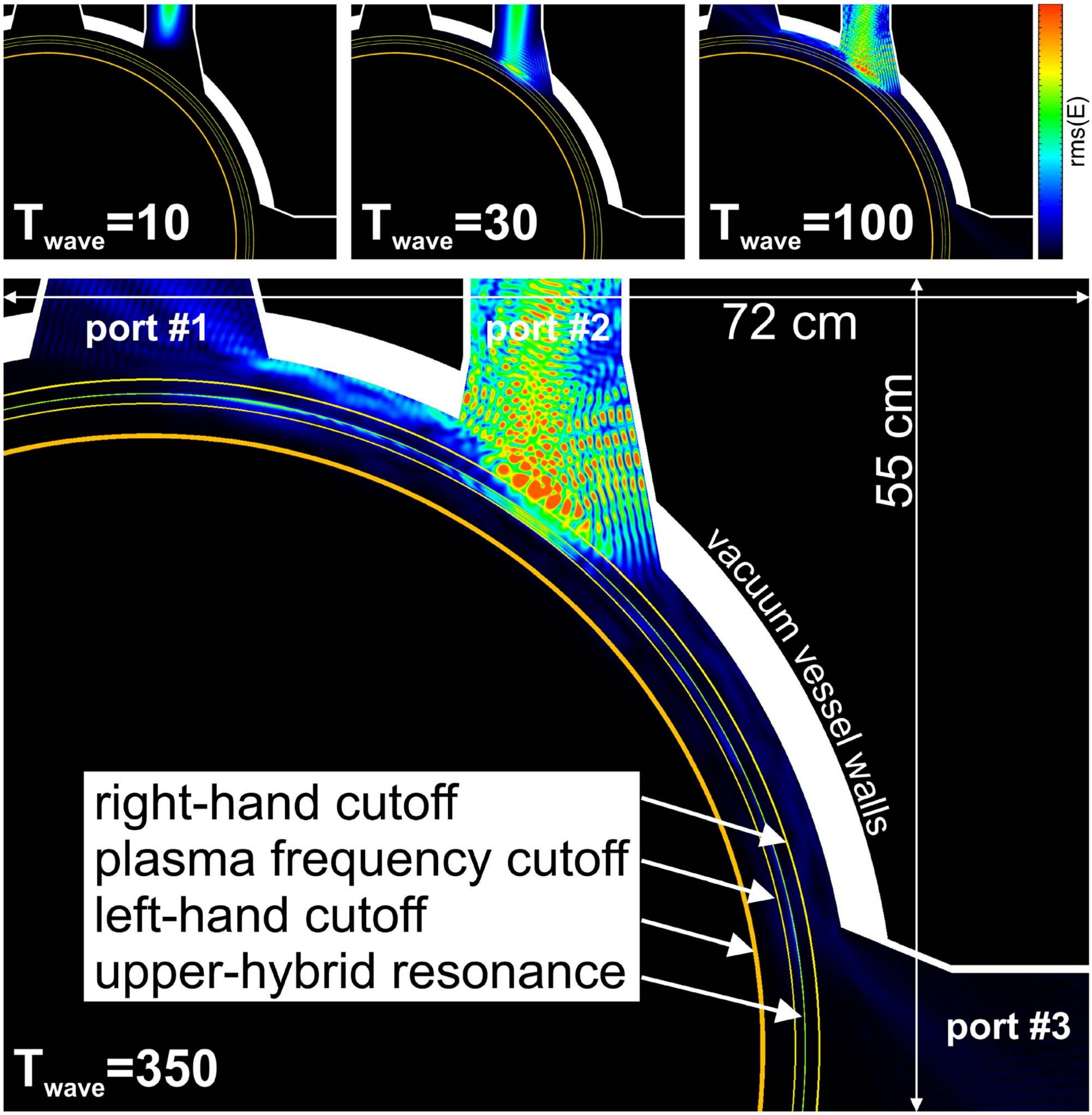

Fig. 1. Simulation results obtained in the poloidal cross section of RFX-mod for $f_0 = 28$ GHz. Plotted is the RMS value of the wave electric field as contour (linear color scale) at four successive time steps. Colored plot in online version.

information that might be of vital importance for the operation of the experiment.

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