Simulation of multiband swept reflectometry for profile evaluation on DEMO using a FDTD Maxwell fullwave code

F. da Silva[1], A. Silva[1], S. Heuraux[2]

[1] *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal*

[2] *Institut Jean Lamour, UMR 7198 CNRS-University of Lorraine, Vandœuvre, France*

Abstract

Numerical simulation constitutes an important tool to understand and access the capabilities of existing or planed reflectometry diagnostics such as ITER and DEMO. Microwave diagnostics, like reflectometry and ECE, with their need for reduced access, front-end robustness, space coverage and spatial resolution are strong candidates to provide DEMO with measurements of electron density and temperature profiles and their associated fluctuations. Frequency modulated reflectometry is a technique widely used in fusion plasmas to measure the electron density and to extract information on density fluctuations. O-mode reflectometry is planed to cover the plasma from edge to core both from high and low field side (LFS) in a range of 18–110 GHz. In this work, using finite-difference time-domain full-wave codes for O-mode (REFMUL), we do a first evaluation of a DEMO1 plasma scenario, simulating the beahviour of the Q band (33–50 GHz) in the LFS. We conducted a first assessment of possible problems that may be present. These simulations helped us not only to get a first assessment of the DEMO environment from the point of view of microwave diagnostics in general but also of the availability of data and check if the requirements for performing microwave simulations.

Simulation of the LFS plasma position reflectometer system

A first evaluation of the LFS PPR behavior was done using a 2D full-wave Maxwell FDTD code REFMUL [1]. The main inputs for the simulations come, first from a CAD model of the DEMO machine, which includes the blanket wall. This was used to determine the limits of the wall facing the plasma through which the reflectometer will reach the plasma. At this early state of DEMO development there is not yet a preliminary design of the antennas and how they gain access to the plasma chamber. We have based our model loosely of the same principles planed for ITER. The antennas will be oversized truncated waveguides, one for emission and the second for reception, probing through a gap in the blanket [2, 3], as shown in Fig 1. The second input is a simulation of equilibrium for a DEMO1 scenario from which the data for electronic density $n_e(R,Z)$, needed for this first
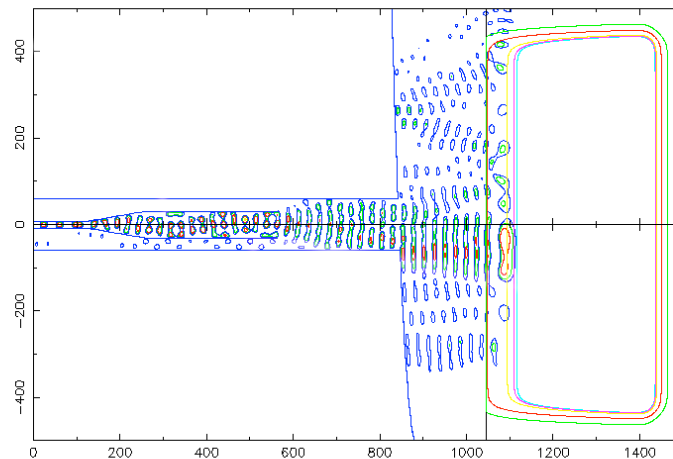
Figure 1: *Snapshot of REFMUL's simulation of FM probing of a LFS DEMO plasma.*

set of simulations is obtained. Electronic temperature T_e, and the magnetic field are also available. The first inconsistencies arise when facing the equilibrium with the CAD model. The given position for the separatrix would fall within the blanked (as well as all the SOL). Clearly the equilibrium was calculated without taking the blanket into account (or at least this blanket). This will force us to contract the spatial scale given for the equilibrium in order to fit the density within the machine. Other fixes could be envisaged but we believe that the proper solution, in future simulations, consists in having coherent supplied by the DEMO organization(s). Another problem detected is the quality and completeness of the equilibrium data, and in particular the density. The number of data points available is extremely low. Shown in Tab. 1 are the planned microwave bands, which will range from

Table 1: *Microwave bands planned for DEMO o-mode reflectometers and the availability of DEMO data. In bold, the Q band used in the simulations.*

Bands	f[GHz]	$n_e[\times 10^{19}\,\mathrm{m}^{-3}]$	Data
—	15–22	0.028–0.060	NO
—	22–33	0.060–0.135	NO
Q	**33–50**	**0.135–0.310**	**NO**
V	50–75	0.310–0.698	Doubtful
W	75–110	0.698–1.500	YES

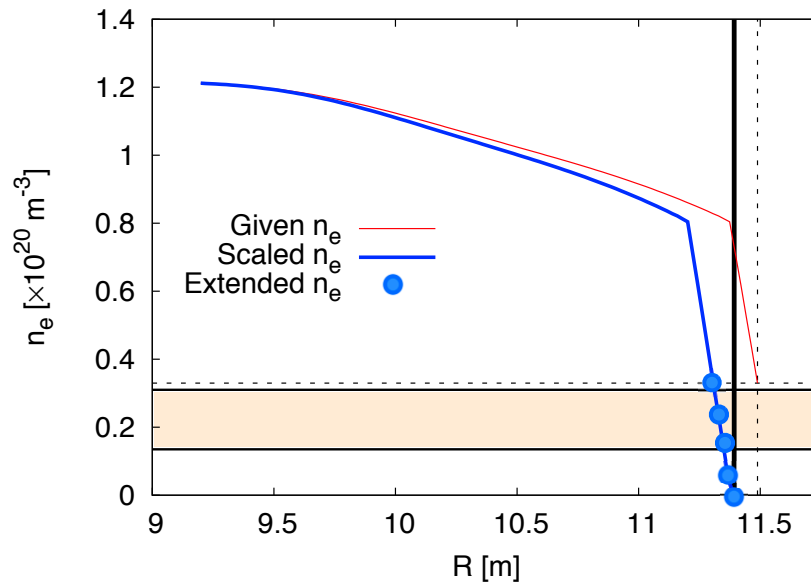15 GHz up to 110 GHz divided by 5 bands, together with the densities covered and the

Figure 2: *Axial cut of the 2D density maps, the given data and the modified one, to enable simulations.*

DEMO data supplied for these simulations. One of the goals of reflectometry in DEMO is plasma positioning, which will use frequencies from the first three bands to probe the edge of the plasma within the SOL. Nevertheless the equilibrium provided stops at the separatrix, and for these initial bands no data is available. For the simulations we had to extrapolate from the edge density. In Fig. 2 an axial cut (along *R*) of the density 2D maps summarizes the problems we have encountered and the solutions needed for performing the simulations presented here. The vertical black thick line marks the blanked wall and the vertical broken line the given position of the separatrix. The horizontal broken line marks the limit of the available data. Knowing that the dark band delimits the Q band used in the simulation. The extrapolation and scale contraction needed can be observed comparing the original data supplied in red and the one used in the simulations in blue. The modified 2D $n_e(R,Z)$ map together with the antenna/blanked setup extracted from the CAD model was integrated in REFMUL and a FM frequency swept probing of the plasma simulated. A snapshot of the electric field map appears in Fig. 2. The occurrence of multi-reflections between the steep plasma and the blanket wall and the possibility of excitation of cavity-like modes within the plasma gap can be sources for disturbance of reflectometry signals, being thus important to evaluate its impact. The simulation signals obtained with this synthetic reflectometer can be subjected to the usual signal processing techniques used in the field (or act as a test bed for new ones) to get the relevant information. In Fig. 3 we show the phase derivative obtained using two techniques, an In-phase/Quadrature detection and using a Sliding FFT (SFFT). The I/Q detection being more sensitive to small phase perturbations shows all the impact of
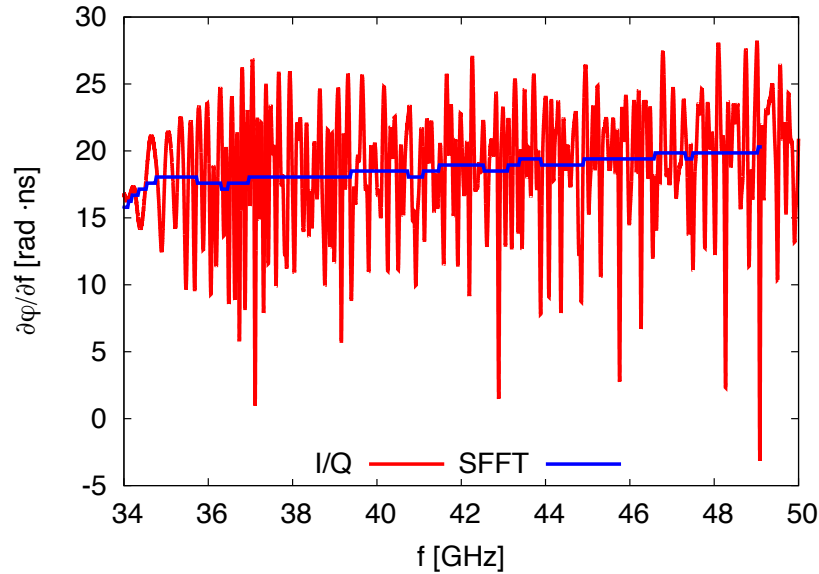
Figure 3: *Phase derivative obtained with a I/Q detection (red) and with a Sliding FFT (blue).*

the multi-reflections and spurious modes occurring during the sweep. The SFFT allows a much cleaner signal but information on the spurious effects is lost. The final use of the data will determine the choice of the technique. These first simulations, using this band and under the limitations forced by the input data, point out reflectometry as a suitable diagnostic to be used in DEMO. This is of course the first step of a work that must be continued and improved. For that is essential better and more accurate edge density profiles.

Acklowledgements

References

[1] F. da Silva, S. Heuraux, S. Hacquin, M. E. Manso, Journal of Computational. Physics **203** 467-492 (2005).

[2] F. da Silva, S. Heuraux and M. Manso, Journal of Plasma Physics **72(6)**, 1205–1208 (2006).

[3] F. da Silva and S. Heuraux, Review of Scientific Instruments **79(10)**, 10F104 (2008).