Numerical Study of Spatial and Temporal Localization of Magnetic Modes using O-mode Reflectometry

F da Silva, †S Heuraux, M Manso and S. Hacquin

Associação EURATOM/IST–Centro de Fusão Nuclear, Instituto Superior Técnico, 1046-001 Lisboa, Portugal

†*Laboratoire de Physique des Milieux Ionisés et Applications, Unité du CNRS 7040, Université Henri Poincaré, Nancy 1, BP 239, 54506 Vandœuvre Cedex, France*

Plasma perturbations can lead to drops in the amplitude of reflectometry signals and to strong variations on the phase derivative. We have shown that a simple model using Gaussian perturbations can reproduce typical perturbations seen in the reflectometry signals of ASDEX Upgrade [1]. We are continuing this study, looking at the effects induced on reflectometry signals by: (1) a chain of islands and (2) a poloidally modulated island. The effect of turbulence on such perturbations is evaluated.

Simulations

Simulations were made using a 2D FDTD Maxwell code (O-mode) on a $51\,\lambda_{40\mathrm{GHz}} \times 36\,\lambda_{40\mathrm{GHz}}$ grid, in fixed frequency, probing a linear plasma n_{e_0}, whose maximum value is $3.11 \cdot 10^{19}\mathrm{m}^{-3}$. The plasma is *damped* close to the box borders to match the vacuum propagation conditions suited to the Perfectly Matched Layer (PML) technique used as boundary conditions. A single antenna, for emission and reception, with unidirectional signal injection (transparent injection) is used, allowing to recover the return (*reflected*) signal alone. Density modes $\delta n_{\mathrm{e}_{\mathrm{mod}}}(t)$ and turbulence $\delta n_{\mathrm{e}_{\mathrm{trb}}}$ are added to the *base* plasma: $n_\mathrm{e} = n_{\mathrm{e}_0} + \delta n_{\mathrm{e}_{\mathrm{mod}}} + \delta n_{\mathrm{e}_{\mathrm{trb}}}$. Density modes evolve on time. Turbulence is simulated according to the model proposed in [2] and is considered frozen during the simulations.

Chain of islands

The chain island is modeled using

$$\delta n_\mathrm{e} = A_f \exp\left[\frac{-(x-x_i)^2}{w_x^2}\right] \mathrm{abs}\{\sin\left[N_\mathrm{i} k_\mathrm{m} y + \varphi_i(t)\right]\}\,, \qquad (1)$$

being k_m the (angular) wavenumber corresponding to the width of the calculation box (poloidally), N_i the number of islands in the box at a time, x_i the radial position of the chain, and w_x determines the radial width of the island. The poloidal position of the evolving chain is obtained varying the phase φ_i in time. In the simulations presented, the chain is placed radially at $x_{c_{35}}$, the cut-off position for $f = 35\,\mathrm{GHz}$. Its amplitude at $x_{c_{35}}$ is $\delta n_\mathrm{e}/n_\mathrm{e} = 23\%$ with a radial length $L_\mathrm{x} = \lambda_{40\mathrm{GHz}}$. This choice of parameters permits to attain a density plateau of $\approx 7\lambda_{40\mathrm{GHz}} = 5.25\,\mathrm{cm}$. The chain starts moving poloidally at $t = 500 \times T_{40\text{GHz}}$ until $t = 2500 \times T_{40\text{GHz}}$ while being probed with fixed frequency at $f = 40\,\text{GHz}$.

With an one-island chain, the electric field E_z at the waveguide is strongly reinforced at the X-point (start of the movement) (see figure 1). As the island moves way from the X-point, the reflected signal reaches a minimum. The field structure close to this instant is shown in figure 2. Figure 3 shows the return signal, in time (*iterations*), detected at the waveguide. The vertical marks (here and henceforth) signal the moments where the field snapshots were taken.

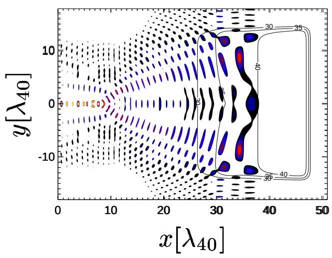

Fig. 1: Electric field at X-point

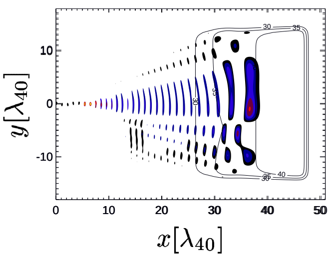

Fig. 2: Electrict field near the moment of minimum detected signal.

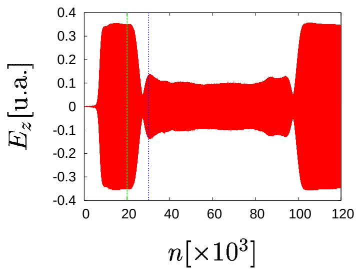

Fig. 3: Detected signal at the waveguide.

Simulations for $N_\text{i} = 4$ (4 islands in the chain) appear on figures 4–6. The level of the return signal is, in general, close to the former ($N_\text{i} = 1$) except at the *one-island* X-point where the strong reinforcement occurs.

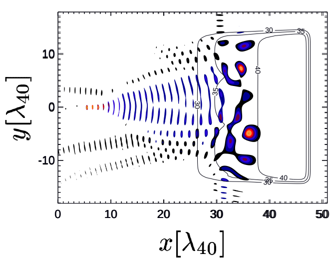

Fig. 4: Electric field at iteration $it = 50000$.

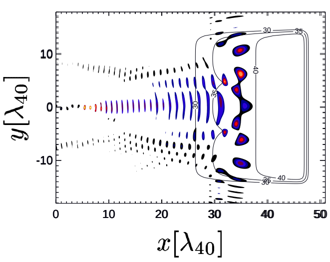

Fig. 5: Electric field at iteration $it = 60000$.

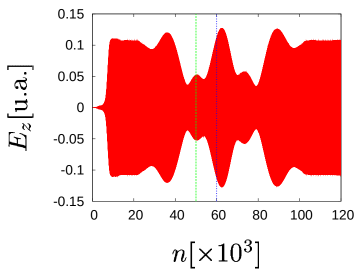

Fig. 6: Detected signal at the waveguide.

Poloidally modulated island

To describe the modulated island the expression

$$\delta n_\text{e} = A_f \exp\left[\frac{-(x - x_f)^2}{w_x^2}\right] \exp\left[\frac{-(y - y_f)^2}{w_y^2}\right] \cos\left[k_f(y - y_0) + \varphi_y\right], \qquad (2)$$

used was. The island is placed radially at the oblique cut-off position of a ray making a $10°$ angle with the antenna axis for a frequency of $f = 35\,\text{GHz}$. It has an amplitude of

$\delta n_{\rm e}/n_{\rm e} = 10\%$ at x_{c35} and dimensions of $L_{\rm x} = 2\,\lambda_{35{\rm GHz}}$ and $L_{\rm y} = 4\,\lambda_{35{\rm GHz}}$. Its poloidal wavenumber is $k_f = 0.35 k_{35{\rm GHz}}$. Figures 7–8 show the electric field structure at the instants marked on the return signal at figure 9. Maintaining the above conditions,

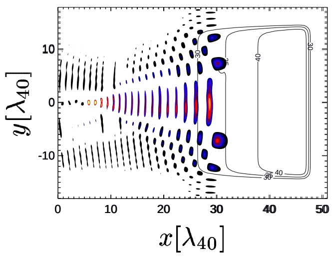

Fig. 7: Electic field at $it = 30000$.

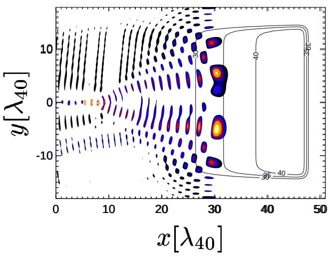

Fig. 8: Electric field at $it = 40000$.

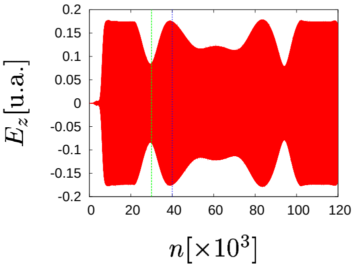

Fig. 9: Return signal.

background turbulence was added to the plasma. The rms value of the turbulence at x_{c35} was $\delta n_{\rm e}/n_{\rm e} = 5\%$. The structure of the electric field for the same instants presented before appear at figures 10–11. With this level of turbulence the island coherent structure is attenuated and the pattern of the moving modulated island in the return field is distorted, as observed in figure 12.

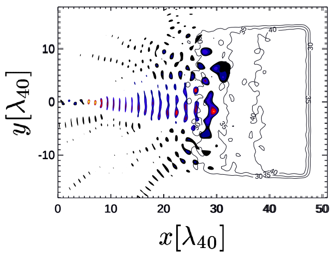

Fig. 10: Field structure. Compare with 7.

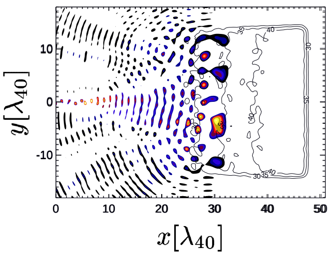

Fig. 11: Field structure. Compare with 8.

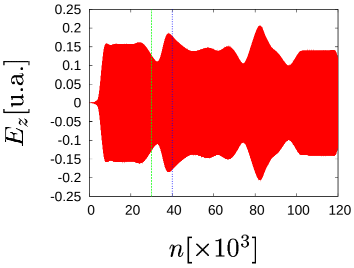

Fig. 12: Return signal. Compare with 9.

Discussion

The configuration used for one-island chain acts, at the X-point, as a corner reflector focusing the electric field back to the antenna, thus enforcing the signal returned to the waveguide to a value of almost 3 times (270%) the amplitude one would have without the chain (base plasma $|E_z| = 0.133$). Close to the X-point the chain redirects the field away from the antenna, leading to a relative drop of the signal ($\approx 1/3$) when compared to the base plasma. With 4 islands in the chain, the resultant structure is more complex. The field at its maximum value is never to far from the amplitude of the unperturbed case. The drop of signal amplitude is comparable to the one-island case.

The island with poloidal modulation causes an higher disturbance at the vicinity of the oblique cutoff, where $k_f = 2k_y = 2k_0 \sin\theta$ for an *injection* angle of $\theta = 10°$ if compared with the unperturbed system (base plasma $|E_z| = 0.14$ at $f = 35\text{GHz}$). Close to this position an increase of the detected signal of $\approx 12\%$ followed by a drop of $\approx 6\%$ and a second increase of the signal. When turbulence rises above a certain limit (between 2.5%–5%, with the values used) its effects start to become comparable with the ones induced by the coherent deformations. Multi-reflection effects appear and break the consistent structure of the electric field and the signature of the islands becomes less apparent until it fades way within turbulence.
This study presents interesting results that will be further investigated. Work concerning the role of the number and shape of islands will be pursued and the effects of turbulence will be deeper explored. We shall also be looking at the behavior of these perturbations on FM reflectometry signals.

Acknowledgments

This work was carried out within the framework of the Contract of Association between the European Atomic Energy Community and Instituto Superior Técnico. Financial support from Fundação para a Ciência e Tecnologia and Praxis XXI was also received.

References

[1] F. da Silva *et al.*, in 28^{th} *EPS Conference on Controlled Fusion and Plasma Physics*, European Physical Society (European Physical Society, 2001), Vol. 25A, p. P3 083.

[2] S Hacquin, F Silva, S Heuraux *et al.*, in 28^{th} *EPS Conference on Controlled Fusion and Plasma Physics*, European Physical Society (European Physical Society, 2001), Vol. 25A, p. P3 078.