TURBULENCE AND BEAM SIZE EFFECTS ON REFLECTOMETRY DENSITY PROFILE MEASUREMENTS

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1. Introduction

Reflectometers are attractive diagnostics for the electron density distribution in reactor like plasmas since they are radiation resistant, have low access requirements and show high time and space resolution (improved in the gradient region where other systems fail to give the required resolution). A possible problem for the reflectometer comes from the fact that the reflecting layer has a corrugated structure, which leads to interference effects and distortion on the phase of the reflected beam. Vector averaging techniques [1] improve the ability of the reflectometer to determine the average density profile but it is difficult to foresee the parameters of fluctuations in large reactor plasmas and therefore the assessment of the reflectometer performance. In this paper, the influence of the turbulence level, fluctuation wavelength and antenna beam size has been studied by numerical simulation.

The simulation code has also been used to analyze correlation measurements with the phase, homodyne (a cosϕ) and time delay signals. The analysis of correlation can also be used as a method for the determination of the time delay in strongly turbulent scenarios.
As simulation tool we will use a 2-dim WKB code [1]. The use of the WKB approximation is based on the fact that we have a beam with short wavelength but broader than the poloidal turbulence wavelengths. The code takes into account interference effects but not diffraction.

2. Effect of turbulence level and antenna beam size

In this work we present to what extent the error in the profiles due to increasing turbulence level can be diminished by increasing the magnitude of the vector average. In the simulation, perpendicular launching with static turbulence has been considered. As a significant example, the FM technique with FFT analysis was selected for the simulations below. The results (being the plasma "frozen") will be similar to those given by AM or Pulse Radar.

In the analysis of the FM reflectometer data with the FFT method, the magnitude of the vector averaging depends on the length of the frequency interval used for the sliding window of the FFT. The profile reconstruction was performed for a plasma with a high turbulence level: 7.5 % of the central density (close to 40% for the lowest edge density analyzed: 2×10^{13}
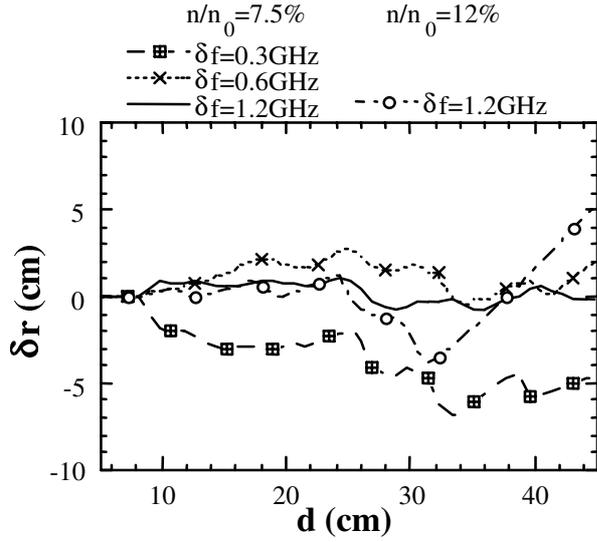
Fig. 1. Spatial errors of the profiles for different levels of average: 0.3, 0.6 and 1.2 GHz ($\tilde{n}/n_0$=7.5 %, λ_θ=6 cm and the poloidal spot size is about 10-15 cm in the density gradient zone), together with the error obtained for very high fluctuation level ($\tilde{n}/n_0$=12%) and the largest frequency interval: δf=1.2 GHz.

cm^{-3}), the dominant fluctuation wavelength (poloidal and radial) was 6 cm and the poloidal spot size about 10-15 cm in the density gradient zone. The spatial errors of the reconstructed profiles are shown in Fig. 1. Increasing the length of the frequency intervals from δf = 0.3 to 1.2 GHz the original profile is nearly reproduced. For the turbulence level of 12% (60% at the edge) the error could not be overcome with the largest δf of 1.2 GHz (see also Fig. 1). Further increase of δf just produced a worse spatial resolution but did not improve the result. This tells us that in the cases of exceptionally high fluctuation levels the errors in the profile reconstruction could remain even for significant vector averaging.

Another parameter which has to be defined is the antenna pattern. In order to study the effect of the antenna beam size on the profile measurements we have considered plasmas with moderate density fluctuation level and constant dominant perturbation wavelength. The behavior of the achieved profiles depends on the effective poloidal beam size, i.e., on the number of illuminated poloidal wavelengths that contribute to the received signal after reflection. Fig.2 shows the spatial errors f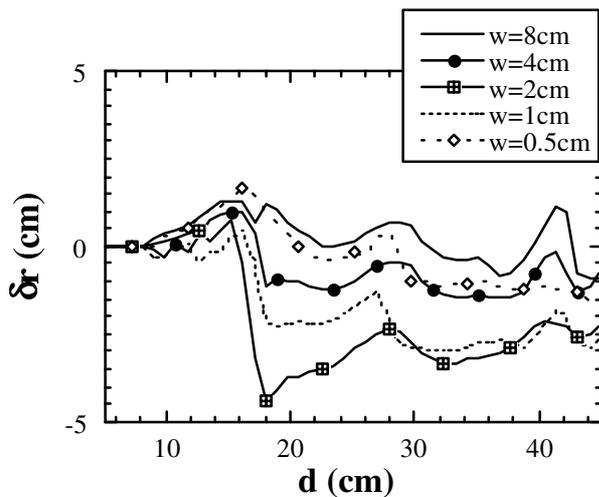or different antenna apertures, w (inverse to the beam diameter); the ratio between the beam size and the dominant poloidal wavelength changes from 1 (w=8 cm) to more than 20 (w=0.5 cm), being close to 6 (w=2 cm) for the poorest reconstruction case. These profiles were obtained for a perturbation with $\tilde{n}/n_0$=1.5 % and λ_θ=6 cm. FM plus FFT was used, with a sliding window of δf = 0.3 GHz. Larger frequency intervals improve the results but do not change the dependence with the antenna aperture. The amplitude of the reflected signals varies strongly for the different incident frequencies,

Fig. 2. Spatial errors for different antenna apertures w ($\tilde{n}/n_0$=1.5% and λ_θ=6cm).

specially for medium and large beam size cases, and its average value decreases as the beam size increases.

For narrow beams (or long poloidal wavelengths) the interference effects are weak and the phase responds close to linearly to the density perturbation. For the case of the intermediate and large beams the phase and amplitude signals are similar in noise level or spectra, but when the FFT is performed it seems that the vector average is more effective for the larger beams: the time delay signal becomes cleaner and the final errors are smaller.
In a recent work [2] the author also concludes that a large beam is appropriate for profile measurements.

3. Simulation of correlation measurements

The simulation of correlation measurements has interest, first as a check of the simulation codes: we will try to reproduce the results of specific experiments [3,4] where correlation measurements with the homodyne signals performed better than the reflectometer phase signal. The simulation considers two reflectometers probing neigbohring plasma layers, separated in radial direction, with rotating turbulent structures. Correlation between the phases, time delay and homodyne signals of both reflectometrs are analyzed and compared with the correlation of the density distribution. Simulations compare cases with different perturbation parameters: average fluctuation level and poloidal wavelength (from weak to strong 2-dim effects) for an ITER-like plasma. The average poloidal wavelength is varied between 1.5 and 5 cm and the local value of the relative density fluctuation level between 2 and 8 % of the central value (10^{20}m-3).

In the cases of long poloidal wavelengths (5 cm) and low fluctuation levels (weak 2-dim effects), the radial correlation of the phase is the best approach to the radial correlation of the density (Fig. 3a). For shorter poloidal wavelengths and higher fluctuation levels interference effects become stronger and the correlation of the reflectometer phase drops faster than that of the density: big errors appear in the radial correlation length (Fig. 3b). The time delay (from AM) and homodyne signals give a better approach to the correlation length in the case of strong 2-dim effects. For the homodyne signal, the effect could be explained considering that the amplitude of the signal is included in the average the coherence calculation performs (FFT....): the contribution to the correlation of the instants with low amplitude and nonsense phase is smaller. A similar effect happens to the time delay signal (from Amplitude Modulation) since it directly includes the amplitudes of the three spectral componentes reflected.

The 2-dim simulation (Figs. 3a, 3b) shows a maxima-minima structure in the homodyne signal as the incident frequency is swept, being the maxima a good approach to the true values of the density correlation. In this structure (observed experimentally in some devices

[3]) the distance between maxima corresponds to increments of π in the phase offset of the reflectometer as the frequency is swept, thus a time delay can be derived as the basis for profile determination.

4. Conclusions

The 2-dim WKB code, able to compute interference effects, was used for qualitative investigation of the perturbations in reflectometry measurements induced by turbulence. Errors in the profile reconstruction due to high turbulence level can be nearly removed by increasing the amount of average of the reflected E-field.

The study of the antenna beam size effects on the profile determination shows the inconvenience of using medium beam sizes, i.e., beam sizes a few times larger than the poloidal wavelengths. Narrow or broad beams lead to better results.

Fig. 3. Radial correlation of the phase, homodyne and time delay signals for $\lambda_\theta = 5$ cm (a) and 1.5 cm (b). Solid line: actual density correlation

Correlation measurements using the reflectometry phase signal may provide a useful information on radial correlation lengths of the turbulence only in cases in which the 2-dim effects are weak, otherwise the AM or homodyne signals can be a better choice.

References

[1] V. Zhuravlev, J. Sánchez and E. de la Luna: Plasma Phys Control Fusion **38** 2231 (1996)
[2] G.D. Conway: Plasma Phys. Control. Fusion **39** 1261 (1997)
[3] J. Sánchez, B. Brañas, E. de la Luna and T. Estrada: Rev. Sci. Instrum. **64** 487 (1993)
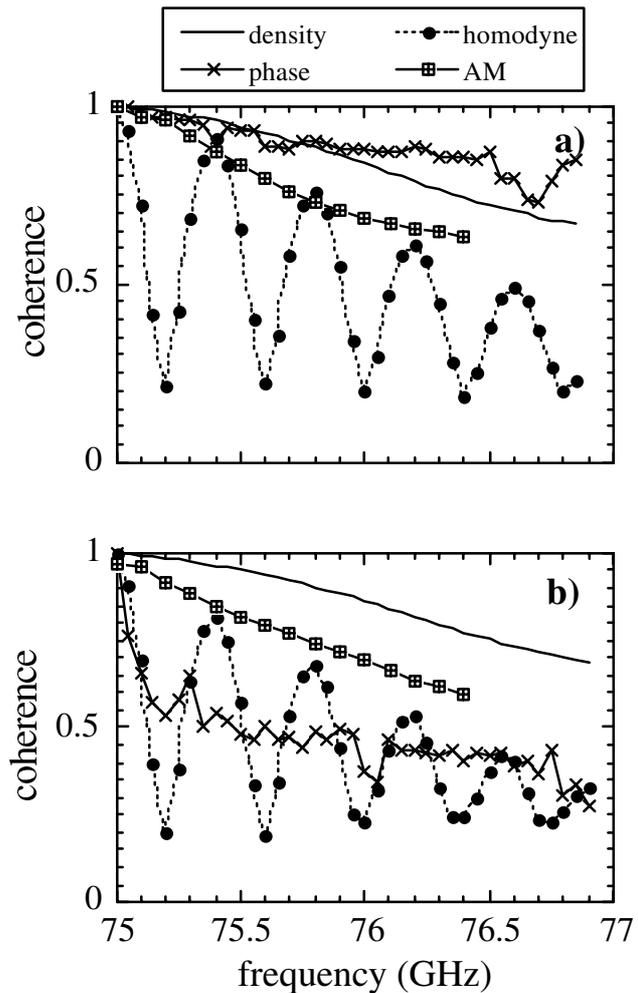[4] T.L. Rhodes, W.A. Peebles, E.J. Doyle, P. Pribyl et al.: Plasma Phys. Control. Fusion **40** 493 (1998)