Broadband Reflectometry to Investigate Profiles and Fluctuations during ELMS on ASDEX UPGRADE

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Introduction

Plasma fluctuations "print" their signature on the reflectometry signals but for profile inversion only the average beat frequency f_B is extracted and the perturbations due to fluctuations are regarded (together with the noise from the system) as problems to the profile evaluation. Here we apply a method based on the estimation of the time-frequency distribution (TFD) of the energy of the reflectometry signals, that gives both f_B and the profile perturbations. The broadband signals are nonstationary because their spectral characteristics vary along the sweep and the method uses the concept of instantaneous frequency *(fi)* that was introduced to describe the frequency of nonstationary signals at a particular time [1]. The *fi* is the first moment of the TFD with respect to the frequency [1]. Several TFD's can be used to estimate the *fi, i*n our study we used the simplest one, the periodogram. This can be computed with a sliding window Short-Time-Fourier Transform (STFT), being applicable as long as the signals are locally (in each window) quasistationary; the method and its application to broadband reflectometry is described in [2]. The analysis contributes to the study of the physical phenomena underlying plasma fluctuations and the understanding of the effect of fluctuations on the profile will improve the accuracy of profile measurement from reflectometry.

2. Evolution of density profile and fluctuations during ELMs

In the experiments we probe the ASDEX Upgrade plasma with the simultaneous operation of several O-mode reflectometry channels [3], in the frequency range *F*: 17-70 GHz corresponding to densities *ne*: 0.4 - 6.5 x 10^{19} m^{-3}. The measurements were performed at the high field side (HFS) during the ELMy phase of shot #8180. The interval between consecutive sweeps was 5 ms and the sweeping time 100 μs. The first time window under analysis is between 1.31 s (sweep 123) and 1.315 s (sweep 124) corresponding to the beginning of the ELMy phase ($\overline{n_e} \cong 6$ x 10^{19} m^{-3}). The periodograms obtained at the peak of the first ELM (Fig.1, sweep 123) and after the ELM (Fig.1, sweep 124), reveal that the plasma layers are mainly disturbed for *ne* below 2.5 x$10^{19}$$m^{-3}$ (F_I < 45 GHz). The profile shape can be inferred from the

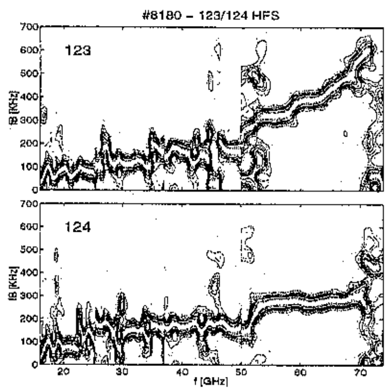
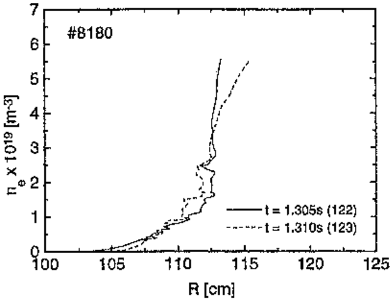
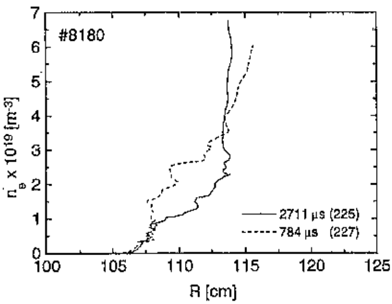


Figure 1



a) $n_{es} \cong$ *1.5 x 10^{19} m^{-3}*

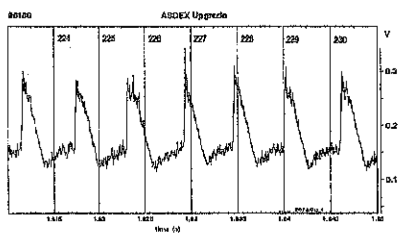


b) $n_{es} \cong$ *4.1 x 10^{19} m^{-3}*

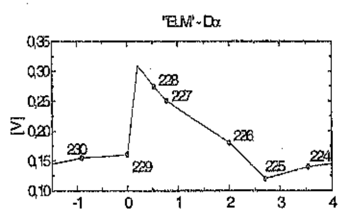
Figure 2

evolution of f_B, by taking into account that $F \propto \sqrt{ne}$, (horizontal axis) and f_B (vertical axis) can be converted into distance, after integration in F. During the ELM (Fig.1, 123) the profile flattens for $F > F_I$ (large increase of f_B), and it peaks (Fig.1, 124) in the same region after the ELM (very small increase of f_B). The density profiles (Fig.2 a) obtained directly from the first moment of the periodograms show that the profile flattening occur close and inside the magnetic separatrix, $n_{es} \cong 1.5 \times 10^{19}$ m^{-3}. Outside the separatrix the changes in the profile are very small, the plasma moves only slightly outward during the ELM.

The second window under analysis [1.815 s (sweep 224) - 1.845s (sweep 230)] is in the ELMy phase (see D_α signal in Fig.3 a), for $\overline{n_e} \cong 9 \times 10^{19}$ m^{-3}. In this interval the magnetic data shows that an m=1 mode is present, with increasing density (during the ramp up of a sawtooth event) until it ends at the sawtooth crash, occurring at 1.83s and preceding the peak of the ELM at 1.835s (sweep 228). The phases of the ELMs covered by the selected sweeps can be seen in (Fig.3.b), where a fictitious "ELM" is represented by plotting the amplitude of the D_α signal at the different sweeps. The time of reference for each sweep ($t' = 0$) is the rise time of D_α in the neighbouring ELM. The periodograms (Fig.4) reveal that the plasma is much more disturbed than in the previous case and the perturbations exhibits a rather different pattern, being stronger in the middle region, 30 - 55 GHz, 1 - 3.7 x 10^{19} m^{-3}. As in this case $n_{es} \cong 4.1 \times 10^{19}$m^{-3}, the disturbed region should be located close and outside the separatrix and may be associated with a satellite of the m=1 mode. In fact the same type of perturbation cannot be seen in the previous case where a large amplitude mode is not present. In addition, the perturbations are stronger even at inner plasma layers when the m=1 mode has the largest amplitude (sweep 227) and also when the mode ends at the



a)



b)

Figure 3

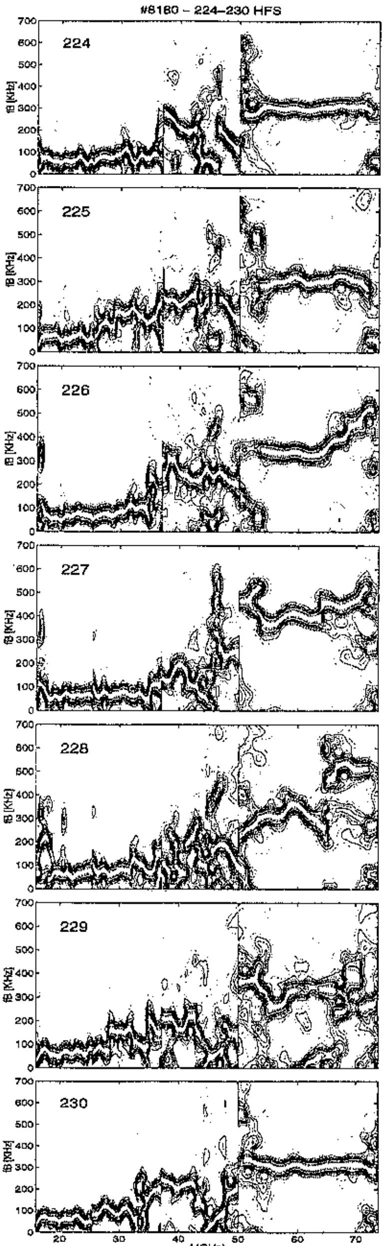


Figure 4

sawtooth crash (sweep 228). The changes of the density profile along the "ELM" observed in the periodograms (Fig.4), can be viewed in more detail from the evolution of the power spectrum at specific density layers, or frequencies F, (Fig.5). At the inner region, (Fig.5.e, f), the beat frequency (dashed line) increases abruptly at the onset of the ELM and decreases after, showing that the flattening of the profile coincides with the rise of the D_α signal. It should be noted that a low frequency perturbation appears at the onset of the ELM. For $t \geq$ 500µs the profile is already peaking whereas in the neighbouring layers, (Fig.5. g, h), the profile movements are less pronounced and are delayed by $\Delta\ t \approx$ 500 µs. This seems to indicate that the profile changes start inside the separatrix and "propagate" and damp towards the separatrix, $F(n_{es}) \cong 60$ GHz. At outer regions, $n_e \leq$ 0.65 x 10^{19} m^{-3} ($F \leq$ 23 GHz), the profile does not change significantly

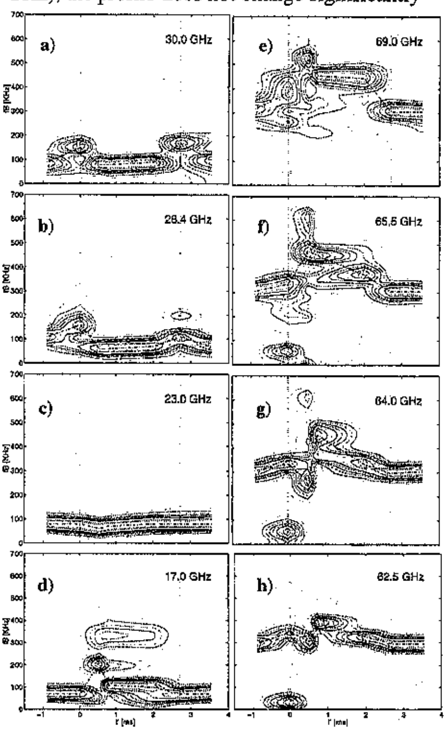


Figure 5

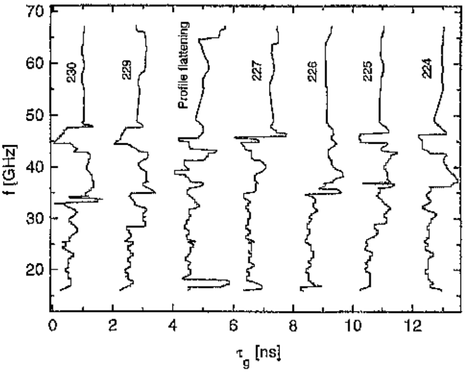


Figure 6

(Fig.5 c), suggesting that the separatrix region acts as a kind of "joint", for profile movements. Indeed, the crossing point of the profiles during an ELM and between ELMs in both studied cases, Fig.2 (a, b), occur at a density close to n_{es}. Outside the strongly disturbed zone, F < 35 GHz, the profile is quiescent except in a very narrow region (Fig.4, sweep 228), at the outer edge (F=17 GHz, ne= 0.37 x 10^{19} m^{-3}). The perturbations are observed coinciding with the profile peaking at the inner region (Fig.5 e, f), suggesting that there may be a link between inner and outer plasma layers. It should also be noted that at the edge, some layers (Fig.5 a, b) are displaced inwards at the beginning and at the end of the ELM. The changes of profile and perturbations along the "ELM" can be viewed simply in the τg curves (Fig.6) obtained from the maximum peak of the periodogram. This provides a direct tool for a first analysis of profile evolution.

3. Discussion

We applied a new data analysis method to broadband reflectometry which unfolds the energy associated with the reflection from the plasma and the energy scattered by fluctuations, giving its particular location in time (density) and frequency.

From the point of view of profile evaluation this is very important because it avoids the use of narrow digital filtering to extract τg and therefore retains details of the group delay curve that may be important for profile accuracy. It is also valuable when a significant part the energy is scattered by fluctuations and many spectral peaks exists. Profiles measured in ASDEX Upgrade during an ELM, show that the profile flattens inside the separatrix coinciding with the rise of the D_α signal; for $t \geq$ 500 μs the profile is already peaking and continues until a new ELM occurs. The profile changes in each density layer and the evolution of the local energy spectrum of plasma perturbations were obtained with great detail from the history of the energy spectrum in each window of analysis. Strong perturbations are present during ELMs and between ELMs, in the middle region of the plasma and at the onset of the ELM, in the inner zone where the profile flattens.

Further studies and more detailed experiments (with sweeps of 20μs, spaced by 30μs) are foreseen to determine if the observed perturbations can be attributed to MHD activity.

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[1] B. Porat (1994), Digital Processing of Random Signals, Prentice-Hall, Englewood Cliffs.

[2] J. Santos et al., (1997), III Reflectometry Workshop for Fusion Plasma, Madrid.

[3] A. Silva et al., (1996), Review of Scientific Instruments 67 (12), 1996.