# Continuous tracking of density profile build-up during L-H transition on ASDEX Upgrade from microwave reflectometry

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## 1. Introduction

The microwave reflectometry system on ASDEX Upgrade uses O-mode (at high-field (HFS) and low-field (LFS) sides), X-mode (low-field), and can operate at broadband ultrafast sweep ($\geq 20$ µs) and at fixed frequency, probing densities up to $\sim 6.5\times10^{19}$ m$^{-3}$ /1/. With fixed frequency specific plasma density layers are probed at a rate of 1 µs (sampling frequency: 1 MHz). A technique to track the plasma position of fixed density layers is presented and demonstrated for the density profile evolution during L- to H- transitions.

The temporal evolution of the frequency spectra of the reflected signals (with 300 kHz maximum imposed by the data acquisition rate) shows an abrupt reduction of the turbulent fluctuations at the L - H transition. The reduction is observed both at the high and low-field sides and permits to identify the time of transition (aside from the decrease of the $D_\alpha$ signal) with high temporal resolution. In the spectral content of the reflected signals a clear low-frequency oscillation ( $\leq 500$ Hz) is also observed around the L-H transition, due to the radial displacement outwards of the reflecting layer as the edge density gradient increases. From the corresponding phase and amplitude variations the incremental shift of the position of the reflecting layers can be inferred, with an accuracy (in the millimetre range) defined by the high temporal resolution of the detected fringes (3µs). Therefore, the profile build-up following the L-H transition can be tracked revealing the temporal development of the transport barrier.

## 2. Analysis of turbulence during an H-mode discharge

In a homodyne system the detected signal is sensitive to amplitude and phase fluctuations, such that $V(t) = A(t) \cos \phi(t)$, where $\phi(t)$ is the phase difference between the signals from the plasma and the reference arm. A reflection layer at a fixed equilibrium position leads to a constant phase angle. Density fluctuations will cause displacements and corrugations of the refractive index surfaces, leading to amplitude and phase variations that will have impact on the spectral components of the detected signal.

The temporal evolution of the power spectra is obtained using a FFT sliding technique. Fig. 1 c-e shows the contour plots , corresponding to three probing frequencies: 22.7 GHz ($n\sim0.64\times10^{19}$ m$^{-3}$,at the HFS),31.7 GHz ($n\sim1.24\times10^{19}$m$^{-3}$,close to the magnetic separatrix, at the LFS), 45.7 GHz ($n\sim 2.58\times10^{19}$ m$^{-3}$ , LFS), for # 8595; it is a discharge with unfavourable gradB drift direction (away from the X-point), where the H-mode is attained through ctr-NBI with high heating power (Fig. 1a). An abrupt reduction in the power spectrum of the turbulent fluctuations is observed both at the high and low field sides, that permits to identify the time of the L-H transition (t=1.704s) aside from the decrease of the Dα signal (Fig. 1b).

Although the reduction of density fluctuations occurs at the transition (simultaneously) for all the probed layers (that should therefore be located inside the suppression zone where the transport barrier builds-up), there is a distinct behaviour when analysing the discharge from the OH to the H phases: at the HFS, outside the separatrix, the frequency spectrum extends up

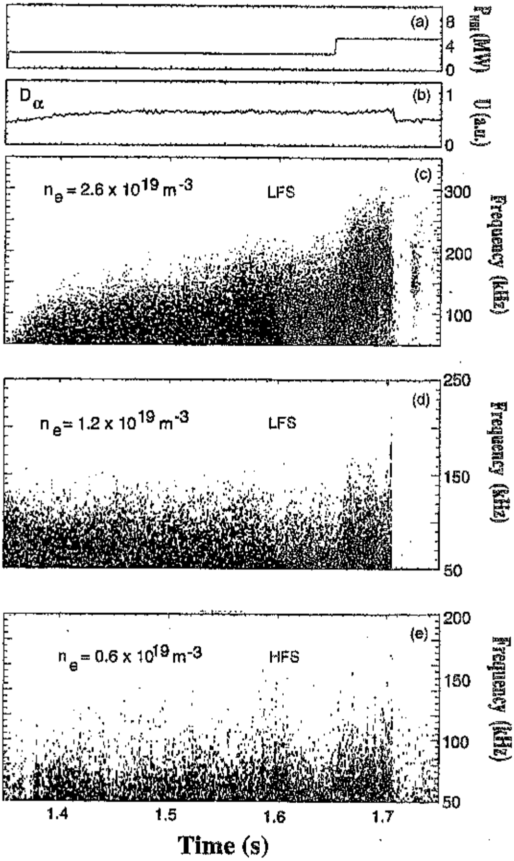

**Fig.1**

to ~ 100 kHz (Fig.1e); at the LFS, close to the separatrix, it extends to ~ 150 kHz (Fig. 1d)with an almost constant temporal behaviour until the transition; in contrast, inside the separatrix, at LFS,a broadening of the frequency spectrum occurs correlated with NBI, specially with high heating power (after 1.65 s) and reaching ~ 300 kHz just before the transition (Fig.1c). The observed broadening might be due to Doppler shift in the reflectometer signals induced by an E×B poloidal velocity rather than an increase of density fluctuations. The significant increase of the ExB velocity before the L-H transition inside the separatrix is consistent with the detected increase of the radial electric field ($E_r$ ) at the edge, as will be discussed in section 3. (see Fig. 2);the distinct behaviour at different radial positions suggests the existence of a highly sheared E×B flow leading to better confinement through the decorrelation of the turbulent fluctuations, the accepted scenario to trigger the L-H transition.

## 3. Detection of density profile modifications during the L - H transition

In the spectral content of the reflected signals a clear low-frequency oscillation ( ≤ 500 Hz) is observed around the L-H transition; it is caused by movements of the reflecting layer associated with radial displacements of the layer during the density profile build-up associated with confinement improvement. In Fig.2 b , the low pass filtered reflectometry signal obtained from the raw data of Fig. 2a (referring to layer $n_e \sim 2.58\times10^{19}$ $m^{-3}$ , LFS) is shown. Periodic oscillations start at t ~1.69s, coinciding with the slow increase of the radial electric field $E_r$ before the transition; this rise in $E_r$ is inferred from changes in the fluxes of ripple-trapped charge exchange (CX) neutrals /2/, (Fig. 2e),in parallel to the edge pressure gradient, revealing an improved confinement still in the L phase (with increasing $n_{e,edge}$ (Fig.2c), and with the presence of ELMs (Fig.2d)).

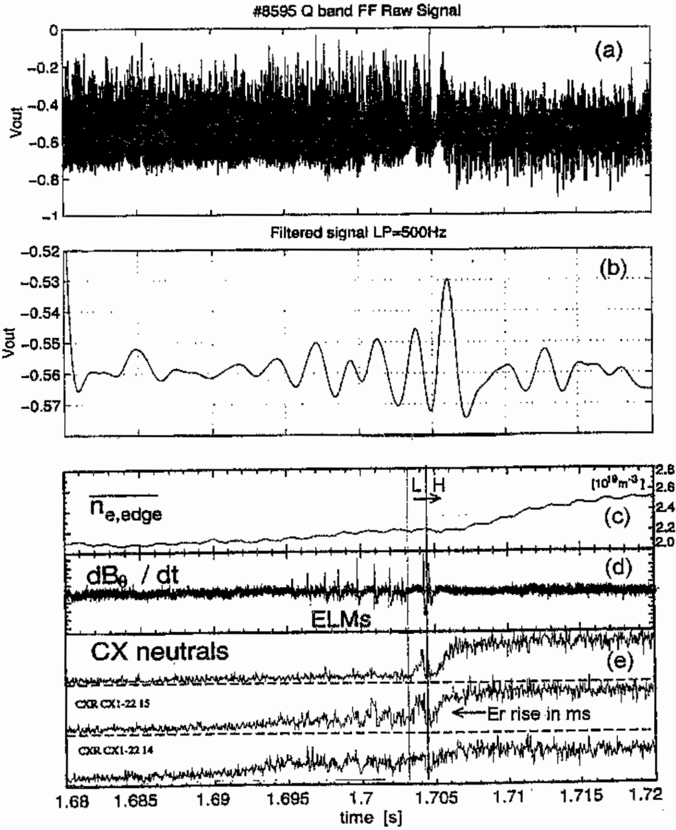

**Fig. 2**

After the L-H transition (t ~ 1.704s), a fringe with high amplitude is observed revealing a radial displacement outwards of the probed layer (towards the receiver antenna), corresponding to the profile build-up during a time interval of ~ 2.5 ms. On the same time interval a fast increase of $E_r$ occurs (Fig.2e), consistent with the build-up of the edge transport barrier following the abrupt drop in turbulence.

The profile evolution at the edge can be inferred by estimating the incremental displacements of the layer. Using a numerical code /3/ which takes into account the antenna-plasma geometry of the reflectometry system and assuming the shape of the evolving density profile (with increasing mean density and no global radial displacement) , the estimated displacement of the reflecting layer ($\Delta R_c$) corresponding to one fringe variation is ~ 0.6 cm; a similar result is obtained through the relation $\Delta R_c \cong \lambda_0 \Delta\phi / (4\pi \overline{N})$, with the mean refractive index $\overline{N} = 0.6$. Assuming as an initial profile the one from Li-beam at 1.7s, a radial displacement of 1.2cm (2 fringes) between 1.703s and 1.708s will lead to a steepening of the edge gradient from $\sim 0.6\times10^{21}\ m^{-4}$ to $\sim 1.0\times10^{21}\ m^{-4}$.

The impact on the density profile of the full development of the transport barrier might therefore be tracked with the "continuous" temporal probing of several density layers (from the edge up to the bulk plasma), as foreseen for the next measuring campaign (with probed densities up to $\sim 14\times10^{19}\ m^{-3}$ ). However, an heterodyne detection system for the direct measurement of the phase will be important in order to overcome ambiguities that might occur with fringe detection when the plasma layers move back and forth (as in the profile changes caused by ELMs).

## 4. Concluding remarks

In addition to information about the abrupt decrease of turbulence and about the increase of plasma rotation at the L - H transition, the spectral content of the reflected signals can also give insight about density profile changes. By low-pass filtering the spectra of the reflected signals, fringes due to radial displacement of the density layers during the profile build-up can be identified. With this technique the incremental shift of the position of the reflecting layer can be estimated with an accuracy in the millimetre range.

A new reflectometry channel has been recently installed for monitoring the L - H transition on ASDEX Upgrade, to operate in fixed frequency, independently of the other channels. Simultaneous measurements with fixed frequency and broadband operation in the same discharge (as foreseen for the next measuring campaign on ASDEX Upgrade), will provide density profile measurements with high temporal and spatial resolutions and further indication about the absolute position of the layers probed in fixed frequency. The potential of a such a highly performant reflectometry diagnostic suggests the possibility of tracking continuously the motion of plasma layers associated with important physical phenomena where fast profile changes occur (such as L-H transition, ELMs and MARFES).

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