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X mode heterodyne reflectometry measurements on Tore Supra.

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Introduction

A heterodyne X mode reflectometer has been installed on the Tore Supra tokamak to measure edge density profiles. Routine edge profile control need to be performed in order to understand, amongst many problems, the physic of heat flux power deposition onto the plasma facing components and the coupling power to the plasma core of the different additional RF heating systems. Also, it is of a great importance to depend on a highly reliable diagnostic in this highly turbulent plasma region. Ultra fast sweep performances of the reflectometer associated with high sensitive heterodyne detection allow now to reach such reliability on the density profiles reconstruction [1] as well as the study of fast dynamic events like MHD mode activity.

Experiment and density profile reconstruction

As X mode propagation depends on the density and the magnetic field, the results presented here are related to a first reflectometer (50-75 GHz) dedicated to radial edge profile measurements at moderate field (3T) plasma discharges. An additional 75-110 GHz reflectometer is at present under development for high field (4T) plasmas. The technical characteristics of the diagnostic in routine operations are : 20 µs sweeping time with heterodyne detection of 50 dB dynamic range, and 10 dBm average output power. A repetition rate of 5 µs between two consecutive sweeps can be achieved to follow the dynamic of fast plasma events. The diagnostic has been routinely operated and the density profiles have been fully automatically calculated using the Bottollier algorithm [2], to be part of the data base of Tore Supra. At present, during one discharge no more than 40 profile measurements are performed for a matter of memory and data transfer limits of the acquisition set up. Since I.Q. detection allows separate measurements of the phase and the amplitude of the signal, the initialization of the profiles is done by an automatic detection of the first cut-off when the amplitude of the reflected signal start increasing (Fig. 1 and 2). An accuracy better than 1 cm on the plasma position can then be achieved. Because of the high dispersivity properties of the phase of the X mode probing wave during its propagation into the plasma, the beat frequency of the detected signal needs to be first calculated using a wide band pass filter (15 MHz) and then processed through a additional sliding band pass filter with narrow bandwidth (2 MHz) in order to reduce the phase noise. Owing to this filtering technique, small plasma structures, in the centimeter range, can be clearly observed on the profiles as they exhibit small density plateaus (Fig. 3a). It is worth noting that these structures are often associated with strong amplitude variations (Fig. 3b) of the reflected signal suggesting their extension in the poloidal and/or in the toroidal direction.

Density regimes

As an example, it is shown the edge density profile evolution during the ramp up of the central density all along the plasma discharge under activation of the ergodic divertor (E.D.) device to test its pumping efficiency. The edge density behavior exhibits successive plasma regimes [3] going from low recycling to high recycling and detached regimes. In agreement with measurement performed inside the E.D. with fixed Langmuir probes (Fig. 4), the density measured by reflectometry shows an increase of the density until the high recycling regime is reached. During the detached regime, when the average plasma density reach its maximum, the edge density profile is getting steeper (fig. 5) along with a recess inside the plasma that is responsible of a collapse of the density measured by the probes. This recess being probably due to an increase of the amount of neutral particles as the edge temperature decreases as well. At the end of the plasma discharge an ultimate reflectometry acquisition occurs right during the disruption. In spite of this particularly turbulent plasma event, the reflected signal is correctly recorded and the density profile perfectly reconstructed. This exhibits a strong endurance and a high reliability of the reflectometry diagnostic for very troublesome plasma conditions.

MHD activity upon the reflectometry signal

Due to the sensitivity to small plasma structures, the reflectometry offers the capabilities of being affected by the MHD modes [4] each time the probing wave encounters a rational q surface at the cut-off layer region. Fig. 6 shows the variations of the amplitude of the reflected signal at the rational q surfaces. Thus, the diagnostic can contribute to the measurement of the radial plasma current profile distribution. By making fast acquisition of 20 μs with a high repetition rate of 5 μs between two consecutive sweeps the reflectometry can record the dynamic of the MHD mode activity. The rate of the occurrence of the magnetic island in front of the reflectometer is ~ 8 kHz in agreement with the magnetic probes and has been measured at the rational magnetic surface q=2. This value has been obtained by using the temporal evolution of the time delay at the position corresponding to q=2 (Fig 7). The way of achieving such measurement is described on the Fig. 8. From the group delay variations versus the probing swept frequencies, it is then possible to recover the shape of the density perturbation near the rational magnetic surface by simulation as shown on Fig. 8.

[1] Ph. Moreau, F. Clairet, J.M. Chareau, M. Paume and C. Laviron : Rev. Sci. Instrum., **71**, 74 (2000).
[2] H. Bottollier-Curtet and G. Ichtchenko : Rev. Sci. Instrum. **58**, 539 (1987).
[3] B. Meslin, Ph. Ghendrih, A. Grosman et al., Proc. of the 24th EPS, Contr. Fusion and Plasma Physics, **21A-I**, 197 (Berchtesgaden 1997).
[4] M. Manso, F. Serra, A. Silva et al., Proc. of the 1st IAEA Tech. comm. Meeting on Reflectometry (Abingdon 1992).

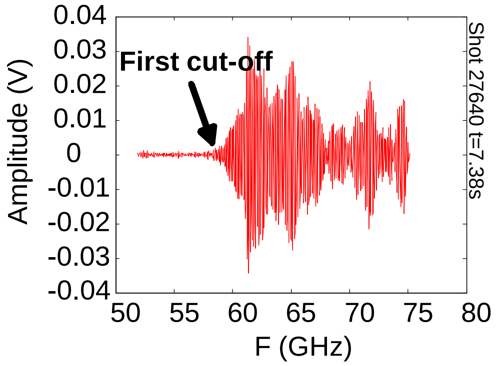

Fig. 1 : Detection of the first cut-off from the reflected signal for profile initialization.

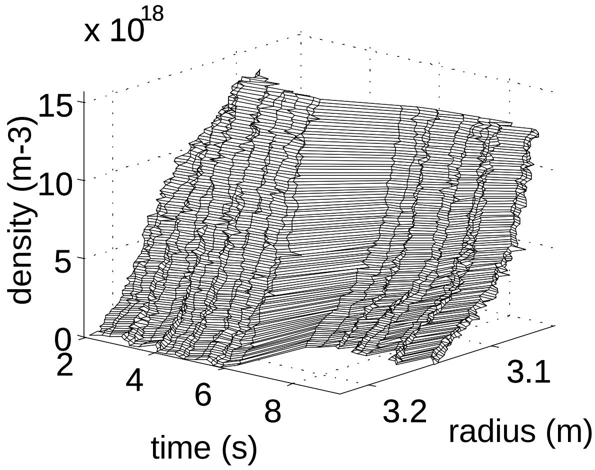

Fig. 2 : Illustration of the automatic edge density profile reconstruction during plasma displacement.

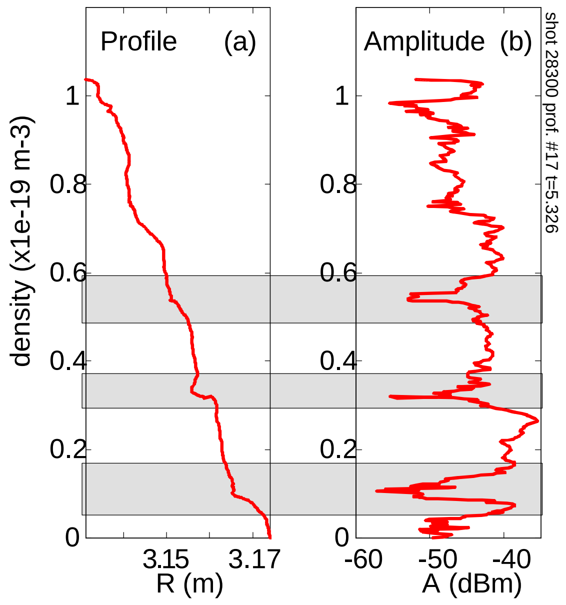

Fig. 3 : Small 2D plasma structures in the SOL exhibit small density plateaus into the profile (a) corresponding (shaded areas) with strong amplitude variations (b) the reflected signal.

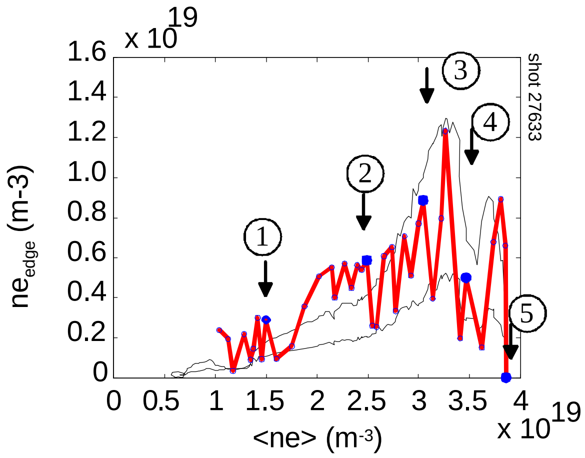

FIg. 4 : Comparison of edge density measurements between Langmuir probes (thin lines) and X mode reflectometry in the SOL at R=3.19 m (thick line).

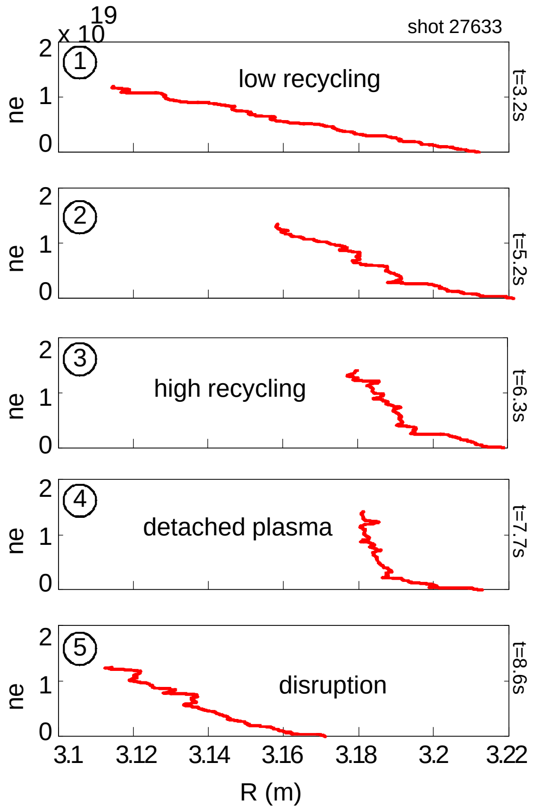

Fig. 5 : Density profile according to successive plasma regimes quoted from Fig. 4.

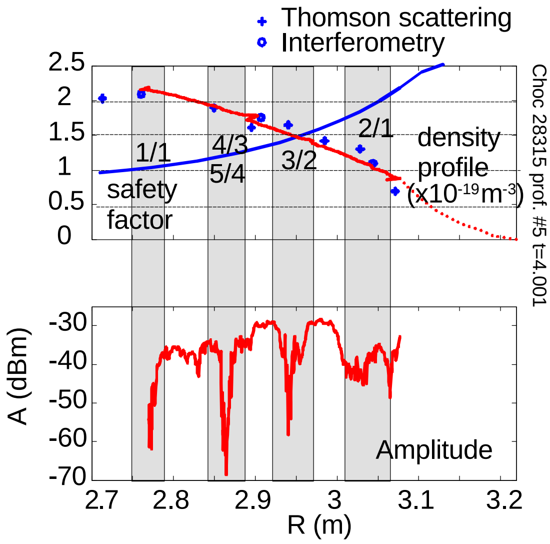

Fig. 6 : Amplitude and phase variations of the reflected signal at the rational q surfaces.

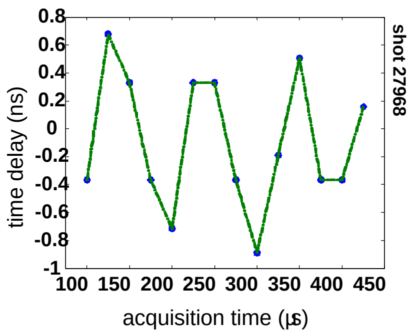

Fig. 7 : Temporal variation of the time delay measured at the rational q=2/1 mode. Thus the frequency measured is about 8 kHz.

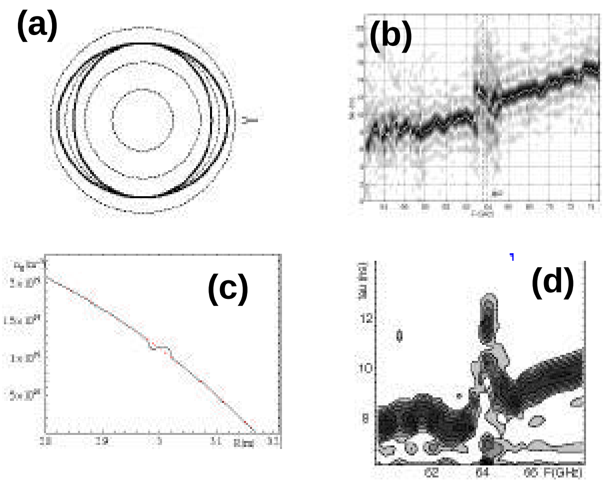

Fig. 8 : (a) Schematic of the q=2/1 mode with emitting antenna and (b) the corresponding time delay measured by the reflectometer. With a simulated perturbed profiles (c) the corresponding time delay (d).