ABSOLUTE CALIBRATION OF DENSITY PROFILES FROM BOTH O AND X MODE REFLECTOMETRY ON ASDEX UPGRADE

I. Nunes, P Varela, G. D. Conway[1], F.Silva,F. Serra, M. Manso and the ASDEX Upgrade team[1]

Centro de Fusão Nuclear, Associação EURATOMIST, Instituto Superior Técnico, 1049-001, Lisboa, Portugal
[1]MPI für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany

1. Reflectometry system at ASDEX Upgrade

Reflectometry is a promising diagnostic for future fusion devices like ITER as it allows measuring density profiles with high temporal resolution, using either O or X mode operation. O mode has the advantage of simplicity, since the cut-off frequency depends only on plasma density, but it can only probe densities typically above 0.3 x 10^{19} m^{-3} because the wavelength needed to probe lower densities becomes too long compared to the density gradient scale length. X-mode sensitivity to both magnetic field and plasma density allows reflection from almost zero density where the cut-off frequency is the same as f_{ce} ($f_{ce} = \frac{eB(r)}{2\pi m_e}$). With combined O and X-mode operation (at the plasma edge) the complete profile can be probed.

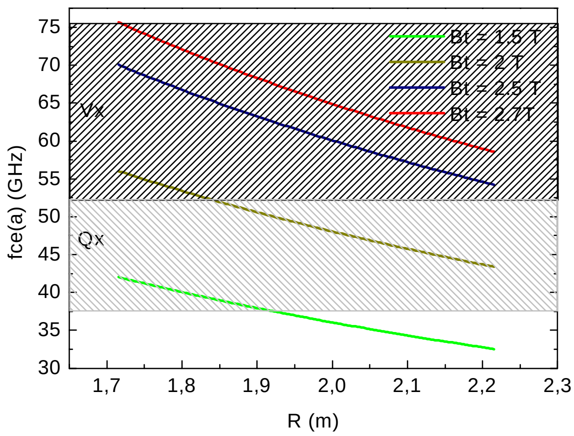

Fig 1 - Typical values of magnetic field used in ASDEX Upgrade Tokamak and reflectometry measurement range (Qx [32 50] GHz, Vx [50 72] GHz)

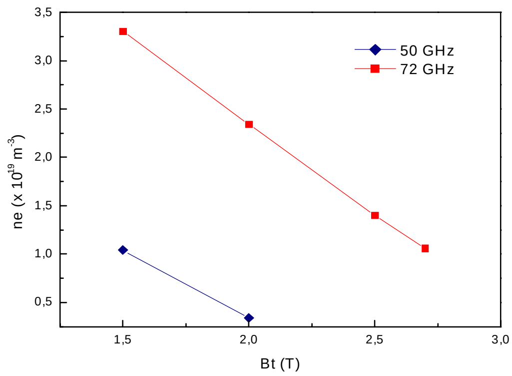

Fig 2 - Higher density values for the magnetic fields considered in Fig. 1 and a given density profile with $n_{e0} = 7 \times 10^{19}$ m^{-3}; $\alpha = 7; \beta = 1$

However, there are situations where X mode is not useful as occurs in some experiments in ASDEX Upgrade where the cut-off frequencies are out of the reflectometer frequency range.
It may also happen when no reliable information about the magnetic filed exists, as it will be the case for the reflectometer planned for ITER to control the plasma position in long pulse operation. In ASDEX Upgrade a reflectometer with five channels in O mode and two in X mode at the LFS (low field side) is fully operating [1]. The density range covered by the O mode goes from 0.3 x 10^{19} to 1.5 10^{20} m^{-3} while the density range covered by the X mode channels changes according to the magnetic field as is shown if Fig 1. The frequency range is 37-72 GHz, which as can be seen in Fig. 2, may or may not allow measurements for typical values of magnetic field on ASDEX Upgrade. Due to this dependence with the magnetic field, X mode is a very good tool to provide data for edge physics studies since the very early beginning of the plasma can be probed, although limited to the frequency range available at ASDEX Upgrade. The values of Fig. 2 were obtained using a magnetic field profile decaying with 1/R and the density profile used was based on the following equation in order to reproduce a typical plasma of ASDEX Upgrade

$$n_e = n_{e0}\left(1-(r_0/(x_0+R_0))^{\alpha}\right)^{\beta}$$

The detection system for the Q_x band is homodyne, which means that the experimental data contain both signal phase and amplitude, while the detection system for the V_x band is single ended heterodyne, which means that at the end we also don't have separate amplitude and phase. Since we cannot separate these quantities, a method for the detection of the first reflected frequency that is not simply based on the signal amplitude is needed. This paper describes the method used to determine the first reflected frequency and the errors due to the uncertainties on the detection of the first reflected frequency. Also experimental results from O mode combined with X mode using only Q_x band are shown.

2. Detection of the first reflected frequency

As said before, homodyne detection does not allow to have phase and amplitude separately

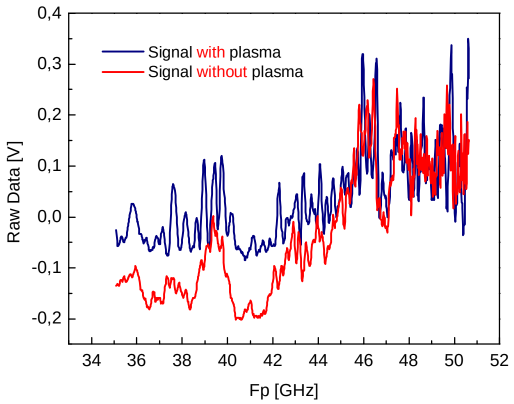

Fig 3 – Raw data of two signals of the Q_x band from the same shot with and without plasma

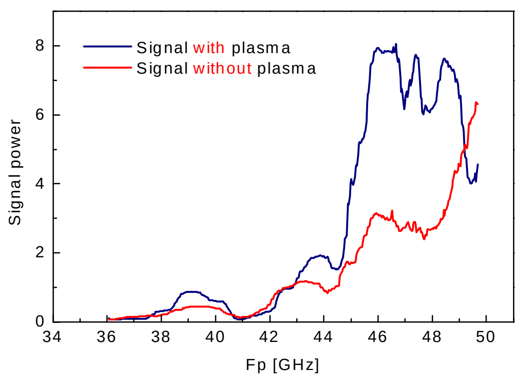

Fig 4 – Signal power from the two signals showed in Fig 3 with and without plasma

which means that the amplitude signal cannot be used directly as in Tore Supra [2]. A method to determine the first reflected frequency (first fringe) is needed. This method consists in taken the information directly from the raw data (Fig 3) and treat it in a way where it is possible to obtain the desired information. First the lower frequency (base line of the signal) is removed using a bandpass filter. For the calculation of the signal power, the square of the filtered signal was determined and then multiplied by the acquisition sampling rate. In Fig 4 is shown the signal power of the two signals from Fig 1 where is clearly seen that the signal with plasma leads to an increase of the detected power. From these curves we clearly see when the first fringe occurred, but there are cases that are not that simple. To be able to detect these cases some assumptions were made. At zero density the first reflected frequency matches the electron cyclotron frequency (f_{ce}). Assuming that behind the antenna does not exist plasma, a minor value for the first reflected frequency is found (antenna position = 2.374 - major radius). To major the interval where the first fringe should lie, an estimated value that is routinely used by reflectometry to do profile inversion at ASDEX Upgrade was imposed (R = 2.215 m). With these two values two f_{ce} boundaries for the first reflected frequency are imposed as shown in Fig 5 where the lower curve (green) corresponds to R=2.374 m and the upper curve (blue) to R = 2.215 m. As said before for some cases it is not easy to take the first fringe value from the signal power itself. The difference between both curves (with and without plasma) is so small for some cases that some artefacts have to be used. The gradient of a curve is more sensitive to these differences. For this reason the gradient of the signal

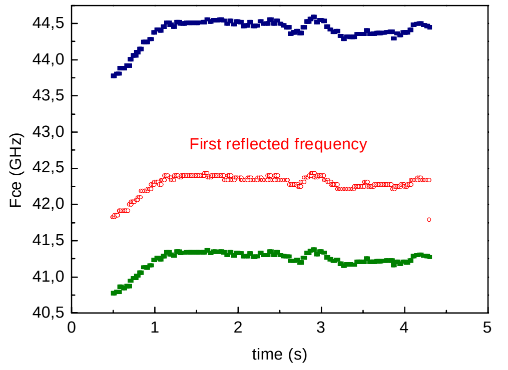

Fig 5 – The lower and upper curves correspond to the boundaries that defines the interval where the first reflected frequency must be in (middle curve)

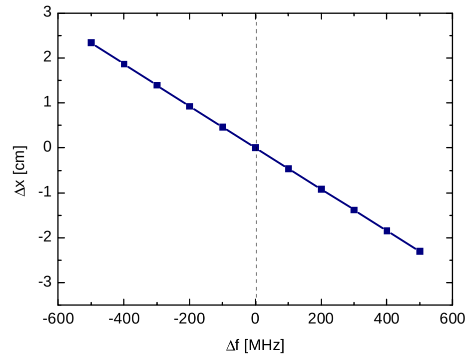

Fig 6 – Errors in the positioning of the density profile due to an error in the first reflected frequency

power was used to determine the first fringe. In the defined interval the first jump of the gradient defines then the first reflected frequency. As it will be shown in the experimental results this way of calculating the first fringe gives very good results but one has to be aware that an error of 1GHz gives a deviation of 4 cm in the density profile position. In Fig 6 the position errors of the density profiles in function of an error in the detection of the first reflected fringe are shown.

3. Experimental results

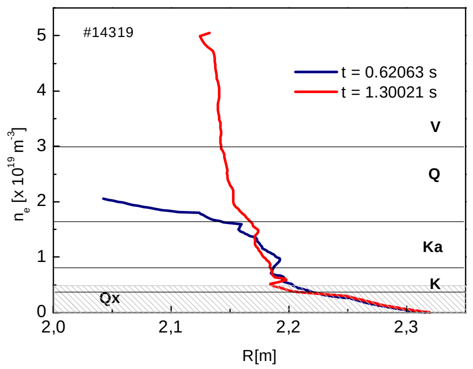

Fig 7 – Reconstructed density profiles using the X mode for the initialisation (Q_x band)

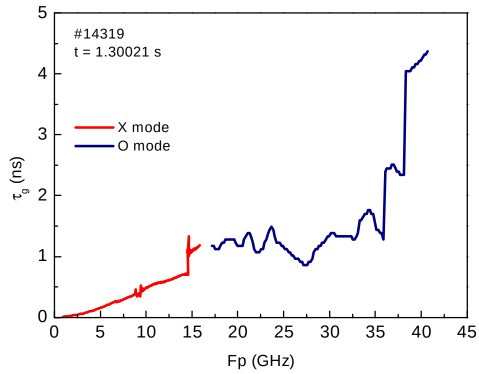

Fig 8 – This figure shows group delay using X mode (red) and also using O mode (blue)

In Fig 7 two density profiles using both information from O and X mode are shown. It can also been seen the different bands used at the ASDEX Upgrade reflectometer. For this case study the magnetic field is 2.083 T. In order to obtain the group delay for the initialisation with X mode the following steps are needed [2] [3] since the frequencies from both modes do not have a direct correspondency; (i) the group delay in X mode is obtained using the SFFT method [4] (ii) using a numerical algorithm the profile is calculated [2]; (iii) Using another numerical algorithm this electron density profile obtained in X mode is converted into O mode group delay as shown in Fig 8 (with the correspondent frequencies in O mode). In fig 7 the two shown profiles were reconstructed using information from the entire X mode signal. In Fig 9 a comparison between two profiles where only the information from x_0 (position of zero density) was used and the initialisation is linear (more comonly used in ASDEX Upgrade). As can be seen from the figure, changing the x_0 can lead to errors of the positioning at the edge profile that decrease with an increasing density, but this displacement can be very

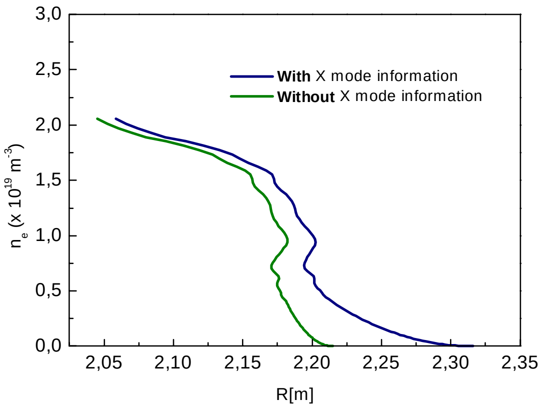

Fig 9 – Comparison between two profiles using a linear initialisation with a different x_0

important when measurements of phenomena at the very edge are required.

4. Conclusions

From the results described above, one can say that the X mode reflectometry is a good tool to give density profiles at the edge taking into account the dependency with the magnetic field. The detection of the first fringe is therefore an important parameter that has to be used with careful. The used method has proved to be robust and might give a significant improvement to O mode only measurements. Other two methods based on the power spectrum in time and frequency were used, but the conclusion was that these methods were more complicated and time demanding, although the results were very similar. Apart from the errors that are introduced by the first fringe detection also we have to take into account the limitation of the possible measured electron density due to the frequency range available. For high magnetic fields we need to have higher probing frequencies in order to have the edge plasma density

Acknowledgements

This work has been carried out within the framework of the Contract of Association between the European Atomic Energy Community and “Instituto Superior Técnico”, and has also received financial support from “Fundação para a Ciência e Tecnoligia” and “Praxis XXI”.

References

[1] A. Silva et al., this conference

[1] F. Clairet et al. “Edge density profile Measurements by X-mode reflectometry on Tore Supra”, Plasma Phys. and Controlled Fusion, 43, Nº 4 (2001)

[2] I. Nunes, Master Thesis, Instituto Superior Técnico, (1997)

[3] M. Manso, I. Nunes, F. Silva, Varena (1997)

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