

OBSERVATION OF POLOIDAL ROTATION BY MICROWAVE REFLECTOMETRY

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Abstract

Density turbulence measurements are obtained by microwave reflectometry under various conditions and confinement regimes of W7AS. Use of the microwave reflectometer to measure poloidal propagation of electron density fluctuations is demonstrated. Properties of poloidal propagation of electron density fluctuations are investigated, and features observed in the microwave spectra are found to display different effects in the different confinement regimes studied.

1. Microwave Reflectometry

The W7AS microwave reflectometer [1,2] uses X-mode propagation and operates in the W band (75-110GHz). The instrument possesses two conical antennas oriented radially towards the centre of the torus axis and separated poloidally by 12° with their symmetry axis in the equatorial plane. The normal to the cut-off surface lies at a tilt angle of 2.6° to the probing direction resulting in an asymmetric fluctuation frequency spectrum. This diagnostic has been used to measure density profiles and to investigate fluctuation propagation by the phase runaway method [3]. There exist three possible components to the backscattered signal detected by the receiver antenna; (i) the coherently reflected signal with unshifted frequency, (ii) the symmetrically Doppler-broadened signal resulting from the phase modulation signal caused by radial movement of the cut-off layer, and (iii) the asymmetric frequency shifted sidebands caused by scattering from density fluctuations propagating in the poloidal direction across the field of view of the reflectometer.

2. Reflectometry and confinement

Differences in reflectometry spectra for different confinement regimes are illustrated in figures 1a-d, which show frequency-time plots obtained with two D_2 plasma shots heated by 400kW ECRH. The confinement time is different due to a small change in edge iota value. All other shot parameters are unchanged. The first example, with confinement time τ_e of 20ms and diamagnetic energy W_{dia} of 10kJ, shows a sideband feature clearly separated from the sharp central peak at the carrier frequency, in contrast to the second example ($\tau_e = 10\text{ms}$, $W_{\text{dia}} = 5\text{kJ}$) where no such separation is observed. Additionally, analysis of the spectrum close to the carrier frequency shows that the central peak is broader and lower in the shot with the lower confinement time. A similar result occurs with NBI shots, where the peak at the carrier frequency is seen to become sharper with an increase in τ_e . Possible causes for the broadening of the peak include the presence of the asymmetric feature at very small frequency shifts and the Doppler shift of the reflected signal caused by the radial movement of the cut-off layer.

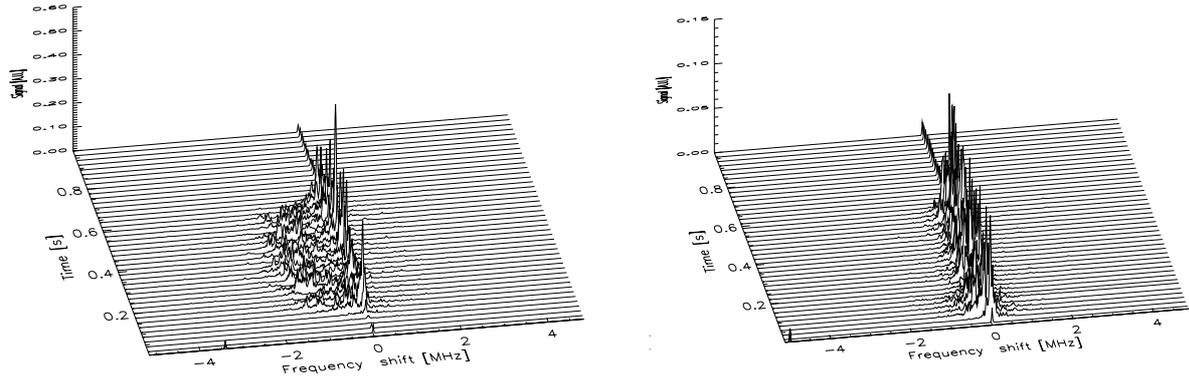


Fig. 1a&b: Reflectometer spectra from ECRH discharges. Left, $\tau_e = 20\text{ms}$, Right, $\tau_e = 10\text{ms}$.

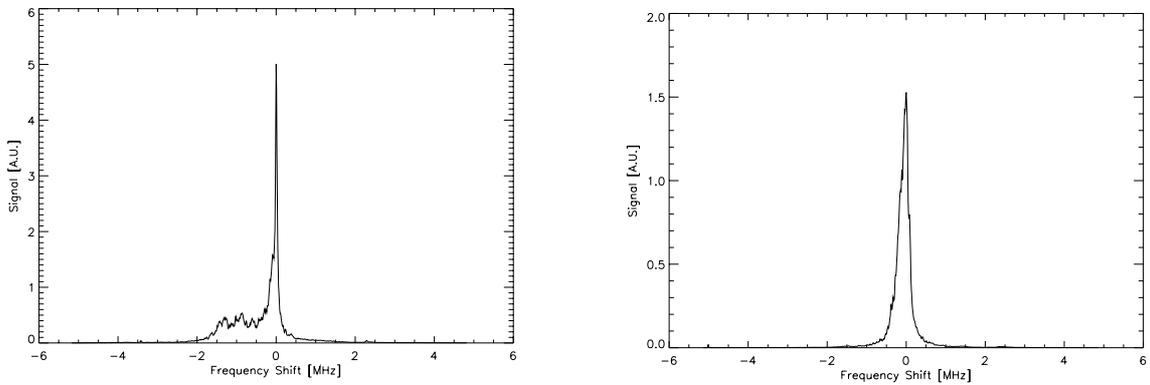


Fig. 1c&d: Time integrated sum of spectra shown in Fig. 1a&b. Left, $\tau_e = 20\text{ms}$, Right, $\tau_e = 10\text{ms}$.

In order to quantify the spectral development, numerical routines have been developed to fit the signal with various curves. Usually, the backscattered frequency spectrum was fitted with a triple Gaussian curve. The degrees of freedom in these fits were the heights, widths and frequencies of the sidebands and of the peak near the carrier frequency. Good fits were obtained for time-frequency traces with pronounced sidebands. The fitting was not so successful for shots in which no clear separation could be seen between sidebands and the peak near the carrier frequency. In the latter case the single apparent peak was found to be broader than the carrier peak observed in spectra with clearly defined sidebands, and this apparent single peak was found to reproducibly shift from the carrier frequency. It was therefore concluded that the single apparent peak contained both the peak at the carrier frequency and the sidebands.

3. Spectroscopic measurement of the radial electric field

The radial electric field E_r near the plasma edge is determined by spectroscopic measurement of the Doppler spectral line shift $\Delta\lambda$ in the B IV line at a wavelength of $\lambda_0 = 2822 \text{ \AA}$, due to the B IV poloidal rotation velocity [4]. Time traces of the wavelength shift $\Delta\lambda(t)$ are recorded at fixed minor radii between 13 cm (in the gradient region) and 19 cm (outside the plasma). The poloidal rotation velocity $V_\theta = c\Delta\lambda/\lambda_0$, where c is the velocity of light, is

related to the B IV ion pressure gradient term $\partial p_i/\partial r$ and the $E \times B$ drift velocity corresponding to the simplified radial force balance equation:

$$V_\theta(r) = \frac{-1}{eZ_i B n_i(r)} \cdot \frac{\partial p_i(r)}{\partial r} + \frac{E_r(r)}{B}$$

Here, eZ_i is the ion charge, B is the magnetic field, and n_i the ion density. By determination of the ion pressure profile $p_i(r)$ the value of E_r at a particular minor radius is obtained [5]. For typical discharge conditions, V_θ is dominated by the $E \times B$ contribution (60% - 80%) in comparison to the $\partial p_i/\partial r$ contribution (20% - 40%). Therefore, the relative value of $V_\theta(r,t)$ and its temporal changes are a rough estimate for the temporal development of E_r during an individual shot. Those time traces are used to derive a qualitative comparison to the temporal frequency shift of the reflectometry sideband. As E_r (and, thus $V_\theta(r,t)$) is a decisive factor for transport and confinement [6], that comparison reveals the significance of the reflectometry sideband feature in conjunction with the transport analysis in W7-AS.

For the evaluation of the electron poloidal rotation profile (which is given by the force balance equation above, correspondingly) the $E \times B$ contribution is taken into account as obtained by the procedure described above. The electron pressure gradient term is calculated from electron temperature and density data, delivered by Thomson scattering, electron cyclotron emission ECE, multichannel interferometry and Lithium-beam diagnostics.

4. Correlation of reflectometry and spectroscopy

Figure 2 is a contour plot of the spectral power measured for a 500kW NBI discharge in D_2 . The confinement time, τ_e in this case was 20ms. The prominent feature in this signal is the development of strongly shifted sidebands in the reflectometry spectrum. The poloidal rotation velocity for the same shot has been determined from the Doppler shift of the B IV emission line, and is shown in figure 3. Comparison of the two figures shows that the sideband shift increases when the poloidal rotation increases and remains constant when the poloidal rotation value is constant. For shots with similar conditions but a lower confinement time, the measured poloidal rotation velocity is much lower, and also the fluctuation velocity is reduced to an extent that the shifted sidebands are indistinguishable from the peak at the carrier frequency. The velocity determined from Doppler shift measurements is the impurity ion poloidal drift velocity, whereas the reflectometer measures the propagation velocity of density fluctuations, which includes the poloidal rotation due to the electron pressure gradient, and the group velocity of the fluctuations in the plasma. Typical calculated values for poloidal propagation of density fluctuations are greater than a theoretically calculated electron poloidal drift velocity by a factor of 2-5 and are significantly greater than the ion poloidal rotation velocity. Uncertainty in the angle of incidence at the cut-off layer make absolute measurements difficult.

5. Confinement transitions

A time-frequency plot for a 1MW NBI-heated D_2 plasma is shown in figure 4. In this shot, confinement time has a higher value in the time from 0.5 to 0.65s. During this phase τ_e is

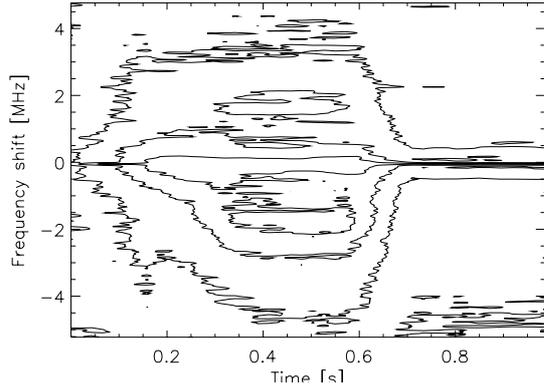


Fig. 2. Time-frequency reflectometry spectrum

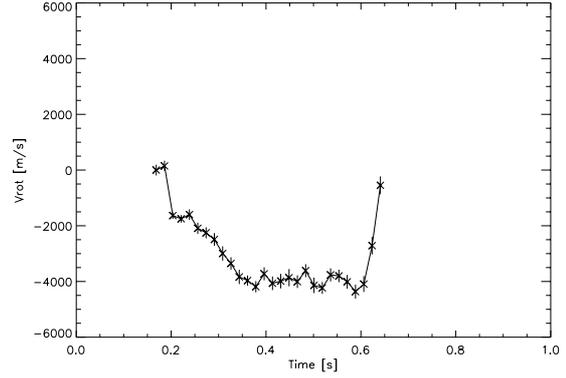


Fig. 3. Ion poloidal rotation—same shot as Fig. 2

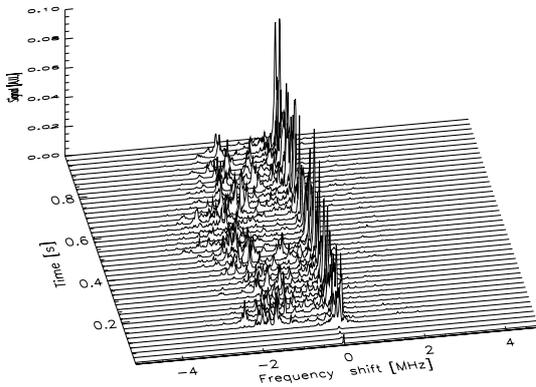


Fig. 4. Time-frequency reflectometry spectrum

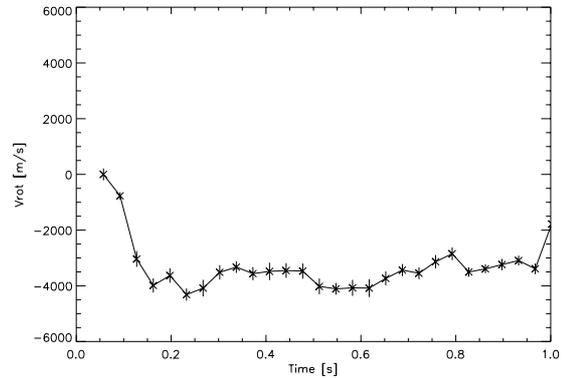


Fig. 5. Ion poloidal rotation—same shot as Fig. 4

approximately 16ms and the impurity ion poloidal rotation velocity is 4.0km/s, compared with τ_e of 13ms and V_{poloidal} of 3.4km/s before and after this phase. The sideband shift measured by the reflectometer increases during the phase with better confinement, corresponding to an increase in poloidal propagation velocity of density fluctuations. There is a clear reduction in the reflectometry signal at frequency values between the unshifted signal and the asymmetric sideband during the period of enhanced confinement. This may be due to the damping of density fluctuation activity in the 0 to 1MHz range during the higher confinement operation.

6. Conclusions

Microwave reflectometry is demonstrated to be a practicable tool for the analysis of poloidal propagation of density fluctuations, and backscattered spectra are seen to reflect confinement characteristics of the W7-AS plasma.

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