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Density Fluctuation Measurements at TEXTOR by Pulsed Radar and CW Reflectometry

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The results of pulsed radar and continuous-wave reflectometry for fluctuation measurements are compared. Pulsed radar is found to be more robust against high turbulence levels than the phase spectrum of continuous-wave reflectometry. The poloidal wave numbers for quasi-coherent turbulence are estimated. A finite radial phase shift is found for the quasi-coherent turbulence, higher than previously reported.

The electron density fluctuations due to microturbulence in the gradient region of the TEXTOR plasma are diagnosed by two different microwave reflectometry diagnostics. To get a better and more complete picture of the turbulence properties, a combined analysis of the results from both diagnostics is performed.

The two reflectometers use fundamentally different techniques. One measures the flight time, that is the group delay, of short microwave packets (the pulsed radar technique), the other measures amplitude and phase fluctuations of a continuous microwave beam (cw). The use of pulsed radar as a fluctuation diagnostic is new, and the comparison with cw reflectometry should also be applicable to ultra short pulse reflectometers, since the measured quantity is the same.

The pulsed radar system was designed for both profile measurements and fluctuation measurements [1]. Its fixed microwave frequencies range from 18 to 57 GHz, at typical sampling rates from 1 up to 5 MHz. The cw reflectometer is fully dedicated to the study of density fluctuations [2]. Its frequency is currently tuneable from 26 to 37 GHz, the sampling rate is 500 MHz. Two receiving antennas separated poloidally allow to carry out spectral and correlation analysis of the turbulence. With the pulsed radar reflectometer the spectral measurement can be extended towards lower and towards higher densities, into the plasma core. Radial correlation and propagation of the fluctuations can be measured.

Comparison of spectra

The fluctuation spectra of the two diagnostic techniques have been compared in a number of different plasma regimes. Neighbouring microwave frequencies

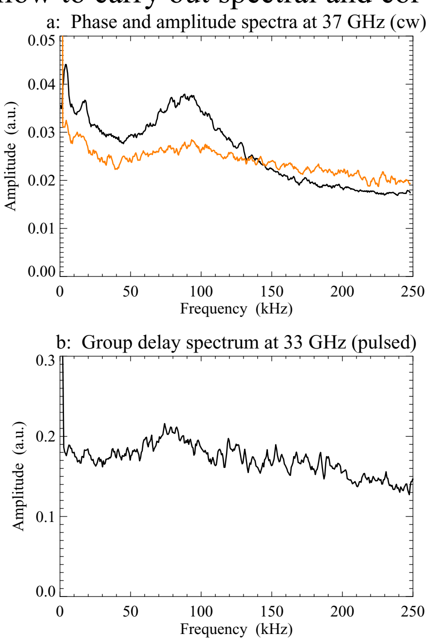

Figure 1: Spectra of a) phase (black) and amplitude (orange, × 4) and of b) group delay (reflected pulse flight time variations) for Ohmic phase (t = 2.0 s) of pulse 90977.

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have been used for this comparison: 37 GHz for the cw reflectometer, and 33, 36 and 39 GHz for the pulsed radar reflectometer. Results are shown in figures 1 and 2.

Figure 1 shows spectra of amplitude and phase fluctuations for the cw reflectometer (1a) and spectra of flight time fluctuations for pulse radar (1b) measured in the Ohmically heated part of discharge 90977. The cw reflectometer at 37 GHz and the pulsed radar channel at 33 GHz reflect from density layers at 6 cm and 3 cm inside of the limiter radius, respectively. Different types of turbulence can be identified in these spectra (see also [6]). Broad band turbulence forms the basis of the spectrum, extending smoothly over the entire frequency range. Broad peaks are seen at frequencies around 90 kHz, these have been referred to as quasi-coherent (QC) fluctuations. Note the good agreement between phase and time-of-flight spectra here.

In figure 2 spectra from different reflectometer channels are shown for three different phases of discharge 91081. The blue spectra were taken in the L-mode phase with neutral beam and ion cyclotron heating. Neon was injected into the discharge, leading to a Radiative Improved (RI) mode phase with higher confinement, and a strongly peaked density profile. In this phase the green spectra were taken. Finally a strong deuterium gas puff was applied, destroying the RI mode, and the red spectra were measured during the following high-density L mode phase. Note that the density and the density gradient rise at each transition, so that the reflecting radii for 36 to 39 GHz move from a few cm inside the limiter radius in the first phase to in or near the scrape-off layer (SOL) in the last phase.

Because of the high turbulence level in the plasma periphery, the phase fluctuations of the cw reflectometer signal in discharge 91081 become comparible with or larger than 2π. This gives rise to a phase random walk effect and leads to the strong broadening of the phase spectrum as seen in figure 2a (blue and green curves). In the first stage of the discharge (blue curves) the QC mode seen by the 39 GHz channel of pulsed radar around 80 kHz is not present in the phase spectrum, but can be seen on the amplitude spectrum (2b) of the cw reflectometer. This confirms the fact that the

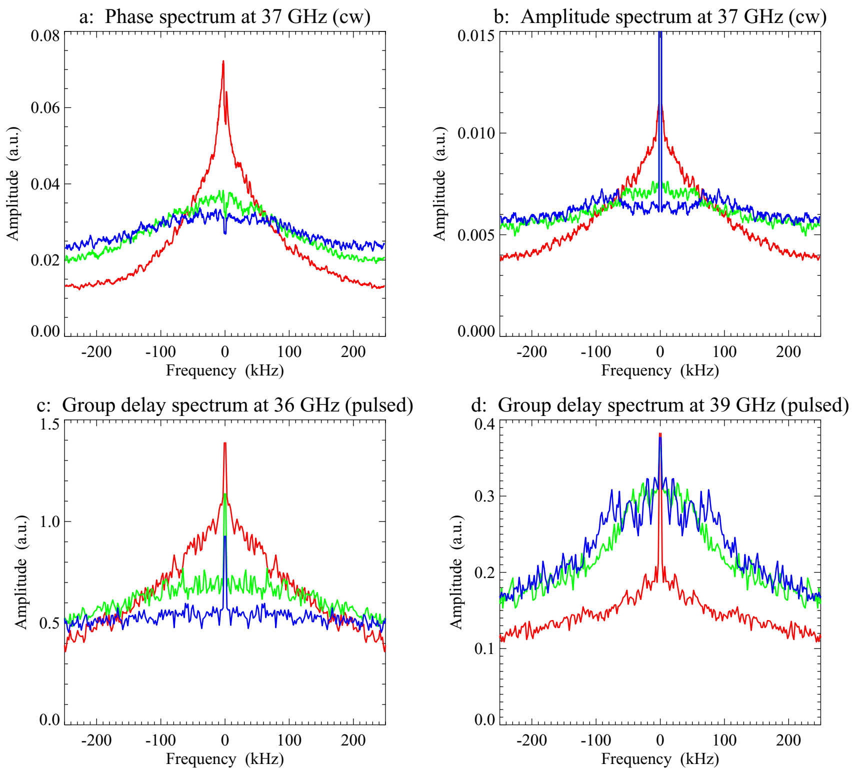

Fig. 2: Spectra for discharge 91081 at times 1.0 s (blue, L mode), 1.6 s (green, RI mode), and 2.5 s (red, high-density L mode).

wave amplitude is more robust to a high level of turbulence than the phase, and that amplitude fluctuations can provide some information about the turbulence properties in the cutoff layer even in a high level of turbulence [3]. Also some narrowing of the phase spectrum going from 1.0 s to 1.6 s may be linked to the decrease of the level of phase fluctuations as a consequence of the density gradient increase. The decrease at high frequencies is indeed only seen on the phase spectrum, and not on the amplitude or on the pulsed radar spectra.

Note that in the case of a moderate level of turbulence (figure 1), the pulsed radar group delay spectrum agrees with the cw phase spectrum. In the case of enhanced turbulence the cw phase spectrum is corrupted. The pulsed radar group delay spectrum is obviously more robust against high turbulence levels.

Focusing more on the density fluctuations at the different radii and in the different regimes, several effects can be seen. First, all channels except the highest-frequency 39 GHz channel change to a low-frequency dominated spectrum at 2.5 s. This shape is characteristic for SOL turbulence [6]. Probably only the 39 GHz channel remains in the main plasma and shows only a low level of group delay fluctuations because of the extremely steep density gradient.

As the reflecting layers move outwards at the transition from L to RI mode (blue to green spectra), the amplitude of the low frequencies increases on the 36 and 37 GHz channels. The narrowing of the phase spectrum may just be a combination of this low-frequency increase with the high-frequency decrease associated with the aforementioned decrease of phase random walk.

The QC mode seen on amplitude and pulsed radar spectra disappears during the transition to RI mode. A key question is whether this is connected to the transition, or just a consequence of the outward shift of the channel locations (the QC being absent near the limiter [6]). A first answer to this dilemma has been found in the pulsed radar channel at 57 GHz: this channel shows a QC mode in the RI mode, centred around 90 kHz, 6 cm inside the limiter radius (figure not shown here).

Coherence and propagation

By cross-correlating two reflectometer channels the coherence lengths and propagation velocities of the turbulence can be obtained. In this way we have analysed the QC mode in Ohmic and in L mode discharges. From the time delay between the poloidally displaced channels of the cw reflectometer the m numbers of the QC mode were estimated. For the Ohmic plasma at t = 2.0 s in discharge 90977 (fig. 1) they lie in the range m = 35 – 45 (at $r/a \approx 0.87$). For the L-mode plasma at t = 1.0 s in discharge 91081 (fig. 1, blue) the range m = 25 – 33 was found (at $r/a \approx 0.97$ and different plasma current).

Radial correlation analysis has been performed on an L-mode plasma in the second beam-heated phase of discharge 90977. The density rises considerably, and as a result the reflecting layers of the pulsed radar channels at 33 and 39 GHz move close together (36 GHz was not available on this day). At their nearest point the separation between the two channels, 6 GHz apart in frequency, is estimated from the combination of different diagnostics to be in the range of 1 to 3 cm. The fluctuation spectra, coherence spectra and cross-phase for these channels are presented in figure 4. The QC fluctuations are still clearly present on both channels, although more pronounced on the 39 GHz channel. The coherence spectrum shows that the broad-band fluctuations possess absolutely no coherence on this radial length scale, whereas the QC modes show a not very large but very clear coherence of up to 7 %. The cross-phase shows a clear and constant slope in the frequency range of the QC modes. This slope corresponds to a radial time delay of 5 μs. A radial delay has also been reported from T-10 for density fluctuations [4], and from W7-AS for temperature fluctuations [5]. The value for the velocity found at T-10 was higher, however. The delay does not have to originate in a real radial propagation of the perturbations, it may also originate in rotating perturbations with a slanted shape.

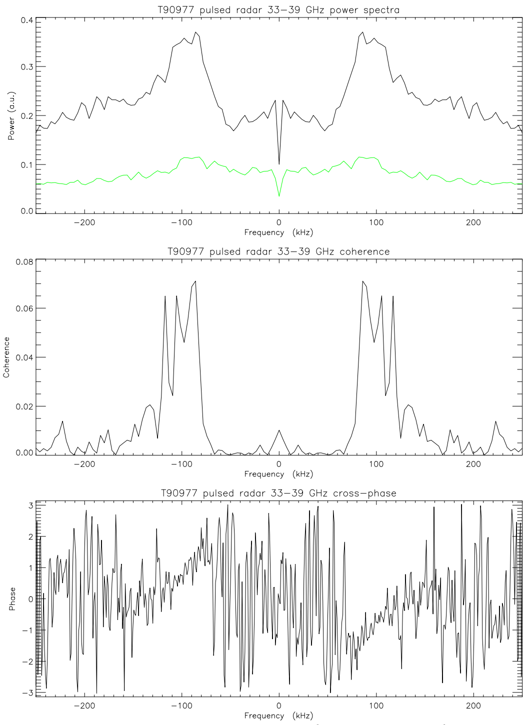

Fig. 3: Power spectra, coherence and cross-phase between pulsed radar channels at 33 and 39 GHz (green = 33 GHz).

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