Study of plasma filaments with hopping reflectometry at ASDEX Upgrade

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1. Introduction

Filamentary structures of high plasma pressure, elongated along the magnetic field lines, have been observed to travel with a large radial velocity component in the edge of the ASDEX Upgrade tokamak (AUG) and as-well in various other magnetic fusion devices (see [1] and references therein). These phenomena occur most notoriously on the tokamak low magnetic field side (LFS) during disruptive periods of type-I edge-localized modes (ELMs). However, filaments are also observed to be *born* and *ejected* in the inter-ELM periods, as well as in the low plasma confinement L-mode, and even in ohmic regimes of operation. The nature of such filaments is not yet understood and remaining questions, such as their impact on first wall materials, make filaments a prominent field of study. In this paper we present new results on signatures of various plasma filaments using the frequency hopping reflectometers of AUG.

2. Measurement Technique

Reflectometry is a radar-like technique where, in the case of ordinary (O-mode) polarization, a microwave/mm-wave of frequency F, launched into the plasma is reflected from a certain critical density layer, n_c, according to $F \sim \sqrt{n_c}$. On AUG two O-mode reflectometry systems operating in the Q (33-49.2 GHz) and V (49.4-72 GHz) bands respectively, with frequency hopping capability (i.e. able to probe different plasma density layers during each discharge) are used routinely to monitor density fluctuations. Their data acquisition rate and resolution have been extended to 2 MHz and 14 bits, giving a temporal resolution (0.5 μs) suitable to resolve fast events. Both systems use monostatic antennas located on the LFS with a ~32 cm poloidal separation, and are equipped with heterodyne receivers and in-phase/quadrature detection schemes thus producing phase and amplitude signals [2]. The phase shift, $\Delta\varphi$, of the reflected wave is proportional to a radial displacement of the reflecting density layer.

3. Detection of Filaments

In the experiments reported here both reflectometer channels were operated at their lowest fixed frequency (33 and 49.4 GHz) so as to probe the lowest possible densities and thus most further out density layers, together with a Langmuir probe plunged into the plasma from the LFS, just above the midplane, in order to provide a simultaneous measurement of the ion saturation current, I_{sat}, which is proportional to the plasma density. The I_{sat} has been extensively used to previously detect and characterize plasma filaments [1]. Assuming the reflectometer phase shift is indeed caused by changes in the radial position of the reflecting layer, this radial displacement can be estimated by $\Delta r \approx \Delta\varphi c/4\pi F$, where c is the velocity of light [3]. And, consequently, a radial velocity V_{rad} can as well be obtained from $d\Delta\varphi/dt$.

Fig.1 shows time traces, from AUG discharge #26981, of V_{rad} from both reflectometer channels around a type-I ELM together with the I_{sat} measured by the Langmuir probe. The ELM is clearly seen in the inner divertor tile current (a), obtained from a toroidal set of tile shunt resistances. In fig.2 the density profile before the ELM crash and the density layers probed by each reflectometer, as well as the position of the Langmuir probe in this period are shown. The bursty behaviour observed in the two reflectometers appears to be well correlated, and to a good extent both channels correlate as well with spikes in I_{sat} which are revealing of filaments impinging on the probe. Repeated observations indicate a *background* V_{rad} of much lower values than in periods of filamentary activity, which leads to establishment of a filament detection criterion using a threshold in the V_{rad} signal obtained from the outer probed layer (Q-band). In these experiments the unwrapped phase signals were preconditioned using a 3-point boxcar average (V_{rad} signals in blue

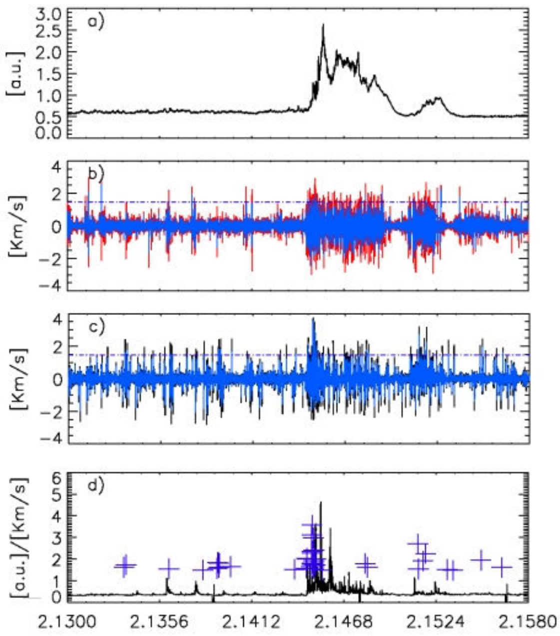

Fig. 1: Filament detection: a) Divertor current, b) V_{rad} signals from V-band, c) V_{rad} signals from Q-band, d) I_{sat} from Langmuir probe and velocities (+) from Q-band filament detection at 6*rms.

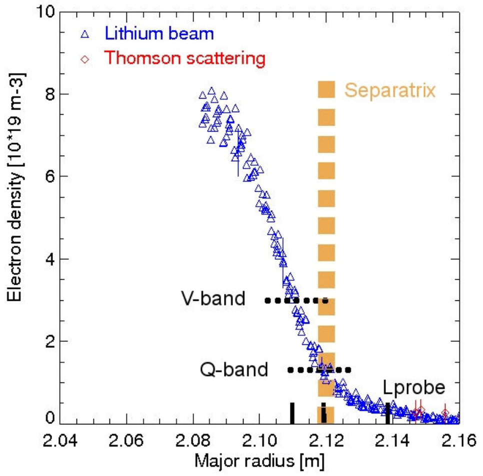

Fig. 2: Electron density profile. Probed layers by reflectometers , and probe radial position (Lprobe).

at b) and c) of Fig.1, comparing with the *raw* signals in red and black, respectively). The V_{rad} threshold was chosen to be 6 times the root mean square (rms) of the V_{rad} signal and local peaks with higher values were considered detected events. These local maxima, found to be in the range of ~1.5-4 Km/s, were plotted at their detection times together with the I_{sat} on fig.1 d), and again display a reasonably good agreement between ELM and inter-ELM spikes in I_{sat}.

4. Typical filament signatures

Using the above method, typical filament signatures in the Q-band signals were found by conditional averaging many events detected during fairly constant plasma conditions. Cross-conditional averaging has also been performed using the signals from the V-band channel whenever possible (most L-modes do not have high enough density for the V-band wave to reflect). The results are shown in fig.3 for an L-mode, an H-mode type-I ELMy period and an intermediate phase between L-mode and H-mode, described in this case as an I-phase [4].

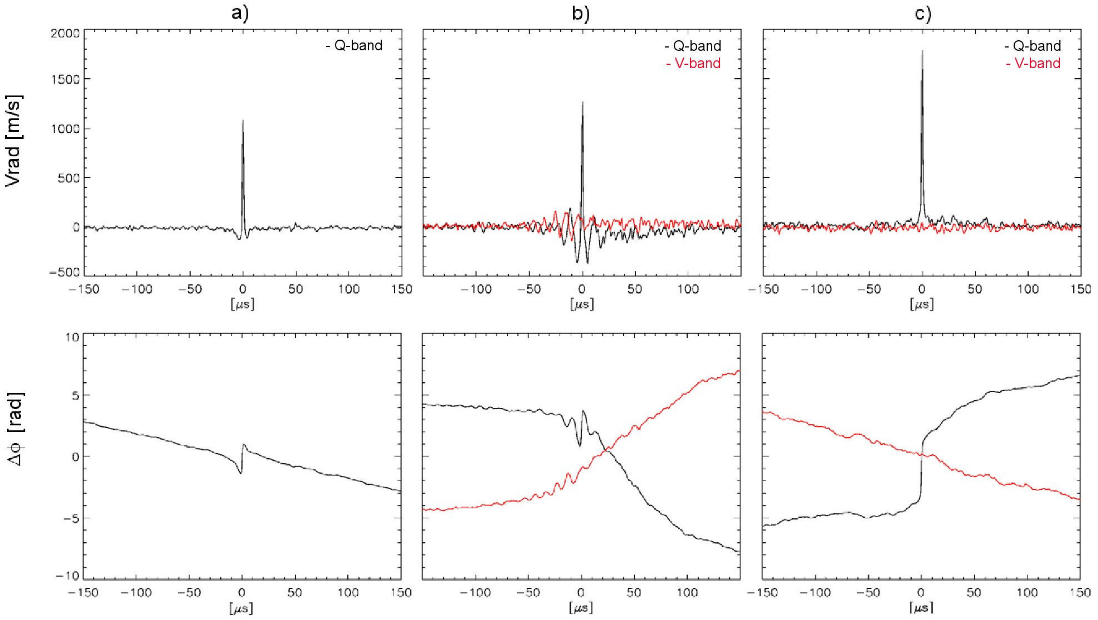

Fig. 3: Conditional averaging results using 300μs intervals around V_{rad} peaks. Q-band signals in **(black)** and V-band signals in **(red)** for cases of a) L-mode, b) I-phase, and c) type-I ELMy H-mode.

The density layers probed by the Q-channel in both the L-mode and the I-phase were located approximately ~1cm inside the separatrix, while the V-channel was ~1 cm further inwards in the I-phase. Each averaging took more than 200 events and the thresholds used were selected in order to have a good detection agreement with the Langmuir probe data, in the shorter periods where the latter was available (3.5*rms for L-mode and I-phase and 7*rms for H-mode). While the maximum typical V_{rad} values are generally observed to increase when going from L-mode to H-mode, the shape of the V_{rad} profiles is quite distinct for the different regimes. The *original* phase shift measurements, also conditionally averaged, are also shown in fig.3. One should note the phase jump observed in the H-mode for the Q-band and the apparently uncorrelated behaviour of the V-band. A possible explanation for the latter is given by broad distributions of the velocity vector components of the detected filaments, thus leading to a smearing of the V-band signature. In contrast, the I-phase results show not only a phase jump but also well defined oscillations in the phase response, and a well correlated signature in the V-band, but with lower peak V_{rad} values, suggesting an outward acceleration.

5. Discussion and Prospects

If one were to take a simple model for the filament to be a travelling gaussian perturbation superposed on a linear background profile, which is reasonable, then the L-mode signature resembles the simulation results (from 1D Helmholtz code, see [5]) for a small amplitude perturbation while the H-mode phase jump is replicated by one of large amplitude [6]. I-phase signatures could result from a perturbation of moderate amplitude, but, a higher radial wavenumber than that associated with a simple gaussian perturbation could also produce similar phase responses due to Bragg backscattering. To address these and other issues, such as the detection limit regarding the ratio of filament size to beam width, work is underway to run new simulations using a 2D Finite Difference Time Domain full-wave code (see [7]). Also, yet to explore is the true frequency hopping capability of the diagnostics, e.g. to determine birth locations of the filaments.

6. Conclusions

With recently enhanced data sampling rate and resolution, the frequency hopping reflectometers installed at AUG are well able to measure fast transient events such as filaments. Preliminary results show filament radial velocities of few Km/s, in agreement with other diagnostics [1]. Further, the velocity and amplitude of the filaments appears to increase from L-mode to H-mode. In I-phase, at least, filaments originate somewhere inside the separatrix and accelerate outwards. The possibility of Bragg backscattering of the beam and the detection limits, are issues requiring further attention and which new simulations can enlighten.

References

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