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ABSTRACT.

The X-mode radial correlation reflectometry diagnostic on JET has long suffered from strong signal attenuation in the original transmission lines. To reach higher performances, new low attenuation corrugated circular wave-guides and a new cluster of six antennas have been supplied and successfully installed in autumn 2005. The increase of the signal-to-noise ratio using these new transmission lines is found to be in the order of magnitude of 20 dBs, thus enabling good dynamic of reflectometry measurement. First X-mode reflectometry measurements of density fluctuations in the core region of the JET plasma are reported in this paper.

1. INTRODUCTION

The X-mode radial correlation reflectometry diagnostic on JET has been recently upgraded with the installation of new low attenuation transmission lines, which significantly improve its performances. In Sec.II, the main features of the diagnostic and of its new transmission lines (composed of circular corrugated wave-guides and a new cluster of six antennas) are described. Some illustrative results are shown in Sec.III, showing that measurement of density fluctuations (associated with toroidal Alfvén eigenmodes in this case) localized in the plasma core region is possible. Sec.IV is devoted to concluding remarks and perspectives of this work.

2. DESCRIPTION OF THE RADIAL CORRELATION REFLECTOMETRY DIAGNOSTIC

2.1. GENERAL CHARACTERISTICS

The radial correlation reflectometry diagnostic on JET is composed of four different instruments, some details of which can be found in Ref. 1, 2 and 3. Each reflectometer instrument probes the mid-plane plasma in the X-mode polarization with two different millimeter waves, one at fixed frequency (76, 85, 92, 103 GHz respectively) and the other one whose frequency can be changed step-by-step (in the range 76−78, 85−87, 92−96, 100−106GHz respectively) to allow radial correlation measurements. All four reflectometer systems are equipped with a micro-controller and I/Q detectors, delivering A cos φ and A sin φ signals for both the fixed frequency and tuneable frequency channels. I/Q detection allows phase and amplitude of the reflected signal to be separately analysed. All the diagnostic is fully and remotely controlled (via an http protocol and a software program running in the JET control room) by a VME based system including a PC module, two intelligent transient recorders with Digital Signal Processors (DSP) and two fast acquisition boards, as described in Ref. 1. The fast acquisition can be performed at variable sampling frequency (from 100kHz up to 2MHz) with a memory restricted to 1.5 million samples per channel. Up to 20 identical fast acquisition windows per shot and up to 20 frequency steps of the tuneable source per window can be set. In addition, a slow acquisition at sampling frequency of 200kHz is also performed using 16 DSP channels. A real time digital signal algorithm runs over the acquired data delivering 1KHz data that aims at evaluating the Root Mean Square of the signals in the two frequency ranges 0−10kHz and 10−250kHz.

2.1. UPGRADE OF THE TRANSMISSION LINES

The restricted access to the fusion reactor together with the long distance from the diagnostic hall make the microwave diagnostics particularly challenging on JET and performances of the reflectometry measurement have long suffered from strong attenuation of the probing signals in the transmission lines. In order to cope with this limitation, new transmission lines were recently installed at JET under the EFDA enhancement project "Millimeter Wave Access (MWA)". These transmission lines are composed of new low-attenuation circular corrugated wave-guides and of a new cluster of six antennas (four dedicated to reflectometry and two for oblique ECE radiometry). New quasi-optical boxes were also supplied to simultaneously connect the four reflectometry instruments to the same pair of wave-guides, inducing limited 4dB losses in emission and 4dB losses in reception for each instrument. All the probing signals and the corresponding reflected ones are respectively launched and received in two different open circular antennas separated by 25mm ? poloidally around the plasma mid-plane. A full description of these new transmission lines can be found in Ref.4. An illustration of the improvement of the signal-to-noise ratio is depicted in Fig.1, where the signals of the 103GHz channel for two similar discharges before and after the installation of the new transmission lines are compared. The amplitude of the raw signal increases from +/− 20 A.U. with the old lines (on the left-hand side) up to from +/− 1000 A.U. with the new lines (on the right-hand side). Considering that the received signal was mainly noise with the old lines (as suggested by the flat shape of the signal spectrum), this means that an improvement of at least 17dBs has been reached. Furthermore a clear dynamic is now observed on the signal spectrum with the new transmission lines, indicating that plasma effects can be studied.

3. SOME MEASUREMENTS

3.1. PRINCIPLES OF MEASUREMENT

Reflectometry measurements are mainly affected by density fluctuations localised in the cutoff layer region (see Ref. 5). In the X-mode case, the localization of the reflectometry measurements depends on the magnetic field value as depicted in Fig.2. Spectral analysis techniques (simple or sliding FFT) of the reflectometry signals are usually used to infer the frequency of the density fluctuations in the vicinity of the cutoff layer. Moreover, the correlation reflectometry systems can provide information on the radial structure of the density fluctuations. Coherence between two signals with close frequencies is sensitive to the radial separation of the respective cutoff layers and to the density fluctuation characteristics. The evaluation of the coherence can then give some information either on the radial correlation length of the density fluctuations (see Ref.3) or on the fast changes of the density profile (as exemplified in Ref.1).

3.2. OBSERVATION OF MHD STRUCTURES

The following example illustrates the potential of X-mode reflectometry to observe localized MHD structures on JET (Pulse No: 64342). In the considered plasma scenario (B_0 = 3.15T, $n_e{\cdot}dl$ =

4.6×10^{19} m^{-2}), the radial localization of the cutoff layers for the different channels of our reflectometry diagnostic are shown in Fig.3. The magnetic field profile obtained from a flux surface reconstruction (EFIT) and the density profile measured by a Lidar Thomson scattering diagnostic are used to reconstruct the radial profile of the X-mode upper cutoff frequency depicted in Fig.3. Clear MHD structures as toroidal Alfvén eigenmodes are observed on the spectrogram (sliding FFT) of the raw signal $A(t) \cos \varphi(t)$ from the 103GHz channel, which is represented in Fig.4. In particular, a “tornado” mode with frequency of about 300kHz is detected (as depicted on Fig.5). This mode is not observed on the lower frequency channels, thus indicating that it is localized in the core region (i.e. at $R \approx 3.1$ m corresponding to the cutoff layer position for the 103GHz signal as shown on Fig. 3). This is in agreement with theoretical considerations discussed in Ref.6. Taking benefit of the I/Q detection, the phase $\varphi(t)$ of the reflected signal can be computed. On Fig.5 are depicted the fluctuations of the phase induced by the density fluctuations. The decomposition as Fourier series of these phase fluctuations (see Fig.5) clearly shows that the “tornado” mode with frequencies of 300kHz induces phase fluctuations of half a radian.

CONCLUDING REMARKS

Unlike for the O-mode, the use of X-mode polarisation in reflectometry experiment enables localized measurements of the density fluctuations in the core and high magnetic field plasma regions. To cope with the severe conditions met on JET, new low attenuation transmission lines (including circular corrugated wave-guides and a cluster of six antennas) were successfully installed for X-mode reflectometry diagnostic. The first measurements obtained with this new transmission lines have shown that an improvement of the signal-to-noise ratio by about 20dB was reached, thus allowing localized measurement of the density fluctuations in the plasma core region. This is illustrated with the first reflectometry measurement on JET of the so-called “Tornado” modes, which are Toroidal Alfvén Eigenmodes localized in the core region. The use of a four-reflectometer system diagnostic enables in this case a precise localization of these modes. This demonstrates the possibility of turbulence measurement in the plasma core region, which is an important topic at JET for the development of advanced scenarios with improved confinement regimes.

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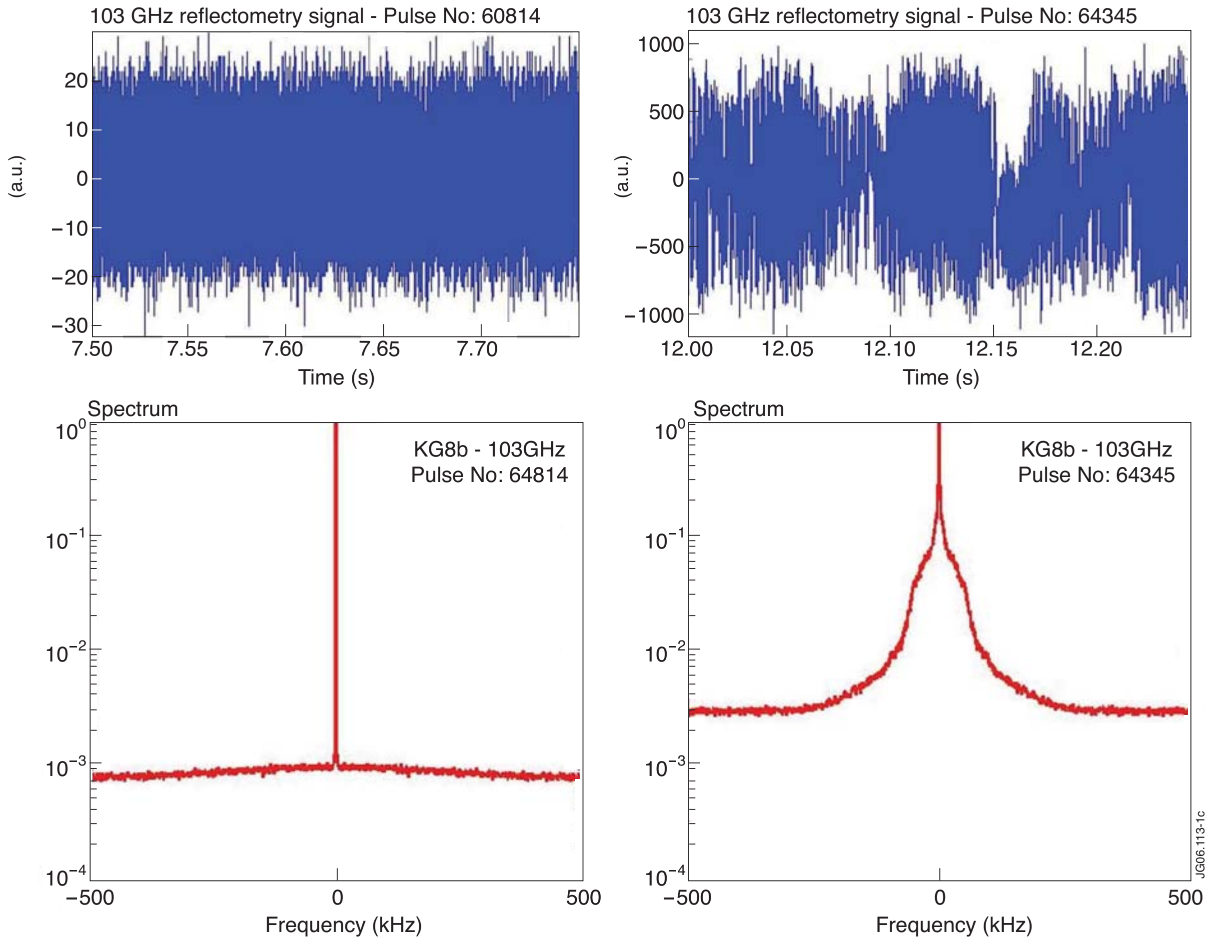

Figure 1: Comparison of the raw signal from the 103GHz X-mode reflectometry channel and of its frequency spectrum (on the top and on the bottom respectively); before (on the left-hand side) and after (on the right-hand side) the installation of new transmission lines.

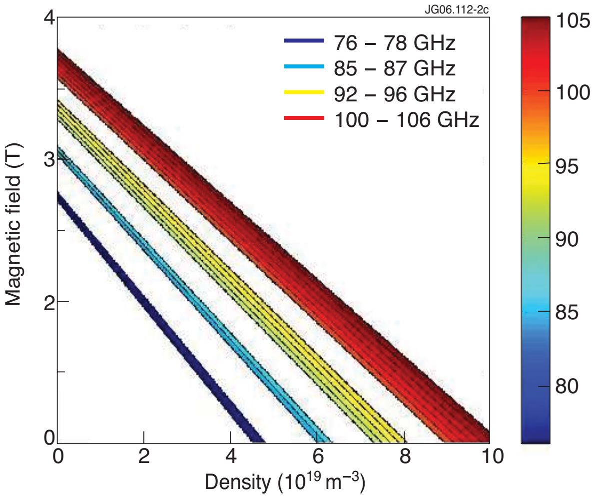

Figure 2: Localization of X-mode reflectometry measurement as a function of the local values of plasma density and magnetic field

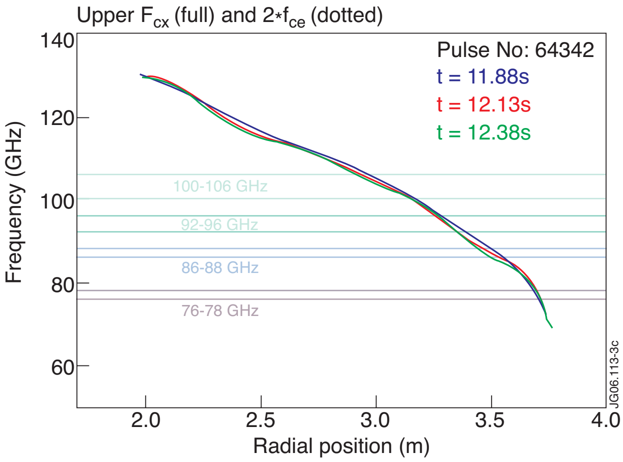

Figure 3: Radial profile of the X-mode upper cutoff frequency indicating the localisation of the reflecting layers for the different channels of the JET X-mode reflectometry diagnostic (JET Pulse No: 64342 at t ≈ 12.1s).

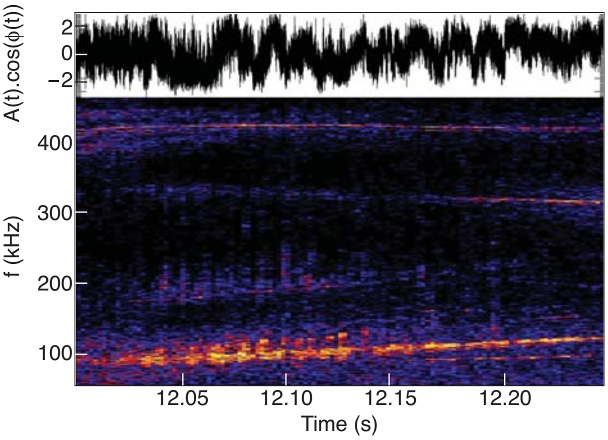

Figure 4: Reflectometry signal from the 103GHz channel (on the top) and its spectrogram (sliding FFT) displaying some toroidal Alfvén modes (on the bottom).

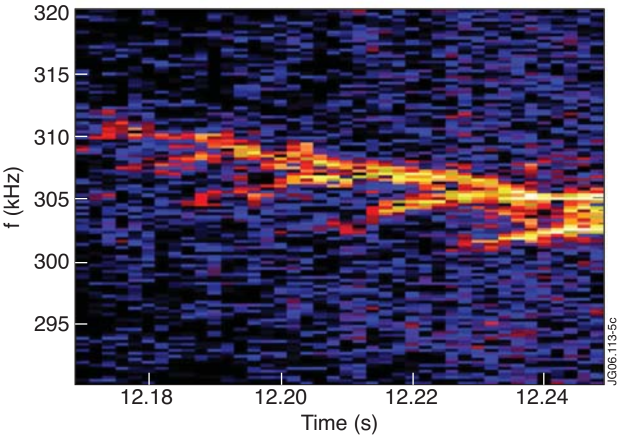

Figure 5: Zoom of Fig.4 showing a “tornado” mode with frequency around 300kHz.

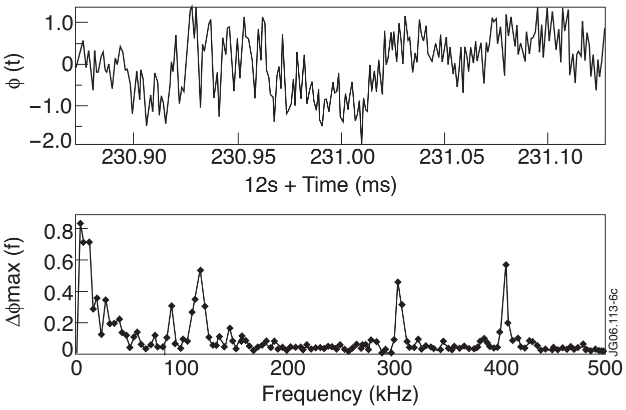

Figure 6: Phase fluctuations induced by the density fluctuations associated with toroidal Alfvén Eigenmodes (on the top); Fourier decomposition of the phase showing the clear contribution of the “tornado” mode at frequency of 300kHz (on the bottom).