Fast sweeping reflectometry upgrade on Tore Supra

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Introduction

While the nature (ballistic or diffusive) of the transport in a fusion magnetized plasma remains questionable [Garbet 2007], the last improvement of the ultra-fast frequency sweep has the ability to study of the temporal dynamic of turbulent processes like blobs (plasma bubble moving radially) or turbulent wavefront propagation induced by heat pulse. In order to reach this goal, a substantial decrease of the sweeping time, below the correlation time of the turbulence, of the FM-CW reflectometers (V and W bands) has been performed. Thus, measurement of the time evolution of the plasma turbulence including correlation time can be envisaged over the whole plasma discharge through a wide range of wavenumbers.

Fluctuation measurements

The FM-CW reflectometers installed on Tore Supra are routinely providing density profiles in the data base for nearly 10 years. It has been widely admitted that in order to provide accurate and robust profile measurements, it is necessary to associate fast frequency sweep to freeze the turbulence along with a heterodyne detection to overcome the strong amplitude variations of the reflected signal. Moreover, in addition to the average phase of the detected signal for the profile reconstruction, the fluctuations of the phase provide information on the density fluctuations. Traditionally devoted to the fixed and fast hopping frequency set-up, it has been recently demonstrated how the sweep devices can also provide the radial profiles along with the radial wavenumber spectra of the density fluctuations. Fast sweep reflectometer systems use VCOs which are frequency agile, as they can provide sweep as fast as 20GHz/µs, but are consequently naturally noisy sources. Thus, based on a statistical approach, the spectra are recovered from multiple sweeps performed during stable plasma periods has explained on figure 1.

The density fluctuations spectra are then recovered from the fluctuating phase through a transfer function $[T(L_N, k_r)]$ calculated with a full wave 1D Helmhlotz code in such way that:

$$S_{\delta n}(k_r) = S_{\delta\Phi}(k_r) \times T(L_N, k_r)$$

and the level of the density fluctuations can thus be determined through the Parseval relationship $\left\langle \frac{\delta n_e}{n_e} \right\rangle^2 = \frac{1}{k_2 - k_1} \int_{k_1}^{k_2} S_{\delta n}(k)dk$. The radial variation of the density fluctuations is determined through radial windows analysis of 6 cm.

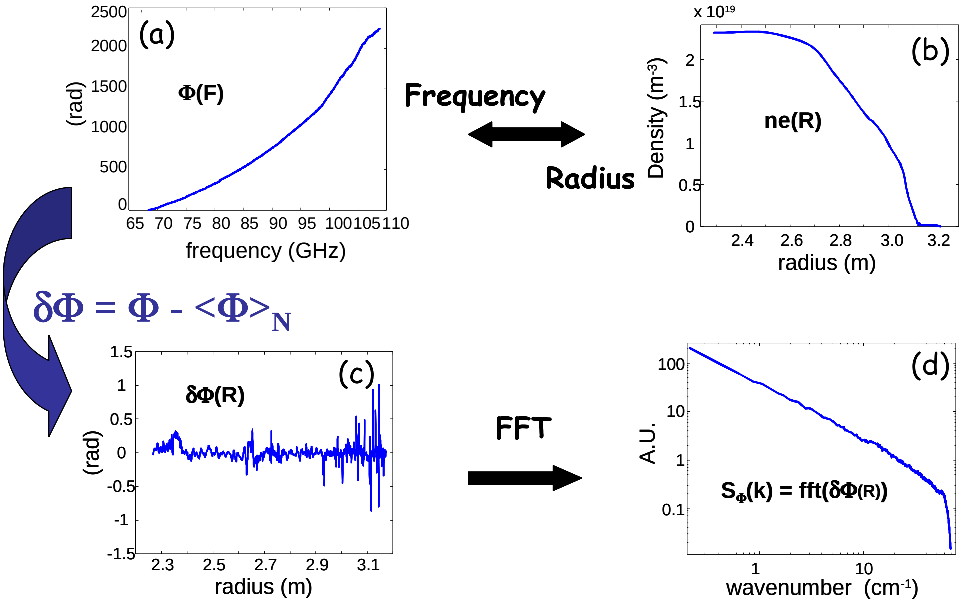

Figure 1 : Phase fluctuation spectra recovered from FM-CW reflectometry : the radial correspondence of the cut-off frequencies of the phase (a) is extracted from the calculated density profile (b); the radial profile of the phase fluctuations (c) is determined from the phase of one sweep and the average phase over typically N=100 samples. The FFT of the radial fluctuating phase provides a radial wavenumber spectrum of the fluctuations (d). A sliding FFT analysis would provide a radial evolution of the fluctuations.

Characteristic time of the turbulence

In order to observe the temporal dynamic of the turbulence we propose an estimation of its characteristic times. Considering a correlation of τ_{turb} ~ 10µs, and a radial velocity of V_r ~ 0.1 mm/s (corresponding to a diamagnetic drift of 100 m/s [Goncalves 2005]). According to the characteristics of the Tore Supra reflectometers which give approximately 1 cm for 1 GHz sweep, we obtain a frozen turbulence situation for sweep time < 100 µs. In order to be able to observe a turbulence wave front the sweep time should be decreased to 6 µs.

Reflectometry upgrade

Since the fluctuation measurements require a statistic approach, several sweeps are performed during a burst mode. It consists in performing numerous repetitive sweeps as fast as possible. The former operations of our reflectometer were a sweep time of 20 µs with a dead time between sweeps of 5 µs. In these conditions the beat frequencies of our detected ranged up to 50 MHz. As the beat frequency is proportional to the sweep time $F_b = \tau \frac{\Delta F}{T_{sweep}}$ (with τ the propagation time of the wave into the plasma), the detection part of the set up along with the acquisition system is the main part, which need to be upgraded (Figure 2). The modulation frequency has been increased from 100 MHz to 300 MHz to prevent from frequency overlap, as well as the IF filter width which has been broaden up to 300 MHz.

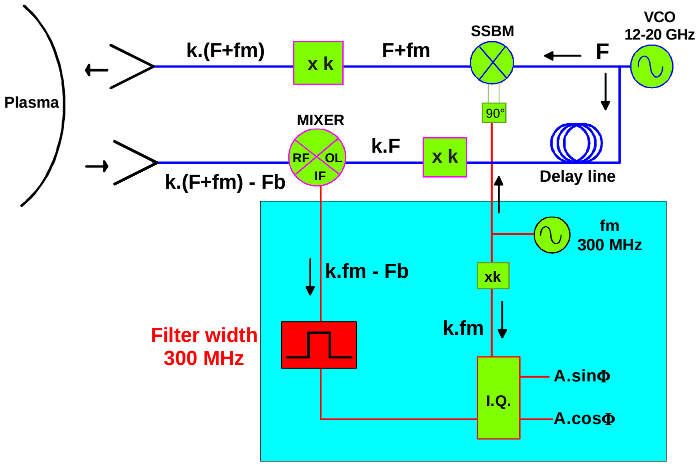

Figure 2 : Schematic of the reflectometers (with k = 4 and 6 respectively for the V and W bands). The blue area is related to the IF part which has been mostly renewed to account for the beat frequency (Fb) range increase.

The acquisition system has also been renewed with a 2 GHz sampling rate frequency 4 channels compact PCI board. An industrial PC running Linux OS control a distant acquisition device through an optical fiber PCI to PCI bridge. Others technologies were used such as : specific triggering (Timers & FPGA), time-stamping, GPIB's controlled sweep ramp generator and shared reflective memory network.

At last, one key aspect comes from the VCO ramp driving voltage which is performed by an arbitrary generator to provide linear frequency sweeping. Stability and reproducibility of the ramps is of major importance and attention must be taken with the voltage amplification to reach the required 0-20V VCO ramping voltage since the generator provides only 2 V_{pp} range. The performance of the sweeps in burst mode has been test on mirror (figure 3).

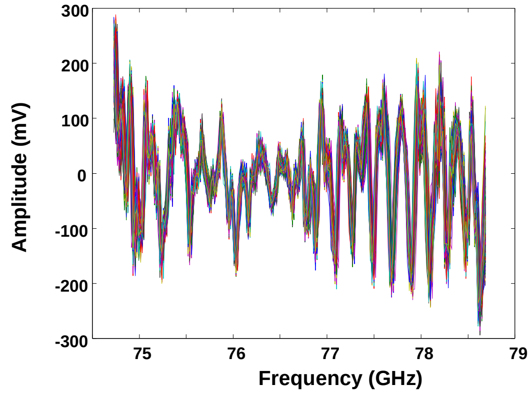

Figure 3 : Test for stability of the reflectometers by a superposition of 1000 signals reflected on mirror (beginning of the V-band reflectometer). The burst mode conditions are : sweep time 4 μs dead time = 1 μs.

First results

Considering the following parameters: $T_{sweep} = \frac{L_{corr}}{V_{sweep}}$, $T_{turb} = \frac{L_{corr}}{V_{turb}}$ (L_{corr} is the correlation length of the turbulence) and a Gaussian type spectrum for the density fluctuations $\delta n^2 \sim \exp\left[-\frac{L_{corr}^2 k^2}{4} - \pi^2 T_{turb}^2 F^2\right]$, the numerical simulations predict a modification of the spectrum with the sweep time as shown on figure 4 :

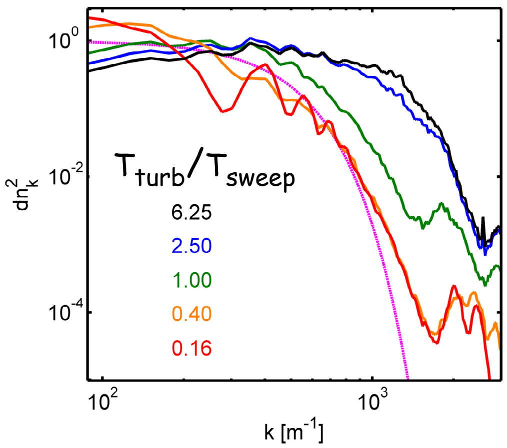

Figure 4 : Numerical simulation of the wave number fluctuation spectrum modification with respect to the sweep time with the input spectrum (magneta).

Preliminary experimental results have been performed before the one year 2009 shut down of the tore Supra tokamak. On figure 5 is shown a comparison between to sweep times (2 and 40 µs full band) on similar plasma discharges.

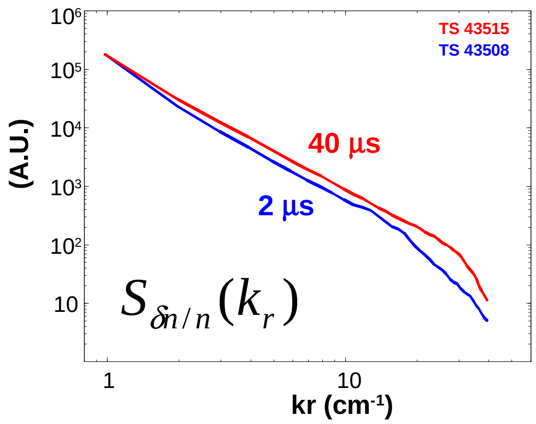

Figure 5 : Experimental wavenumber density fluctuation spectrum record on similar ohmic plasma discharges

References

X. Garbet et al. Phys. of Plasma **14**, 122305 (2007)
B. Gonçalves et al. J. Nuc. Mat. p376 (2005).

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