A dual source reflectometer for density profile and fluctuations measurements in Tore-Supra core

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Abstract The stepped fixed frequency X-mode reflectometer operating between 105–160 GHz that was designed for density fluctuations measurement has been modified to measure the density profile. It runs now with two sources in parallel: a fast swept source and a frequency synthesizer to measure during the same shot the density profile and density fluctuations. Using fixed measurement, modes in the range 20-80 kHz have been detected in various plasma conditions and at various locations. The nature of these modes is still under investigation.

1. Introduction

Density fluctuation measurement from fixed frequency measurements asks for a precise density profile to locate precisely the cut-off layer [1]. The density gradient is also required to evaluate the level of density fluctuations from the phase fluctuation level using Bretz like expressions [2].

The 105-155 GHz X-mode heterodyne reflectometer that was designed for core density fluctuation measurements [3] can now measure during the shot density profile and density fluctuations. It operates with two sources: a frequency synthesiser for frequency steps and a fast swept VCO for density profile measurements. The reflectometer will be described briefly in this proceeding, a longer article will be submitted to Nuclear Fusion special issue on reflectometry that should appear in 2006.

2. Microwave set-up

2.1. Fluctuation measurements

The 105-155 GHz reflectometer (figure 1) is based on the set-up developed for Tore-Supra profile reflectometers: low frequency source, frequency multipliers and Single Side Band Modulator [4]. The 105-155 GHz multiplier is made of a V-band active quadrupler and a passive doubler. The output power is low: -10<P<0dBm. A high performance single sideband modulator (SSBM) shifts the frequency ahead of the octupler for heterodyne detection. On the reference arm, a second quadrupler drives a second harmonic mixer. High gain Gaussian antennas (38 dB) were chosen to increase the reflected signal since the antennas are 2 meters from the plasma centre and to produce an almost parallel beam (divergence ~1° HPHW). With bistatic antennas parasitic reflections are minimised.
The source should be very stable for fluctuations measurements because of the frequency multipliers. The source phase noise is indeed multiplied by 64, the square of the multiplication order. Frequency synthesizers are very suitable for fluctuation measurements. They have very low phase noise and can describe stair frequency pattern with 1 to 30 milliseconds between steps. A fast hopping synthesiser is currently used (dwell time below 1 ms), 15 steps of 8.2 ms are described in less than 200 ms. The phase noise after a inner wall reflection is only few degrees as shown figure 2. With a VCO, the phase noise is more than 180 degrees during an 8.2 ms step although the delay line is optimised for zero delay at outer plasma edge.

2.2. Profile measurements

The VCO being not suitable for fluctuation measurements, the frequency synthesiser in swept mode was tested for profile measurements, but that was not a satisfying solution. The 5 millisecond sweeping time was too long and the synthesiser did not allow step and sweep mode operation in the same shot.

The frequency synthesiser being not suitable for profile measurements and VCO being too noisy for fluctuations measurements, we modify the reflectometer to run with two sources in parallel. The reflectometer uses also two acquisition systems. Fixed frequency measurements are recorded with a 1 MHz VME card. A 100 MHz acquisition is used for profile. Up to 1000 profiles equally sampled during the plasma discharge can be measured. The VCO is usually swept in 60 to 100 microseconds to limit the beat frequency below 50 MHz. A microwave switch changes the source to the synthesiser at the time predefined for density fluctuations measurements.

The reconstruction relies on the Bottelier-Curtet method [5] and uses the density profile measured with the 50-110 GHz reflectometers or the interferometry diagnostic for initialisation. Combining the 3 X-mode reflectometers covering the band 50 to 150 GHz, the
density profile from the edge on the low field side up to the high field side can be measured if
the magnetic field is high enough (B>3T) [1].
A burst mode is now in operation fast profile evolution. The dwelt time between two profiles
can be reduced to 5 μs. This mode will be used for MHD studies like q=1 [6] and to compare
to method proposed by S. Heuraux to measured density fluctuations from fast swept
reflectometer [7] to the classic fixed frequency method.

3. Detection of high frequency modes
High frequency coherent mode in the range 30 to 80 kHz have been observed in various
plasmas configuration (Ohmic, LH or ICRH heating) and at various locations (gradient zone
on the low and/or the high field side, centre). Figure 3 shows the frequency spectrum of the
complex signal for one of the best example in a high power discharge (P_{ICRH}=4MW +
P_{LH}=2 MW).

![Figure 3: Example of a high frequency (54 kHz) mode detected in the centre (r/a=0.06)](image)

On the frequency spectrum of the phase, harmonics of the mode are very low showing that
they are Bessel harmonics on the complex signal. A radial movement of the cut-off layer thus
probably causes these phase oscillation. In helium plasma, the frequency of these modes is
lower, maybe an indication of a mass dependence.
The nature of the mode is still under investigations. The frequency range and the mass
dependence could point to Geodesic Acoustic Modes [8] but theory predicts GAMS are stable
in the core. It could also be coherent Ion Temperature Gradient modes, but in the centre, the
temperature gradient is very low.
These modes are not Alfvèn modes since Alfvèn frequency in the core are much higher. At
high power ICRH, they have been observed in the range 150-500 kHz with the 105-155 GHz
reflectometer.

4. Conclusion
The microwave source incompatibility between agility for profile measurements and stability
for fluctuation measurements was solved using two sources in parallel for the 105-155 GHz
reflectometer. Commercially sources being imperfect, the reflectometry community needs a
versatile source to measure with the same reflectometer the density profile and density
fluctuations.
Although fast swept reflectometer can detect low MHD modes and a method has been developed to measure the level of fluctuations, only fixed frequency measurements can detect high frequency modes.

References