Profile reflectometry upgrade on JET

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Introduction:

Density profile measurements on JET with reflectometry began with a simple fixed-frequency microwave reflectometer in 1985 [1]. An upgrade with a 12 channels O-Mode reflectometer occurred in 1992 [2]. In 2005, new transmission lines and antennae have been installed under the EFDA enhancement project "Millimetre Wave Access (MWA)" with an X-mode reflectometer swept in the 50-75GHz frequency range [3]
Since May 2008 collaboration between UKAEA, IST and CEA, supported by EFDA, has been established to provide a set of reflectometers for accurate density profile measurements. To access L to H-mode over a broad range of magnetic field values (from 1.3 to 3.5 T), 6 reflectometers, from 33 to 150GHz in Ordinary or Extraordinary polarisation mode are required [4]. Thus, density profiles can be measured from edge to magnetic axis, and sometimes beyond on the high field side. A sweep time of only10 µs provides good time resolution to observe fast plasma events such ELMs or transport barrier formation.

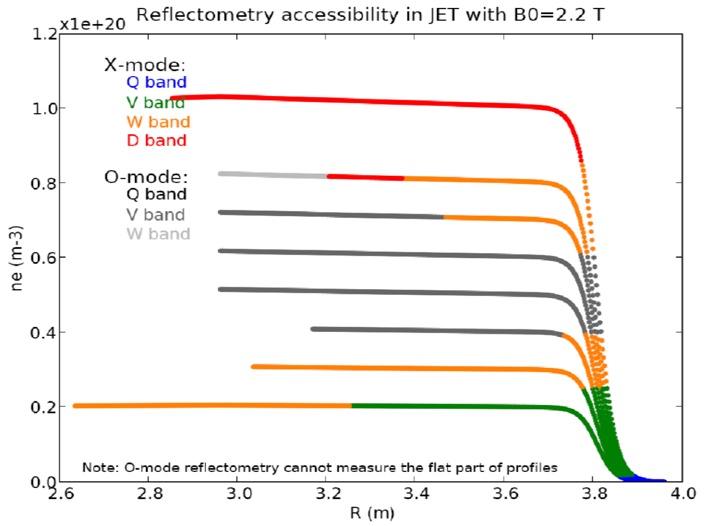

Fig. 1: Example of reflectometry accessibility at B=2.2T for various central densities.

The reflectometers share 3 oversized corrugate waveguides of the MWA. Optical boxes provided by UKAEA [4] separate the different frequency bands 33-50GHz, 50-75GHz, 75-110 GHz and 110-150 GHz and the O or X polarisations.
Each reflectometer can work on either mode, only adding a twist.

In order to simplify and unify the remote control, all the systems use the same ramp generators provided by IST [5], and identical acquisition board modules provided by UKAEA [4].

CEA Reflectometers set up:

Three of these reflectometers covering the range 50-155 GHz have been designed and built by CEA. They are based on technology developments already used on Tore Supra [6, 7, 8], which have been adapted to the JET configuration.
They operate in the frequency ranges of 50-75 GHz (V-Band) and 75-110 GHz (W-Band), in O-Mode or X-mode, and 110-150 GHz (D-band) in X-Mode. They are built on the same microwave scheme shown on figure 2.

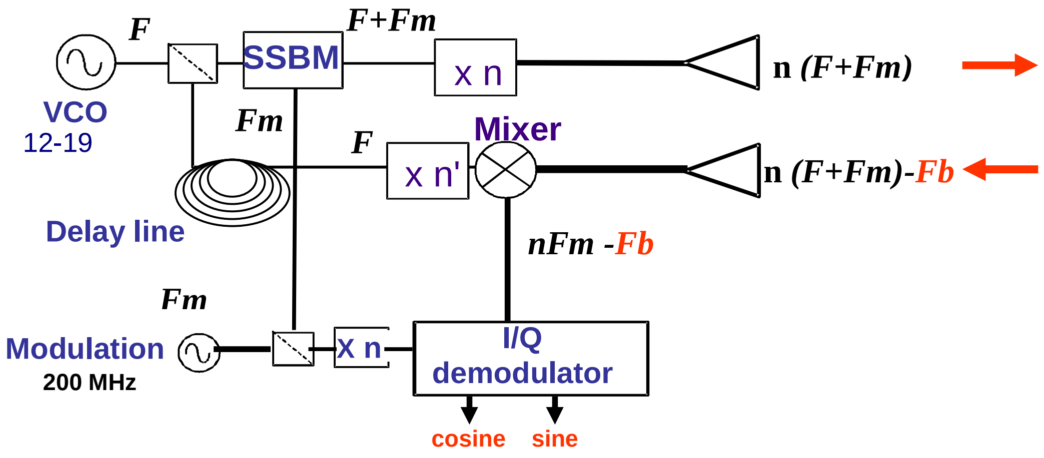

Fig. 2: microwave scheme of V, W and D band reflectometer developed for JET

Emission:

The sources are Voltage Control Oscillator linearly swept from 11.2 to 19 GHz which provide, after frequency multiplication, a good overlap between the V, W and D bands. The source signal is then split in probing and reference arms.
As for Tore-Supra reflectometers, on the probing arm a single side band modulator (SSBM) shifts the frequency for heterodyne detection.
A 10µs sweep produces plasma beat frequencies expected up to 200 MHz. So, to avoid possible overlap between different harmonics, a modulation frequency of 200 MHz as been set to the Single Side Band Mixer.

This technology presents several advantages [9]:

- Suppression of carrier and harmonics is higher than 20dBc, meaning the emission power is launched in only one frequency.
- Signal/noise ratio is much higher than for a simple mixer.
- Intermediate Frequency is at a fixed frequency.

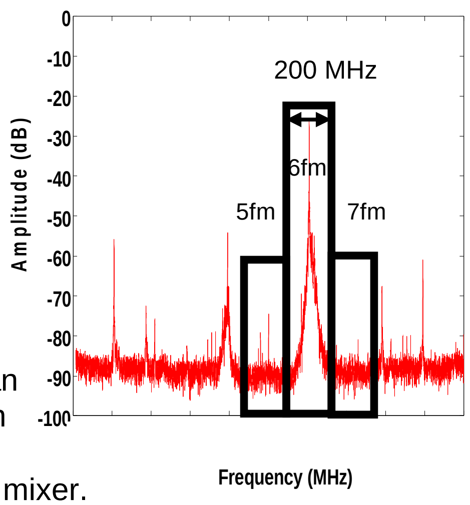

Fig. 3: Intermediate Frequency, after Sub Harmonic Mixer

The frequency is then multiplied by 4, 6 or 9. Powerful multipliers maximise the signal/noise ratio. As shown by figure 4, the output power decreases slightly from 18 to 14 dBm between 50 and 105 GHz. Above 110 GHz, multiplier power hardly reaches 10 dBm. An overlap of 2 GHz at band transition allows a good reconstruction of the density profile.

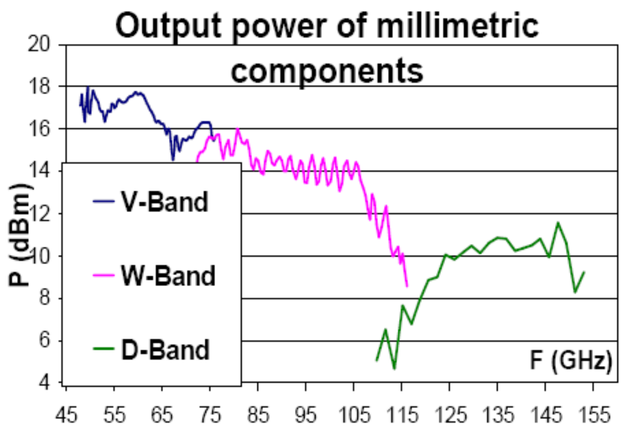

Fig. 4: Multipliers output power

Reference:

On JET, as it will be on ITER, reflectometers are outside the Torus Hall.
The microwaves are launched into the vacuum chamber through 80 m of corrugated waveguides (back and forth). The reference signal is delayed by 66 m of coaxial cable that compensate the approximately 260 ns propagation time. Slope amplifiers account for differential power losses between low and high frequencies and provide flat amplitude, a final gain of 10 dB with a 1dB compression point at 20 dBm to drive the millimetric components. Small and definitive adjustments of the delay line length have been performed during plasma experiments. The reference corresponding to a null beat frequency has been adjusted to be inside the plasma to optimise the measurements for all the following configurations of plasma.

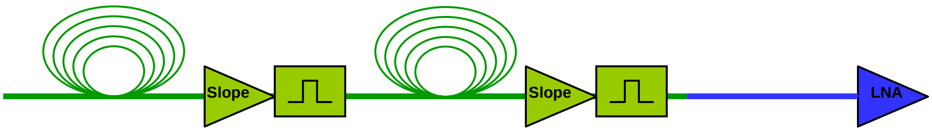

Fig. 5: Scheme of the delay line

Detection:

A second multiplier drives the mixer: a balanced mixer in V-Band, sub-harmonic mixers in W and D-band. Emission and reception millimetric components are installed in small boxes (see fig 6) attached to the optical boxes. Other components as well as VCO, SSBM, power supplies and acquisition system are set in a cubicle several meters away.

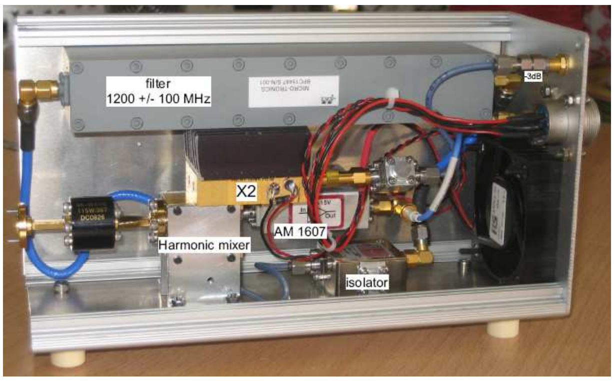

Fig. 6: W band reception box

The detection uses I/Q demodulator which allows a separation between phase and amplitude information from the reflected signal to calculate the density profile. The signal amplitude is adjusted with variable amplification before I/Q demodulator which has a high point of compression. Then, it is compatible with the requirement of the acquisition system. There is no amplifier after the demodulation to add no noise or phase perturbation.

Preliminary results:

A W-Band reflectometer has been installed on JET in March 2009, at the end of the campaign C26. It was set in X-Mode, sweeping in 10 µs.

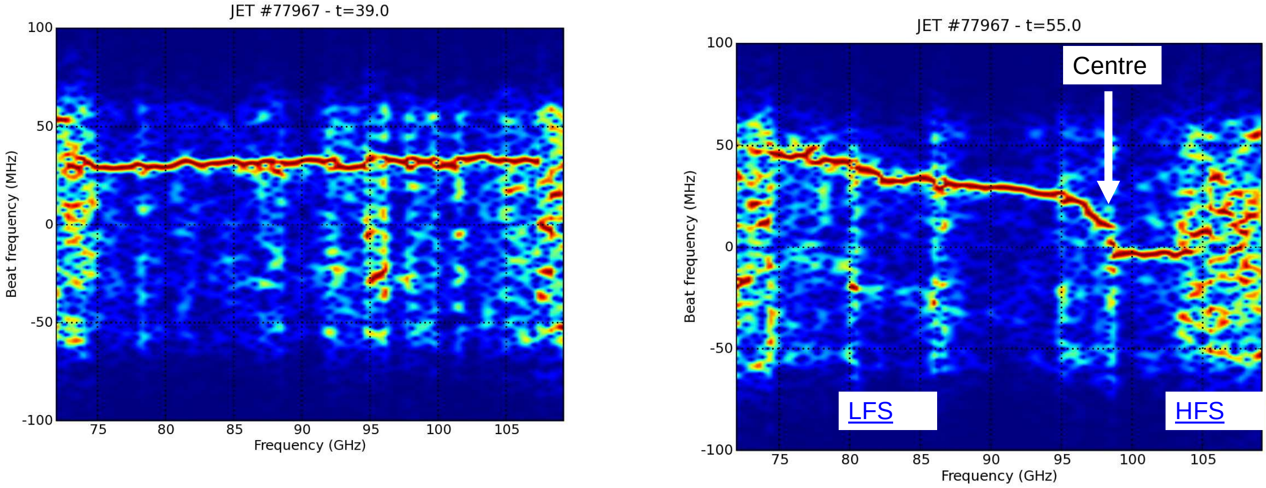

Fig 7: reflection on the back wall (left) and the plasma (right)

Figure 7 presents examples of the first measurements that were performed: a spectrogram shows the evolution of the beat frequency as function of the probing frequency. The back wall beat frequency before plasma is almost constant (left). On the right one, the wave crosses the centre and probes the plasma on the high field side. These first results are good omens for the next campaign C27.

Since these measurements, all the reflectometers have been installed on JET. They are ready to probe the plasma to give accurate density profiles to find some answers to several questions such different as the study of fast events, pedestal behaviour, evolution of Internal Transport Barrier…

References:

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