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ABSTRACT.

A X-mode reflectometer using an innovative design was developed and installed successfully at JET to investigate the viability of measuring density profiles with high spatial and temporal resolution in large size devices using broadband FM-CW Reflectometry. It probes the plasma in V band (0 up to $1.4 \times 10^{19}\,\mathrm{m}^{-3}$), for magnetic fields between 2.4 and 3.0T. In this paper we discuss the main design options and implementation of the diagnostic. The first experimental results show a high sensitivity of the diagnostic when measuring plasma density profile changes occurring in ITER relevant regimes namely during ELMy H-modes.

This demonstration of the concept at JET was essential for the application of profile reflectometry techniques to next step large devices like ITER. It also motivated a further development of a new broadband FM-CW diagnostic to probe both the edge and bulk JET plasmas using four fundamental frequency bands.

1. INTRODUCTION

A broadband prototype reflectometer diagnostic was developed for JET 1 with two main objectives: (i) to probe the plasma edge electronic density profile not covered by Thompson Scattering diagnostics; (ii) to demonstrate the viability of profile reflectometry in large size devices. The prototype reflectometer system uses the new Millimeter Wave Access (MWA) oversized waveguide cluster2, sharing the same pair of waveguides with other 4 fluctuation reflectometers operating in narrow band regions of the next fundamental band [3]. After the initial installation in JET, it was found that the requirements on the system were more demanding than expected due to the long inward and outward waveguide runs to and from the plasma. The sources coherence and the Linear Frequency Modulation (LFM) had to be improved to avoid errors in the density profile evaluation. As insufficient coherence is due to the use of a multiplied free running Voltage Controlled Oscillator (VCO), an Equalized Delay Line was introduced to improve the signals coherence, operating in the VCO fundamental frequency band (12 to 18GHz). The line, delays the reference signal by an amount close to twice the waveguide delay. Coherent sources which could be another design option were not adopted because they are expensive and difficult to implement for a system that should operate in broadband with very fast sweeping time (less than 10μs) [4].

The Linear Frequency Modulation was ameliorated with a dynamic calibration scheme, using a coaxial delay line interferometer as Frequency Discriminator (FD). In this way it is possible to reproduce the phase errors on the modulation. An accurate, detailed and dynamic calibration process for the VCO tuning voltage was thereby implemented [5].

In this work we present the design solution adopted for FM-CW reflectometer system and the main results from the tests performed with and without plasma (Sec. II). First experimental results obtained in ELMy H-mode regimes are depicted in Sec. III and some conclusions about the system performance and measuring capability are drawn in Sec.IV.

2. SYSTEM DESIGN

The original system 1 was changed in order to accommodate an equalized delay line with (260 ns).

Since this system uses a Direct Conversion [6] scheme with an Intermediate Frequency (IF) determined by the path length, however with the use of the equalized delay line the IF was reduced to less than 50MHz. In order to accommodate the new IF, both the IF amplifier and Filter chain were changed accordingly. The electronic reference used in the Quadrature detector was also modified. As the technology used in the detection (0º and 90º phases are generate digitally) allows operation from 6MHz to 600MHz with less than 6º error the In-phase and Quadrature detection section was not modified.

To improve the sweep linearization, a dedicated arbitrary function generator built on a Field Programmable Gate Array (FPGA) was upgraded to accommodate the new dynamic calibration obtained from a delay line interferometer in the same short interval of the ultrafast swept operation (20μs).

In figure 1 the new design is presented and the actual implementation of the diagnostic at the JET diagnostic hall. In the figure three major blocks can be identified: (i) the equalized delay line; (ii) the microwave front ends and (iii) the FM chirp generator plus IF signal detection (FM-GD).

The Equalized Delay Line (EDL) uses 3 sections with: 18 m of coaxial cable (RG402), a 10dB positive equalizer (developed at CFN) and one or two amplifiers (depending on the required gain). With this setup we could guarantee less than 3 dB ripple across the 12 to 18GHz band and an output power of 10 dBm for a 13dBm input power level. The total gain used in this design is 120 dB.

The Microwave front ends are connected to the EDL and FM-GD by 2 meters of coaxial cable operating in the 12 to 18 GHz band for the frequency multipliers, as well as the IF signal (DC to 50MHz) to the IF amplifier and filter chain. With this setup the losses in the fundamental waveguide are minimized, and the installation simplified, since the front-ends for transmission and reception are directly connected to the Quasi Optical Combiner (QOC)3 .This setup is very flexible and adjustable, since each probing band (in this case 50 to 72GHz) can be changed just by replacing the front-end units.

The dynamic calibration is performed at operational speed (10-20μs). Using the VCO output signal, the detected signal is processed in software in order to generate a nonlinear tuning curve that is loaded into the FPGA memory to be used during plasma measurements. This process to improve the measurement is typical of FMCW radars [5]. The results from the calibration process are presented in figure 2

3. EXPERIMENTAL RESULTS

After the system improvements profile measurements from FM-CW reflectometer at JET were performed with 20μs sweeps on a routine basis. Due to the limitations of the data acquisition system only 51 measurements could be performed for each shot. A new acquisition system was meanwhile installed that will greatly increase the number of measurements per shot.

The ability of the prototype reflectometer to measure density profiles both in L-mode and H-mode regimes is shown in figure 2. The profile measurements were performed in Pulse No: 72300 with repetition rates of 100ms, the reflectometer data is compared with the corresponding profiles obtained from Thompson Scattering diagnostic revealing a good agreement in both L and H plasmas.

The capability of the reflectometer to resolve the time evolution of the density profile during fast events occurring at the plasma edge, such as ELMs was also tested. The measurements were performed in Pulse No: 72346 with a repetition rate is 800μs. In figure 3 the evolution of the density profile is presented at different phases of the ELM as seen in the H signal. The time traces of the position of several density layers is depicted in figure 4. It is represented a normalized distance to the antenna $1 - \left[\frac{(D_{ant} - D(n_e))}{D_{ant}}\right]$ which means that a movement of each fixed density layer towards the antenna corresponds to an decrease of the normalized distance and vice versa a decrease of in the normalized distance means a shift of the plasma layer away from the antenna. A consistent time evolution of the different layers is found following the evolution of the D_α signal. At the onset of the ELM, at t = t3, the plasma is shifted towards the antenna and it collapses for t = t4 recovering afterwards for later time instants. Unfortunately the profile modifications between t3 and t4 cannot be resolved due to the insufficient sampling.

CONCLUSIONS

The installation of the prototype broadband reflectometer at JET proofed the viability of broadband FM-CW reflectometry in large size fusion devices with long and intricate transmission lines and connections (40 m and 9 bends each). The use of Equalized Delay Line is possible and drastically reduces the requirements on the VCO signal purity. Further improvements could be achieved with lower loss coaxial cable, reducing the Mixer output noise floor.

Faster sweep speeds should be tested to reduce considerably the turbulence effects in the measured profile, in particular in H-mode plasmas.

The design presented in this paper has some disadvantages since the Direct Conversion results in a beat frequency band very close to DC and therefore very close to the Mixer AM/PM-conversion noise that in this case extends from DC to 10MHz with the noise level at –40dBm at 1MHz. The reflected plasma signal is in the order of -60dBm, the IF frequency is band is adjusted to be greater than 20MHz. To overcome this issue a full heterodyne solution can be adopted but it may result in large increase of system complexity.

They experimental results obtained with the prototype system although very limited by the data acquisition system revealed the good quality of the density profiles obtained both in L and H regimes.Profile changes occurring at the edge due fast events such as ELMS could be tracked.

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REFERENCES

[1]. Luis Meneses and et al., Rev. Sci. Instrum. **77**, 926 (2006).

[2]. Simonetto A., Joint 29th Conf. on Infrared and Millimeter Waves -12th Int. Conf. on Terahertz Electronics, Karlsruhe, Germany, (2004).

[3]. L. Meneses , et al. ,AIP 44th Metting of Division of Plasma Physics, LP1 35 , Vol. 47, No. 9, (2002)

[4]. “Understanding Synthesizer Designs and Specifications” Application Note, SPINNAKER Microwave, INC

[5]. M. Vossiek et al IEEE MTT-S Digest 1998

[6]. Behzad Razavi, IEEE Transactions on circuits and Systems - II Analog and Digital Signal Processing, Vol. 4, No 6 (1997).

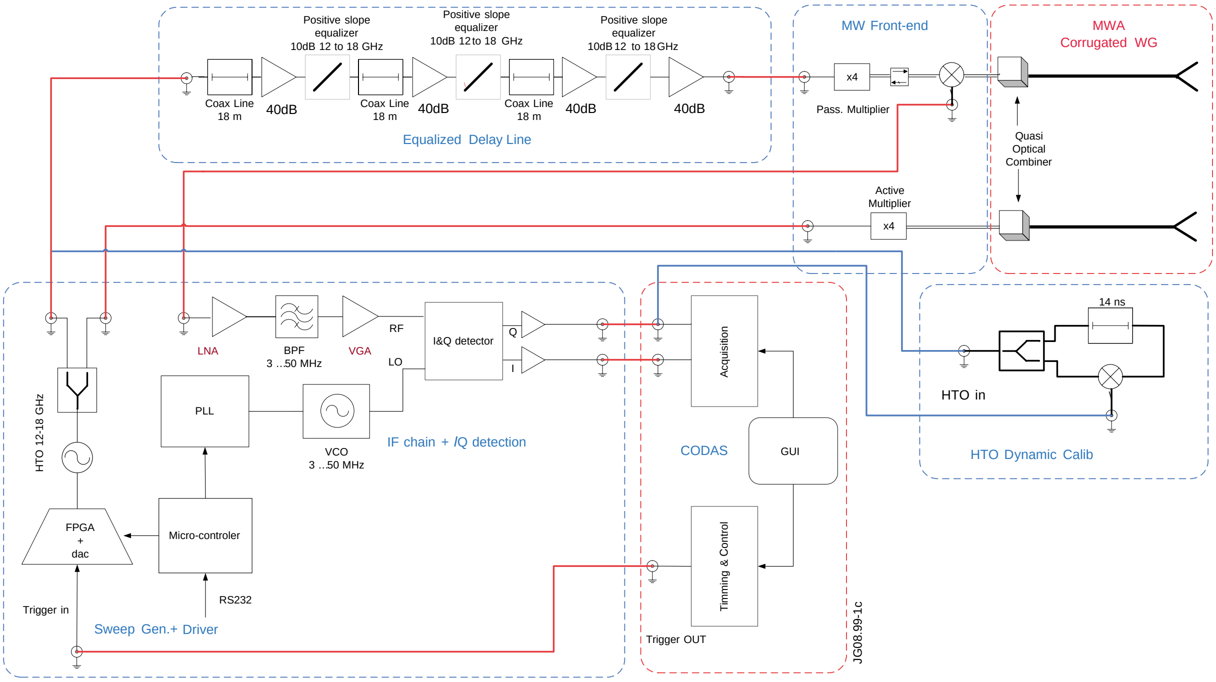

Figure 1: Schematic design of the new profile reflectometer, operating in V band, installed at JET.

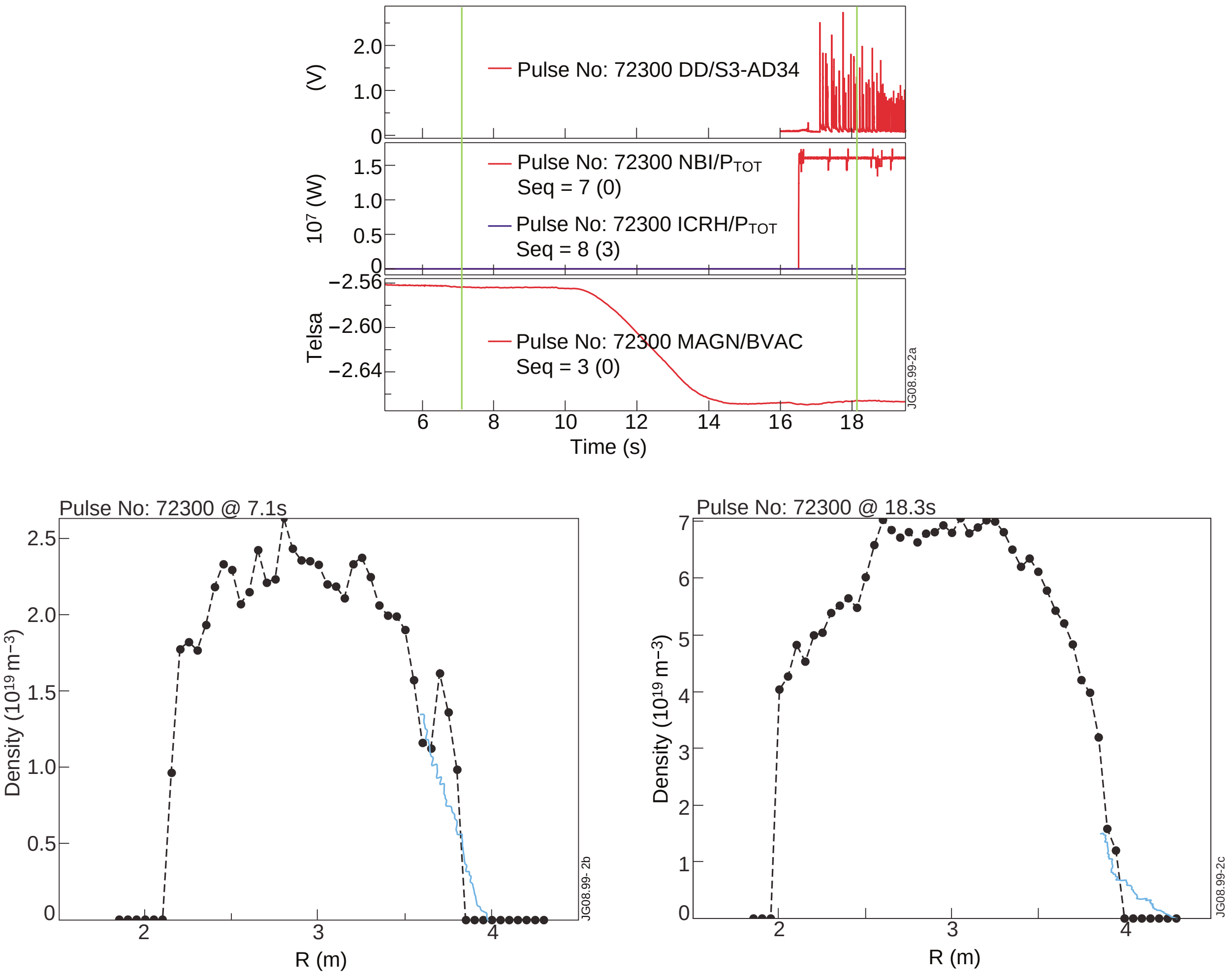

Figure 2: Electronic density profiles comparing LIDAR and reflectometer profiles both in L and H mode plasmas.

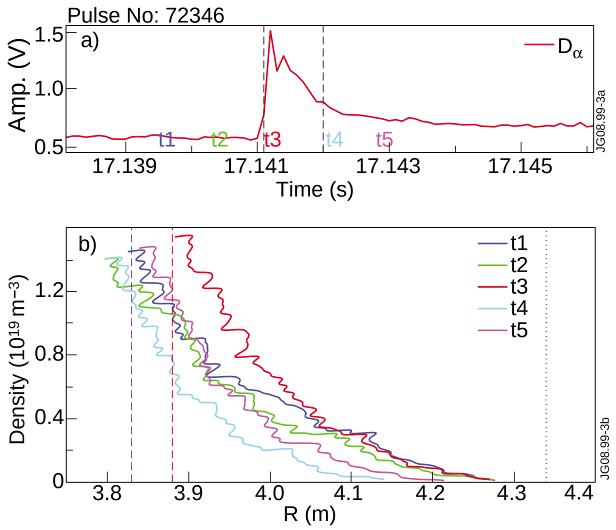

Figure 3: Density profile evolution during the onset of an ELM, with profiles before (t1, t2), during (t3), and after the ELM(t4, t5), the profile is shifted during the ELM towards the Antenna (t3) recovering later to is prior position and shape (t5).

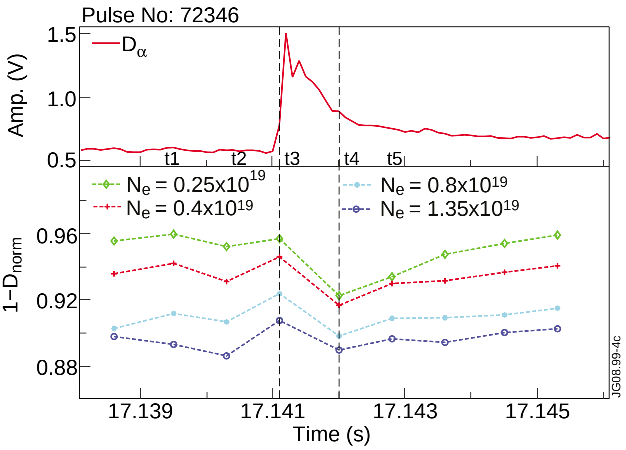

Figure 4: Evolution of density layer during an ELM is depicted with data from profiles presented in fig 3.