PULSED RADAR REFLECTOMETER WITH HIGH REPETITION RATE FOR THE TEXTOR TOKAMAK

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A new pulsed radar reflectometer has been built, enabling electron density measurements with high temporal and spatial resolution. This diagnostic is capable of ten-channel density profile measurements at a repetition rate of 2 MHz, whereas density fluctuation measurements up to 10 MHz repetition rate can be done. The ten channels cover the density range of 4 x 10^{18} to 4 x 10^{19} m^{-3}, measuring from the low-field side. Two additional swept-frequency channels can be used to investigate the correlation length of density fluctuations or to make a detailed 'sweep' of profile perturbations, e.g. magnetic islands.

1. Introduction

Pulsed radar reflectometry is a technique for electron density measurements in which short (~ 1 ns) microwave pulses are launched into the plasma and the reflection from the critical density layer (dependent on the microwave frequency) is detected [1,2]. The measured quantity is the time of flight of the microwave pulse between transmission and detection.

The typical experimental implementation of this measurement consists, like with other reflectometric microwave techniques, of a box with microwave sources and electronics, which can be located conveniently far from the tokamak, and a waveguide structure to carry the microwave pulses to the tokamak vessel and back again. Access to the tokamak can be restricted, depending on the experimental requirements, to just one microwave antenna. Detection of the pulses, as well as the actual flight time measurement, is done at the convenient place outside the radiation shield again.

2. Previous system

The new diagnostic is an upgrade of a four-channel version, which was built for the RTP tokamak and later also operated at the TEXTOR tokamak [3]. At RTP extensive density profile studies were undertaken, using of course only four points on the density profile. Also disruptions, pellet injection and MHD activity were investigated at RTP [4]. In TEXTOR, large rotating magnetic islands were observed and pulsed radar measurements showed a peaking of the density distribution inside the islands [5].

3. Pulsed Radar II – The next generation…

On the basis of the four-channel device a new reflectometer has been developed, featuring ten fixed-frequency plus two variable-frequency channels [6]. The time resolution has been improved from 0.5 MHz for a four-point profile measurement to 2 MHz for ten points, with fluctuation measurements up to 10 MHz for two channels. The tenfold increase in pulse repetition frequency necessary for this improvement has been achieved by time-multiplexing the generation and receival of radar pulses: now every 50 ns a new pulse is starting its 125 ns journey through the waveguide system and plasma vessel.

The experimental setup of the new radar system is depicted in figure 1. In total 12 Impatt oscillators generate the microwaves continuously. Ten of these sources operate at fixed frequencies spread between 18 and 57 GHz, while the remaining two can be swept in frequency in 1 GHz ranges, located near two of the fixed frequencies. Pulses are formed out of the continuous microwaves by fast varactor modulators. The pulse length is chosen around 1 ns, as a trade-off between pulse-broadening effects in waveguides and plasma, which become severe at short pulse lengths, and the desired accuracy of the time of flight measurement.

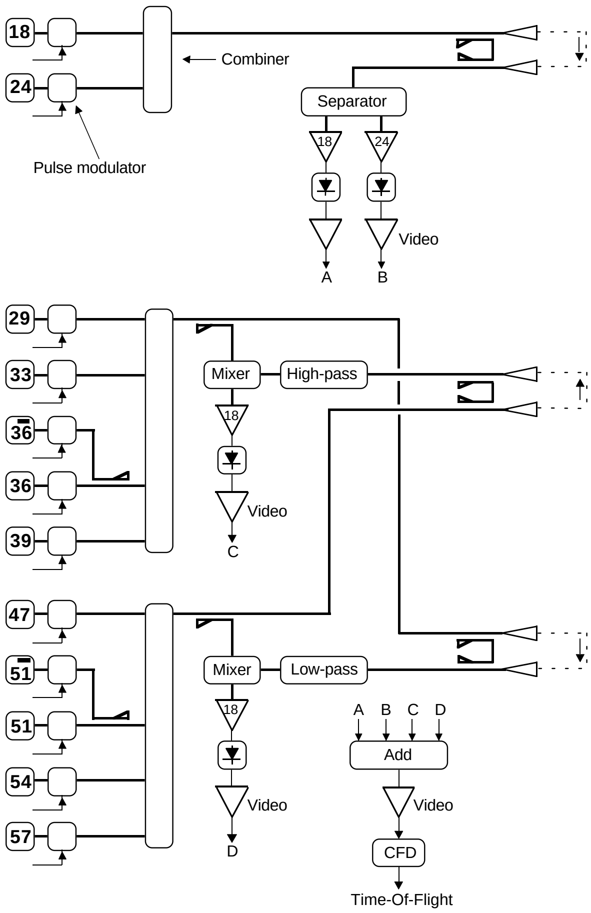

Figure 1. Microwave setup. All frequencies in GHz. The sweepable sources are indicated by a bar above the frequency.

The radar pulses are transferred to the plasma via three waveguide systems: one for each frequency band. They are launched into the plasma in ordinary mode by horn antennas mounted inside the vessel and return to the detectors via adjacent receiving antennas and a similar waveguide system. Except for the two lowest-frequency channels, detection takes place in a heterodyne fashion by mixing with a local oscillator frequency. The same twelve sources that generate the transmitted pulses are used to provide the local oscillator frequencies, and the pulse-forming modulators are used also to switch the local oscillators in 20 ns time windows where the reflected pulses are expected. By this time window selection, possible false reflections in the waveguide path are eliminated.

After amplification, the detected signals are combined and fed into a constant fraction discriminator (CFD), which triggers at 50% of the amplitude on the leading edge of the pulse, regardless of the pulse amplitude. The time of flight of the pulse is then determined by a counter system with a resolution of 70 ps, corresponding to a spatial accuracy of one cm when ranging a metal mirror in vacuum. The data from the counter system (amounting to 64 Mbytes per plasma discharge) is fed into a memory module, and an on-board CPU can perform immediate data analysis and reduction. Schemes for intelligent data reduction have to be developed.

4. First results

Test experiments have been performed at FOM Rijnhuizen with good results. Figure 2 shows a radar pulse of the 33 GHz channel, reflected off of a metal mirror. The full width at half maximum (FWHM) of this pulse is about 700 ps.

The equipment has now been installed at TEXTOR and final commissioning is under way. The first results are encouraging. Radar measurements of one of the frequency channels (24 GHz) for TEXTOR discharge 78511 are shown in figure 3, together with plasma current and density traces. Although the quality of the data will be improved considerably by further commissioning, major features of a pulsed radar reflectometer signal can already be clearly seen. Before the start of the discharge pulses are reflected by the back wall of the vessel; this flight time in vacuum is defined to be zero. As the density builds up, the longer group velocity in the dense plasma gives rise to longer flight times to the back wall. The vertical band of points at t = 0.5 s is largely due to an effect in the counter system when long time delays are measured; this will be improved. After 0.6 s the central density reaches the level of the critical density for this frequency (0.71 x 10^{19} m^{-3} for 24 GHz) and a reflecting layer comes into the plasma. Pulses are now reflected from this layer and show correspondingly shorter flight times. From t = 0.1 s a second trace of points can be distinguished above the main trace. This secondary trace, with a lower density of points, corresponds to pulses that are detected only after a double reflection between the plasma and the LFS vessel liner. As the density builds up

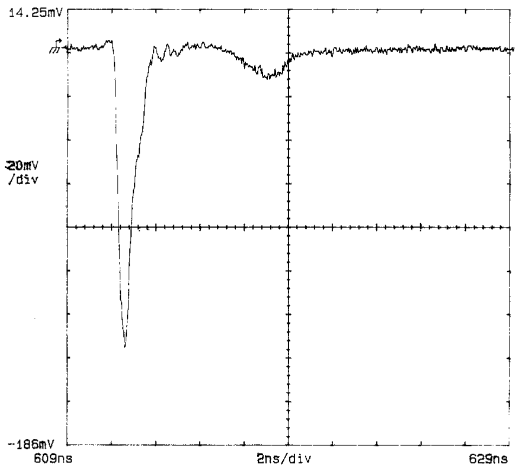

Figure 2. A 33 GHz radar pulse, detected after reflection from a metal mirror. The detection system gives a negative voltage output. The hump in the signal 6 ns after the pulse is due to an effect in the electronics driving the pulse-forming modulator.

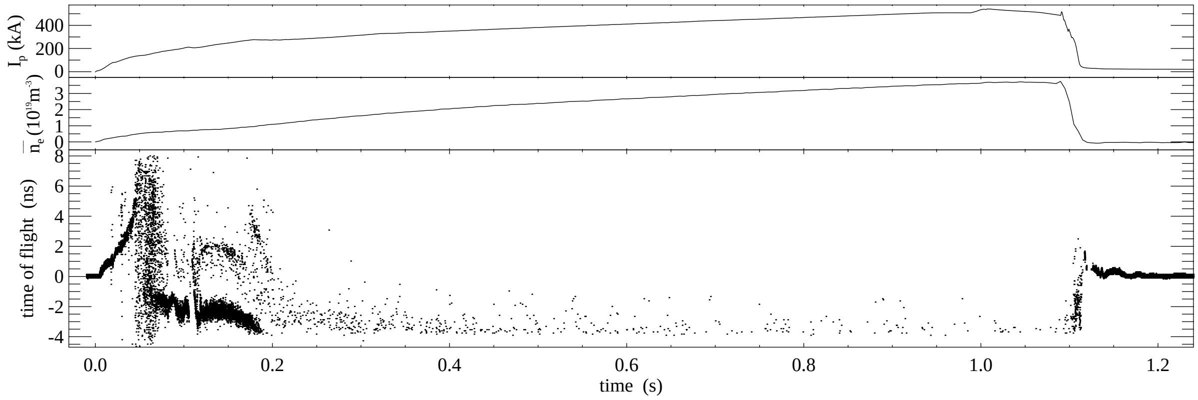

Figure 3. Data taken from TEXTOR discharge 78511: plasma current, line-averaged density and the time of flight of 24 GHz pulses. These very first measurements were done just before the EPS Conference. Further commissioning is needed to improve the quality of the data. For reasons of clarity, only one out of 40 data points has been plotted.

further, the flight time decreases even more because the reflecting layer moves towards the antenna. Here it can be seen in the figure that the system needs further commissioning, since at high densities the flight time of the 24 GHz radar pulses is shorter than the time delay window which the diagnostic is currently set to measure. Therefore only data points in the secondary trace are visible from t = 0.2 s onwards to the disruption ending the discharge.

5. Outlook

The new ten-channel pulsed radar reflectometer with high repetition rate has been built by FOM for the TEXTOR tokamak. Final commissioning is under way. The first full density profile measurements are expected in July 1998. Schemes for advanced data handling and data reduction will be developed; this is especially important for correlation measurements of density fluctuations. This diagnostic is a pilot experiment for the envisaged remote diagnostic operation of the TEXTOR tokamak (Germany) from FOM Rijnhuizen (The Netherlands) within the framework of the Trilateral Euregio Cluster; fully remote operation is already possible and a distributed database is being developed.

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