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Development of a Pulsed Radar Reflectometer for CHS Plasmas

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Abstract

The microwave pulsed radar system developed for CHS device is described. Results of measurements for time delay of short reflected pulses for both ordinary and extraordinary modes are presented and discussed. The measured time delay agrees with the calculated one within error bars.

Keywords:
plasma diagnostic, electron plasma density, microwaves, pulsed radar, time of flight

1. Introduction

Reflectometry is a diagnostic to determine the position of the Critical electron Density Layer (CDL) at which microwaves are reflected in plasma [1]. In the case of pulsed radar reflectometry, short (~ 1 ns) microwave pulses are launched into plasmas. From the time delay between the launched and received pulses, information on the positions of CDL can be determined. By use of multiple frequencies pulsed radar reflectometry has the potential to reconstruct electron density profiles.

Even a part of the reflected pulses is lost, the rest of measurement is not affected. Furthermore, false reflections from microwave components or vacuum window can be easily distinguished in the time domain. Plasma fluctuations in time domain do not influence the measurements because they are almost frozen during the propagation time of the pulse through the plasma.

The CHS configuration has a magnetic shear, and it causes O/X-mode coupling. Thus its effect should be investigated experimentally.

This paper describes the pulsed radar system installed on CHS device and the results of its application for CHS plasmas. Since the system is not completed yet (*e.g.* time measurement electronics), the advantages of pulsed radar reflectometry are not fully shown in this paper.

2. System Description

A multiple frequency (51, 54, 57 GHz) pulsed radar system has been designed for CHS. The difference from the existing systems (in RTP [2] and TEXTOR) is that we multiplex three frequencies into single 'mixed' pulse and split the received pulses with band-pass filters at IF stage. The advantage of this scheme is that we do not have to switch the sources between successive pulses, so that the measurement rate does not decrease with the number of probing frequencies. Figure 1 shows the block diagram of this system. The description of this scheme was presented elsewhere [3].

As a microwave source Gunn oscillators with the output power 50–100 mW have been used. To produce a short, well-shaped microwave pulse two types of fast microwave switches (modulators) have been tested. One is a broad band (54 ± 3 GHz) PIN switch (Millitech) and the other is a narrow band (51-, 54-,

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57 ± 0.25 GHz) varactor diode modulator (developed in Kharkov Institute of Radiophysics and Electronics (IRE), Ukraine) [4]. The obtained pulse widths are $1.8 \sim 2.0$ ns and $0.3 \sim 0.7$ ns, respectively. In order to reduce the power losses and pulse broadening, X-band oversized waveguides (5 m) are used. The loss in the waveguides is about 5 dB for one way transmission.

First experiments on the CHS have shown that the reflected signal from the plasma is rather small. To overcome this problem a heterodyne technique is used.

In the situation when strong changes in the reflected pulse amplitude (due to the beam refraction and plasma density fluctuations) occur, a Constant-Fraction-Discriminator (CFD) which yields the pulse timing independent of amplitude is most appropriate for time-of-flight (TOF) measurement. However, CFD is affected by the pulse shape deformation, which arises from the dispersion in plasmas. A numerical simulation has been done to estimate the CFD timing errors. The pulse deformation is more serious for shorter pulse width, and the deformation leads to a larger error in the timing. We found that the errors are negligible for the pulse width longer than 0.5 ns. Time to Amplitude Converter (TAC) module is used to measure the timing from the output of CFD. TAC yields a square pulse, of which amplitude is proportional to the time delay and an ADC measures this amplitude.

Free space propagation test measurements were done to estimate the timing errors in the system in the range of ± 0.2 m and with the detected power of 1 μW $\sim$ 10 μW [3]. These measurements have shown that the spatial resolution of $\pm 3 \times 10^{-3}$ m (*i.e.* ~ 20 ps in the time resolution) could be achieved.

3. Experiments in CHS

A 51 GHz 1-channel pulsed radar reflectometer has been installed in CHS. As a probing wave both ordinary and extraordinary modes are launched. A conical horn has been used for launching and receiving microwave pulses. The transmitter is placed at the distance of about 5m from CHS. We probed the plasma with microwave pulses of 1.9 ns made by a PIN switch. Detection part is placed close to the device ($\sim$ 1m).

The plasmas were initiated by IBW (Ion Bernstein Wave) or ECH and heated by NBI and ECH. These measurements were done for discharges with the magnetic field of 0.85 T and maximum electron density of about 6×10^{19} m^{-3}. To protect receiver from the influence of strong ECH (53.2 GHz) power the 40 dB band-stop filter was used [5].

Figure 2 shows the signal recorded by a super-fast oscilloscope (LeCroy) with the bandwidth of 0.75 GHz. The first pulse is the reflected pulse at the vacuum window (made of thin mica). The second one is the pulse from CDL, and it has much smaller amplitude.

Since the TAC module can be triggered by the first large pulse, the amplitude of the first one should be smaller than that of the pulse from CDL. The partial diminution of reflected pulse from the window was achieved by installing the attenuator and movable plunger in a receiving arm of reflectometer (Fig.1). This allowed us to decrease the unwanted window reflected pulse by the factor of two. However, that was still not enough for using the TAC module.

Since the time measurement electronics is not completed, the time delay is measured from the waveform of sampling oscilloscope with our eyes. The sampling oscilloscope requires about 10,000 pulses (10 ms) to make a reflected pulse waveform. When the amplitude modulation is very large, each point, which corresponds to a single pulse measurement, scatters and the resultant waveform becomes noisy (Fig.2 (a)). This

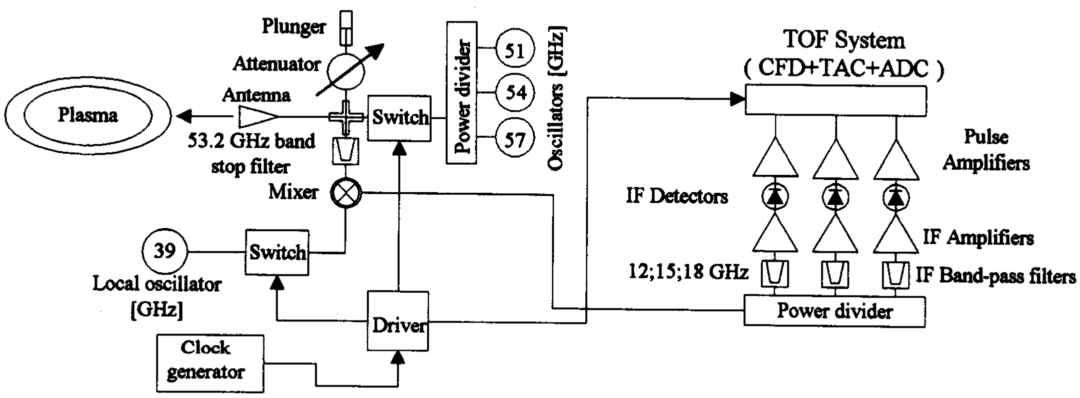

Fig. 1: Block diagram of the CHS multi-frequency pulsed radar reflectometer.

scatter makes us difficult to measure the time delay accurately. The error bars in Figs.3 and 4 represent the scatter of each point in the waveform, and they are much larger than that obtained at a free space propagation test with a flat mirror and with time measurement electronics (TAC) [3]. We also tried to use super-fast LeCroy (0.75 GHz) oscilloscope. Sometimes the amplitude of the reflecting pulse becomes large and the pictures like Fig.2 (b) were obtained, but in most cases the amplitude is small and it is difficult to identify the reflected pulse, because its bandwidth is rather poor.

Without plasma, the reflected pulse is stable, and the measurement is accurate. The small difference between the measurement and calculation is probably due to unsmooth surface of the inner wall, so it is difficult to define the accurate distance to inner wall.

Figures 3, and 4 show the time delay and amplitude of the reflected pulses as a function of central electron density. The measured data can be divided into three regions. The region I is the low density one, where the CDL does not exist in the plasma, and launched wave passes through the plasma. In this case the system is operated as an interferometer. The amplitude of the reflected pulses decreases with the density. This is probably due to the refraction of the wave. The region III is the high density one, where the CDL exists and the amplitude increases as the CDL moves towards the antenna. In the region II adjacent to appearance of reflecting layer the reflected pulses were not observed (possibly due to the strong refraction of microwaves).

Figures 3 and 4 also show calculated time delay for both modes. The density was estimated from the data of line density obtained by an HCN laser interferometer [6], by assuming a parabolic density profile. The measured data on reflected pulse delay follow the calculated curves, but error bars are rather large. This comes from the strong amplitude modulation of the reflected pulse. As shown by the measurements and calculations, the density where reflected pulses begin to appear at the different densities for O/X modes. Since

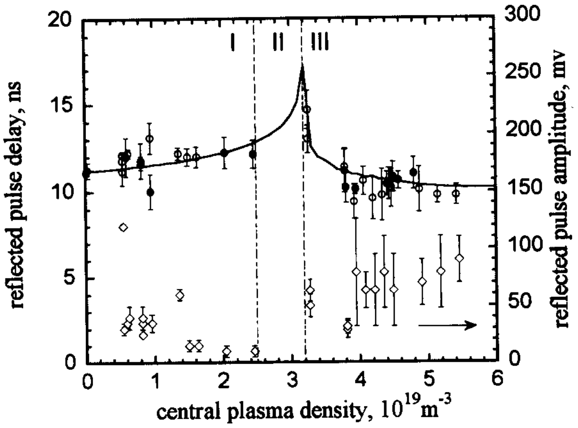

Fig. 3: Reflected pulse delay (open circles - IBW + NBI plasma, solid circles - ECH + NBI plasma), calculated pulse delay for parabolic density profile (solid line) and reflected pulse amplitude (diamonds) as a function of the central electron density for ordinary mode case.

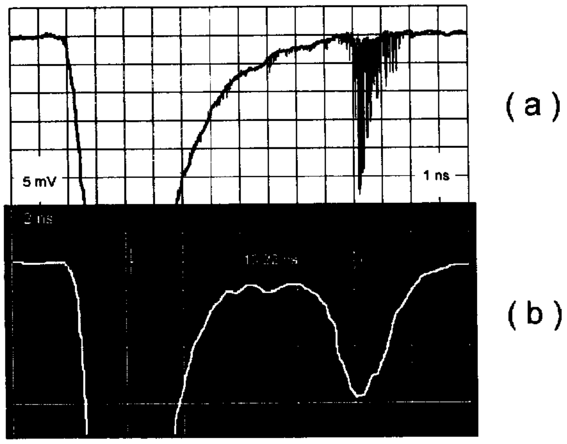

Fig. 2: Measured reflected pulse shape recorded via sampling oscilloscope (Yokogawa DL8100, with the bandwidth of 10 GHz) (a), and by the use of super-fast one (LeCroy with the bandwidth of 0.75 GHz) (b).

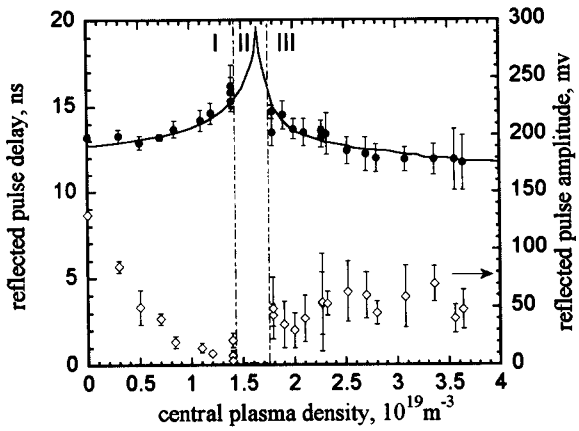

Fig. 4: Reflected pulse delays (circles - ECH + NBI plasma), calculated pulse delay for parabolic density profile (solid line) and reflected pulse amplitude (diamonds) as a function of the central electron density for extraordinary mode case.

the code does not include the effect of mode coupling, the measured delay should show deviation from the calculation. However, the deviation is not observed due to large error.

4. Summary

A pulsed radar reflectometer for CHS experiments has been constructed and tested with/without plasma. For short microwave pulse production, two kinds of fast switches (Millitech, IRE) were tested. These can produce pulses with the width of 1.8–2.0 and 0.3–0.7ns, respectively. The laboratory tests of free space propagation showed that the spatial resolution is $\pm 3 \times 10^{-3}$ m.

Results of time delay measurements are in reasonable agreement with the calculated delay. It must be stressed that the range of change of time delay in CHS experiments is rather small (~ 2 ns). This implies a necessity of using of shorter probing pulses. The IRE switch looks more preferable for CHS system.

Rather strong false reflection from the vacuum window has not allowed us to use CFD time-pick-off technique until now. To overcome the problems with false window reflection the 'gated microwave receiver' is proposed. The key point is the 'gating' of reflected signal in the time window, where only the signals from CHS wall or plasma are detected. Use of second PIN switch in the local oscillator or reference arm (Fig.1) could do this. This modification of the system is under way now.

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