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Microwave Reflectometer for Density Profile and Fluctuation Measurements on LHD

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1. Introduction

For measuring the density profile and plasma fluctuation in the Large Helical Device (LHD), several types of microwave reflectometer have been installed [1, 2]. Recently we have been developing a new type of reflectometer which is used an ultrashort sub cycle pulse. It is called as an ultrashort pulsed radar reflectometer. An ultrashort pulse has broad band frequency components in a Fourier space. It means one ultrashort pulse can take the place of a broad band microwave source. Also this ultrashort pulsed radar reflectometer is categorized in the type of a time-of-flight (TOF) measurement system. This TOF measurement has an advantage which we can easily distinguish between the ordinary polarized wave and the extraordinary polarized wave involving the reflected wave from the plasma, because each cut-off position in the plasma is separated. Currently this ultrashort pulsed radar reflectometer operates on six channels using a filter bank and a super heterodyne detection system for measuring the edge density profile and slow plasma oscillation. However the measurable frequency range of this ultrashort pulsed radar reflectometer system is lower than about 50 kHz, because the repetition rate of the incident pulse and the memory size of the data acquisition are limited. For higher fluctuation measurement we have been developing the three channel heterodyne fixed frequency reflectometer. This system uses a conventional reflectometer technique and measures the density and magnetic fluctuation in the plasma core region. In this paper we present these two reflectometer systems and obtained some results such as low-*n* Magnet-Hydro Dynamics (MHD) mode fluctuation.

2. Ultrashort pulsed radar reflectometer

The schematic of ultrashort pulsed radar reflectometer is shown in Fig. 1. An impulse of -2.2 V, 23 ps full-width half-maximum is used as a source. To extract the desired probing

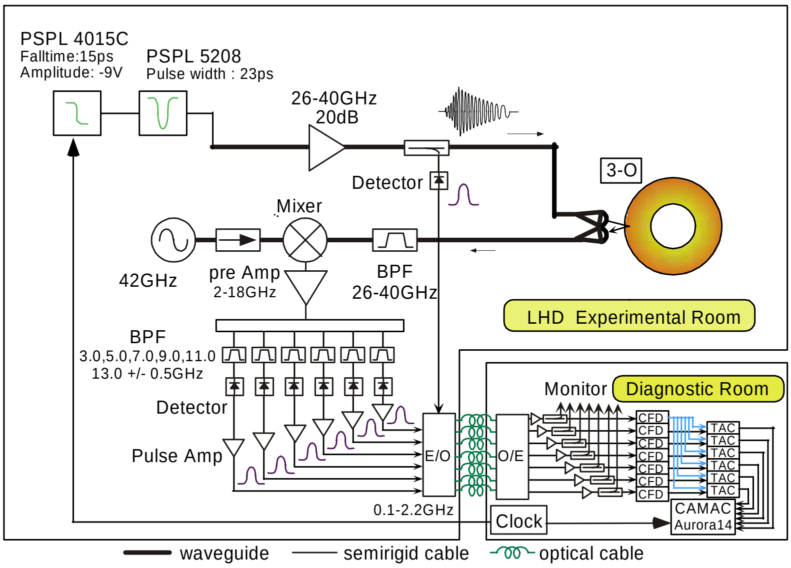

Figure 1 Schematic of ultrashort pulsed radar reflectometer

range of the frequency, we utilize an R-band rectangular waveguide. When the impulse is launched into the waveguide, it is transformed to the chirped wave including a broad frequency spectrum that changes from high to low. It is caused by the dispersion effect of the electromagnetic wave in the waveguide. The lowest frequency is determined with the waveguide aperture size. The output chirped wave from the waveguide is amplified by a power amplifier and then is launched into the plasma. The incident wave reflects from the cut off layers corresponding to each frequency component. The reflected wave is mixed with 42 GHz continuous wave of the local oscillator. The output from the mixer is amplified by the intermediate frequency (IF) amplifier (2 – 18 GHz) and then divided to six. Each IF signal is filtered by band pass filters which the centre frequencies are 3, 5, 7, 11, 13 GHz and they correspond to 39, 37, 35, 33, 31, 29 GHz, respectively, in the incident frequency components. Each 3dB band width is 1.0 GHz. The six signals are detected by the Schottky barrier diode detectors to obtain the reflected signal pulses. The reflected pulses are amplified by pulse amplifiers and leaded to constant fraction discriminators (CFD). A part of the incident wave is extracted with a directional coupler and is detected to obtain the reference pulse. Both the reference pulse as the start signal and the reflected pulse as the stop signal are leaded to the time-to-amplitude converter (TAC). The output voltage of TAC is proportional to the time difference between the start and the stop signal. The spatial ambiguity estimated from the TAC output has been tested and defined lower than 6 mm.

By using the ordinary wave the measured flight time of each frequency pulse reflected from the plasma has been described by

$$\tau_p(\omega_0) = \left(\frac{\delta\phi(\omega)}{\delta\omega}\right)_{\omega=\omega_0} = \frac{2}{c}\int_{r_a}^{r_c(\omega_0)} \frac{1}{\sqrt{1-\dfrac{\omega_{pe}^2(x)}{\omega_0^2}}}\,dx\,,$$

with r_a the edge of the plasma, c the velocity of the light, ω the probing frequency, ω_{pe} the plasma frequency, ω_0 the plasma frequency corresponding to the critical density, and $r_c(\omega_0)$ the position where the plasma frequency equals the probing frequency, respectively. The result of the time evolution of TOF measurement is shown in Fig. 2. The delay time is defined by the travelling time from the assumed plasma edge to each cut off layer. And the TOF behaviour is reasonably agreement with the other diagnostics such as interferometer.

3. Heterodyne Reflectometer System

The schematic of three channel heterodyne reflectometer system is shown in Fig. 3. Three Gunn oscillators with fixed frequencies of 78, 72, 65 GHz are used as sources. Power combined microwaves are travelling to/from the LHD using a corrugated waveguide for avoiding the transmission loss. Receiver system is used the super heterodyne detection technique. By using the extraordinary polarized wave, we can measure the combined fluctuation with the electron density and the magnetic field. In Fig. 4 the temporal behaviour of the reflectometer signal of 78 GHz and its power spectrum are shown. After t=1.45s, the fluctuation appears with the frequency of ~ 1 kHz and its doubler. This mode is identified the m/n=2/1 mode by the magnetic probe analysis. The fluctuation of m/n=2/1 mode is expected to excite in the core region. The reflectometric direct core plasma measurement is utilized to understand the configuration of the fluctuation. Another example of the fast phenomenon in the plasma is shown in Fig. 5. In this shot at $t = t_0$ TESPEL [3] injects into the plasma. Just after TESPEL injection, the electron temperature in the core region rises rapidly in response to the edge cooling. This phenomenon can not be interpreted

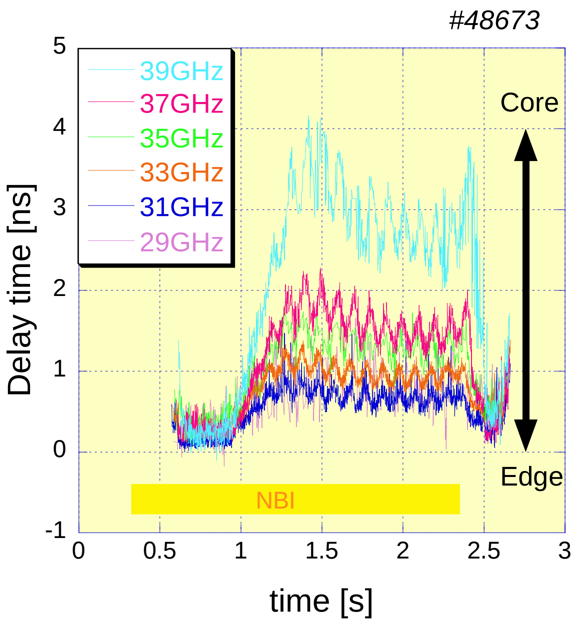

Figure 2 Time evolution of Time-of-flight of six frequency reflected signals

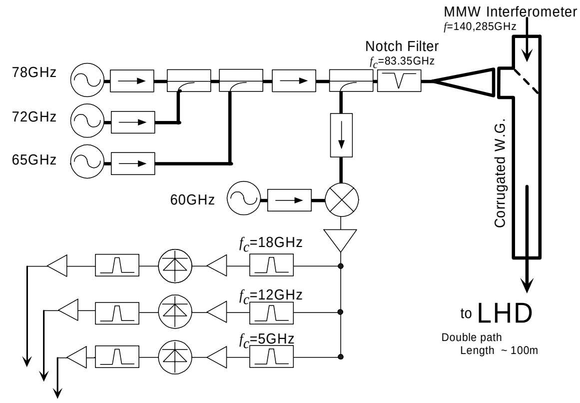

Figure 3 Schematic of three channel fixed frequency CW heterodyne reflectometer

by the conventional transport theory and has not been identified now. At that time in the core region the reduction of the reflectometer signal power is observed. This rapid reduction might trigger the change of the transport. On the other hand in the edge region the decrease is not clear and also low frequency oscillation starts slightly late. The reduction of the reflectometer signal is not caused by the refractive effect in passing. Therefore understanding more detail of this interesting phenomenon, we need to upgrade the reflectometer system and compare with other diagnostics.

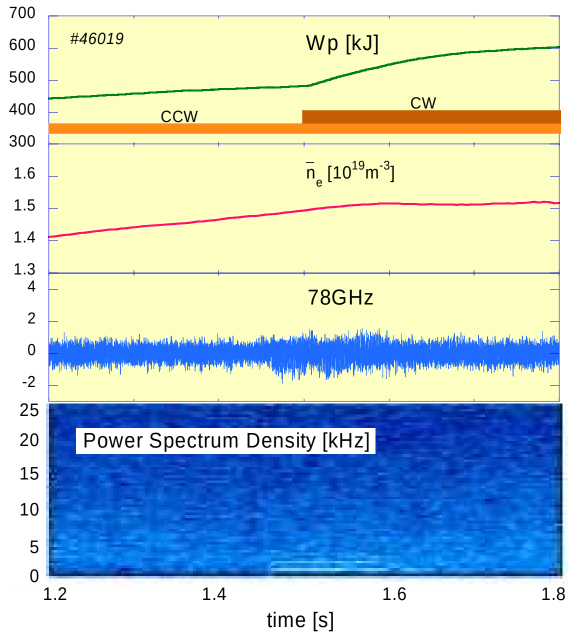

Figure 4 Temporal changes of plasma parameters in low-*n* mode fluctuated discharge

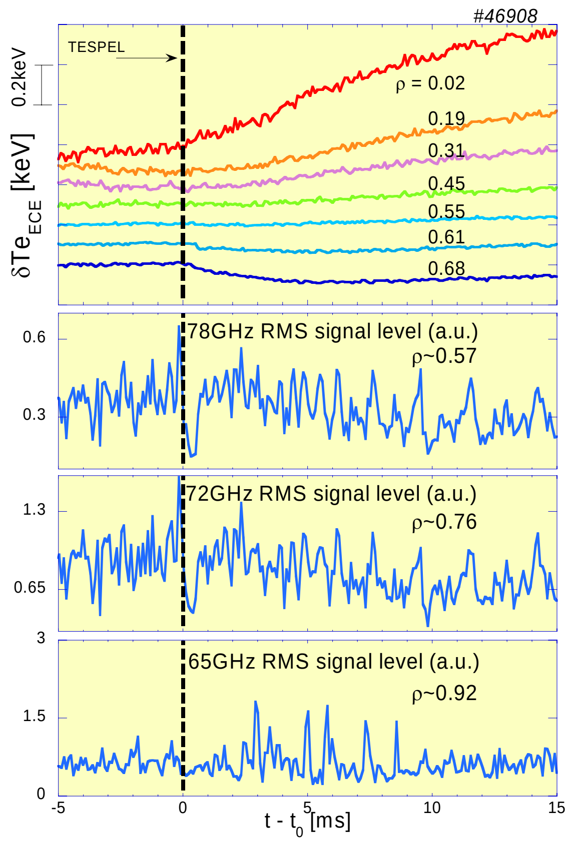

Figure 5 Temporal behaviour of the deference of the electron temperature and each reflectometer signal power

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