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Multichannel ultrashort pulsed radar reflectometer on LHD

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An ultrashort pulsed radar reflectometer with 24 channels in the K_a band and four channels in the X band is used for the electron density profile measurements in the Large Helical Device. An ultrashort pulse has broadband frequency components. However, we have usually utilized the discrete frequency components because we apply a filter bank system in a time-of-flight measurement. To utilize the whole frequency spectrum of the impulse we apply the switching technique of the intermediate frequency signal and the frequency modulation of the local oscillator. A more detailed reconstructed electron density profile, compared to that of the previous system, is obtained by using an Abel inversion method from the profile of the delay time as a function of the probing frequency. © *2006 American Institute of Physics.* [DOI: 10.1063/1.2222168]

I. INTRODUCTION

An ultrashort pulsed radar reflectometer system has been under development in several magnetized fusion plasma devices for the electron density profile measurement.[1–6] Because an ultrashort pulse has broadband frequency components in Fourier space, one ultrashort pulse can take the place of a broadband microwave source. For example when we use a 10 ps full width at half maximum (FWHM) impulse, the usable frequency component is up to 100 GHz. Especially by the terahertz imaging technology the femtosecond impulse had been achieved and applied to time domain spectroscopy.[7,8] In the Large Helical Device (LHD) plasma,[9] we had used a 23 ps FWHM impulse and a six channel K_a band (26–40 GHz) microwave system.[6] For more detailed measurement the probing microwave frequencies are needed in addition to multiple channels and also multiple bands. Usually the ultrashort pulsed radar reflectometer system uses a time-of-flight (TOF) measurement technique. This TOF measurement has an advantage in that ordinary and extraordinary polarizations of each component in the reflected wave can be distinguished by the time lag. On the other hand if we want to add more channel numbers, a large number of TOF measurement electronics such as constant fraction discriminators, time-to-amplitude converters, etc., are needed in the standard way. To overcome this problem we utilize a switching technique for constructing the multichannel system.

In this article, the ultrashort pulsed radar reflectometer system, which is added with multiple channels and multiple bands, is described in Sec. II. The resultant density profile measurement by this reflectometer is presented in Sec. III and then we summarize the present results in Sec. IV.

II. EXPERIMENTAL APPARATUS

The schematic of the ultrashort pulsed radar reflectometer system with the exception of the TOF measurement is shown in Fig. 1. An impulse of −2.2 V, 23 ps FWHM is used as a source. To extract the desired probing range of the frequency, we utilize a 500 mm K_a-band rectangular waveguide for 26–40 GHz microwaves and a 500 mm X-band waveguide for 8–18 GHz. When the impulse is launched into the waveguide, it is transformed to a chirped wave including broad frequency components. The lowest frequency component is determined by the waveguide size. Also higher frequency components than the maximum frequency in the standard frequency band are filtered out by a low pass filter. Therefore we can obtain the microwave of each desired frequency band.

Each obtained chirped microwave is amplified by a power amplifier and launched into the plasma. The incident wave reflects back from the cut-off layers corresponding to each frequency component. The reflected wave is divided and led to the detection stage of each frequency band. X-band frequency components are detected directly through each bandpass filter (BPF). K_a-band components are detected by a superheterodyne detection system. In a mixer the reflected wave is downconverted by the local microwave frequency of around 42 GHz. The output from the mixer is amplified by the intermediate frequency (IF) amplifier (2–18 GHz) and then led to a single-pole double-throw (SPDT) switch. Each IF signal is filtered by 12 BPFs of which the center frequencies are from 3 to 14 GHz. The 12 signals are detected by Schottky barrier diode detectors to obtain the reflected signal pulses. The reflected pulses are amplified by pulse amplifiers and inputted to electro-optical (E/O) converter. Then TOF measurement is carried out using these pulses.[6] The TOF precision is estimated to be around 80 ps.[10]

For the convenient multichannel system we utilize the switching technique. Figure 2 shows the timing diagram of this switching operation. The frequency of the local oscillator is changed from 41.5 to 42.0 GHz with the repetition rate of f_0. A SPDT switch is operated at a $2f_0$ repetition rate. Then the frequency components of the detector output are

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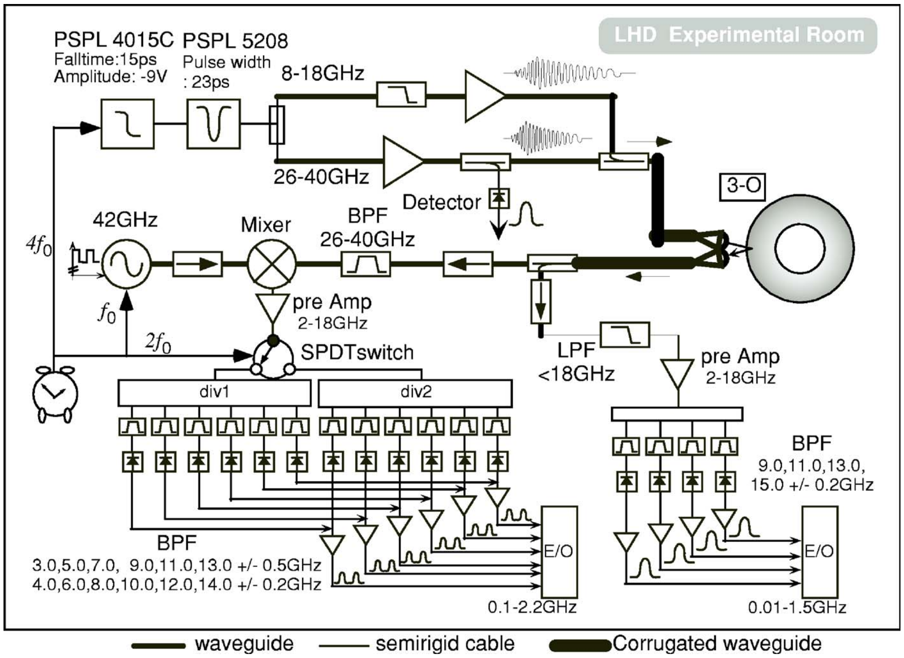

FIG. 1. Schematic of the ultrashort pulsed radar reflectometer.

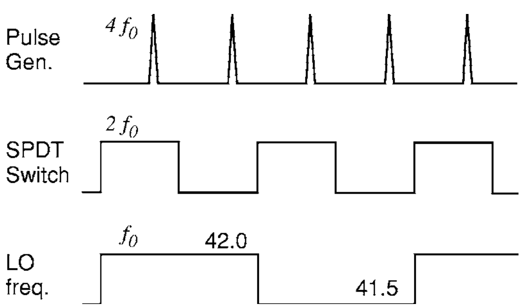

FIG. 2. Timing diagram of the switching operation. The frequency of the local oscillator is changed from 41.5 to 42.0 GHz with the repetition rate of f_0. The SPDT switch is operated with a $2f_0$ repetition rate. Therefore the frequency components of the detector output are changed four times in one operation.

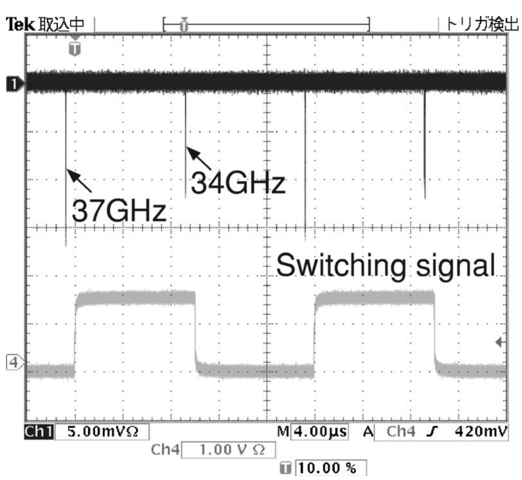

FIG. 3. Example of the frequency switching operation. In this case the local frequency is fixed. The BPF of 37 GHz is located in one six-way divider (divider 1) and the BPF of 34 GHz is located in another one (divider 2). When the switching signal is at a high level, the IF signal leads to divider 2 and only a 34 GHz signal is detected. Both the 37 GHz signal and the 34 GHz signal are collected by the same discriminator.

changed four times in one operation. For example, when the 9 and 10 GHz BPFs are paired, the measurable frequencies are 31.5, 32.0, 32.5, and 33.0 GHz in the incident microwave components. The important advantage is that there is no need for additional TOF measurement electronics. Figure 3 shows an example of frequency switching operation. In this case the

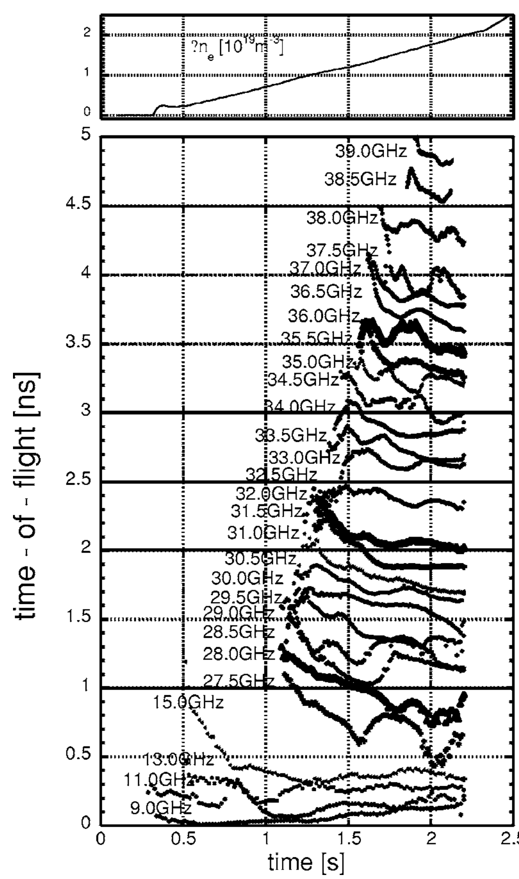

FIG. 4. Time evolution of the averaged electron density and the delay time of each reflected pulse.

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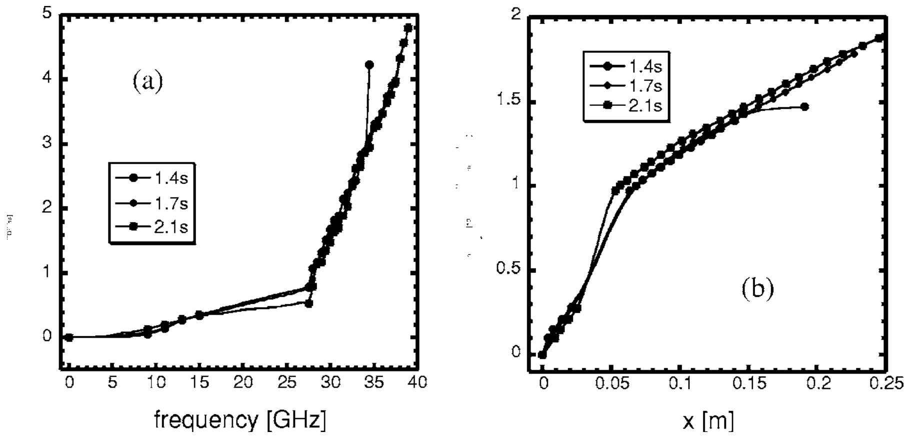

FIG. 5. (a) Profiles of the measured delay time of each channel as a function of the probing frequency. Points are the measured values and lines are from a spline fit. (b) The reconstructed electron density profiles using the Abel inversion method. Here the horizontal axis is defined as the distance from the assumed location of the plasma edge.

local frequency is fixed with 42.0 GHz. Both 5 and 8 GHz BPFs make a pair. The 5 GHz BPF, which has an incident frequency component of 37 GHz, is located after a six-way divider (divider 1) and the 8 GHz BPF, which has an incident frequency component of 34 GHz, is located after another divider (divider 2). When the level of the switching signal is high, the IF signal leads to divider 2 and only the 34 GHz signal is passed. Then the same discriminator collects both the 37 GHz signal and the 34 GHz signal.

III. EXPERIMENTAL RESULTS

Currently the ultrashort pulsed radar reflectometer system operates with the ordinary mode polarization and has 28 channels which are 24 channels of K_a band and 4 channels of X and K_u bands. The experiment is performed with a magnetic field strength of 2.75 T and a magnetic axis position of 3.60 m on LHD. An example of the temporal behaviors of the TOF of each reflected pulse is shown in Fig. 4. Here a moving average technique of ten sampling points each is utilized for equalizing the quality of each channel. The delay time is defined by the traveling time from the plasma edge, the position of which is calculated using the result of *in situ* calibration and a magnetohydrodynamics (MHD) equilibrium calculation, to each cut-off layer. When the corresponding cut-off layer is generated in the plasma, each reflected wave appears in order.

The result of the TOF measurement as a function of the frequency is shown in Fig. 5(a). Because the TOF profile is measured at a discrete and limited number of points, the profile has to be interpolated between the data points. Here the cubic spline interpolation is applied for this aim. Therefore we have calculated the positions of each cut-off layer by the Abel inversion technique and the reconstruction of the electron density profile has been performed as shown in Fig. 5(b). Here the horizontal axis indicates the distance from the assumed plasma edge. As the density ramps up the density gradient seems to increase in the edge region.

IV. SUMMARY AND FUTURE WORKS

We have installed a 28 channel ultrashort pulsed radar reflectometer system on LHD and performed the electron density profile measurement. For a multichannel system the switching technique is utilized for a TOF measurement. Consequently, we have succeeded in measuring the delay time of each probing frequency and reconstructing the electron density profile. In the near future in order to measure a wider plasma region, the system is planned to be upgraded. A shorter time impulse will be used as a source and the expansion of the probing frequency region will be achieved.

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