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Poloidal rotation measurements by Doppler reflectometer in LHD
ドップラー反射計によるＬＨＤプラズマのポロイダル回転速度計測

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In order to measure the poloidal rotation velocity, Doppler reflectometer has been developed in Large Helical Device (LHD). The frequency hopping microwave reflectometer system has been utilized. For tilting an antenna alignment, two types of antenna pair are applied. One has a fixed tilt angle and another has a tunable control. In LHD last experimental campaign we have obtained first Doppler shifted signal and its result is found to consist with the CXRS measured value. At the conference, we will show newly obtained some experimental results and also some problems to be solved.

1. Introduction

Doppler reflectometry is a unique technique combined with the backscattering method and reflectometry. It can measure the perpendicular velocity of electron density fluctuations $v_\perp$, the radial electric field E_r, and the perpendicular wave number spectrum $S(k_\perp)$ in magnetized confinement plasmas [1-8]. Especially, the E_r and its shear are one of the important parameter for the understanding of plasma turbulence and confinement transition phenomena.

The principle of Doppler reflectometry can be explained by the grating reflection model with small sinusoidal corrugation characterized by a wave number $k_\perp$. The signal wave is launched and received under a non-zero tilt angle θ_{tilt} with respect to the normal onto the reflecting layer. This selects perturbations with a finite wave vector component in the reflecting layer $k_\perp$ via microwave scattering into diffraction order -1. This condition determines the probed wave number to $k_\perp$=-2 k_i, where k_i is the local wave vector of the incident beam. For a plasma slab, the Bragg condition $k_i = k_0 \sin(\theta_{tilt})$, where k_0 is the wave number of the microwave in vacuum. By an actuation of θ_{tilt}, the $k_\perp$-spectrum of the density perturbations can be scanned. The unwanted strong 0th order reflection used in conventional reflectometry is at least partially suppressed as it is shifted out of the receiving antenna pattern. For the high-curvature LHD plasma, $k_\perp$=-2 k_i has to be used for determining the perpendicular wave number. To calculate k_i, a 3D beam tracing code LHDGAUSS [9] is employed.

The Doppler shift of the received signal depends on the velocity of the plasma turbulence and on its wave number

$$\omega_D = \mathbf{v}\cdot\mathbf{k} = v_\perp k_\perp + v_\parallel k_\parallel + v_r k_r \quad . \qquad (1)$$

In magnetically confined plasmas it is usually assumed that $k_\perp >> k_\parallel$ and $v_\perp < v_\parallel$, in a way that the second term is negligible with respect to the first one. If in addition the turbulence does not displace itself radially, the third term vanishes and $\omega_D = v_\perp k_\perp$ is obtained. Therefore, the propagation velocity $v_\perp(k_\perp)$ of the selected perturbations can be calculated.

2. Microwave System

The schematic of *ka*-band Doppler reflectometer system is shown in Fig. 1. A microwave synthesizer is used as a source, because its phase noise is low enough to apply the density fluctuation measurements. The utilized frequency range is from 13 to 20 GHz and its output frequency is easily

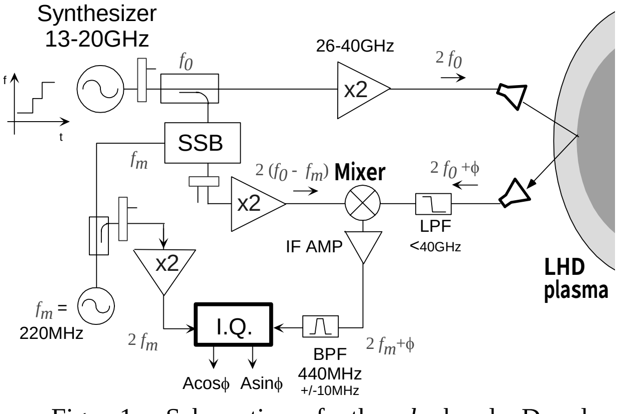

Fig. 1. Schematic of the *ka*-band Doppler reflectometer system.

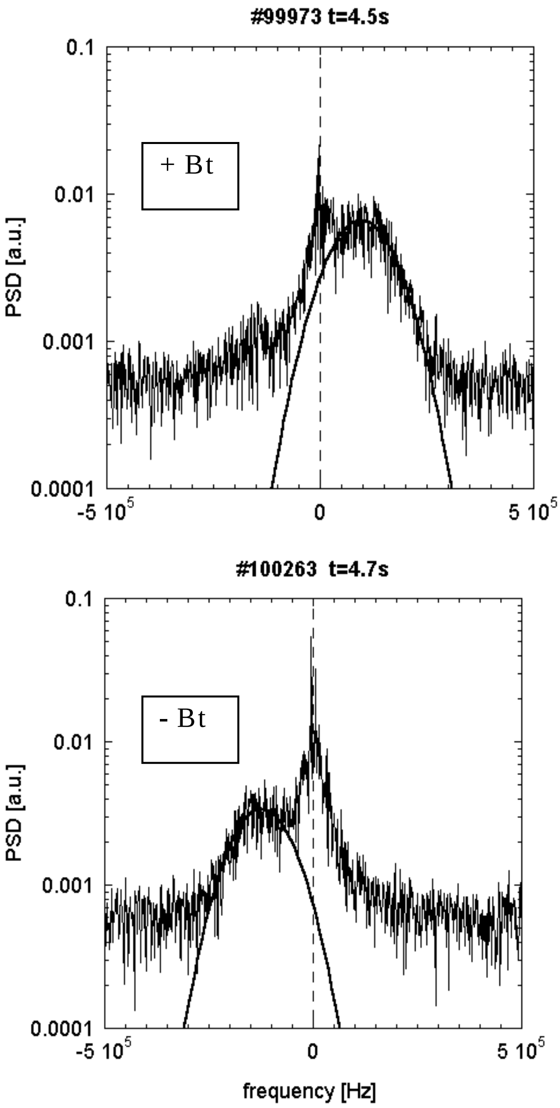

Fig. 2. Complex frequency spectra. Each magnetic field direction is positive (top) and negative (bottom). Solid line shows the Gaussian fitting curve for extracting the Doppler shift.

changed by the external GPIB control. For obtaining the complex frequency components and also the phase fluctuation strength, the single side-band (SSB) modulation is utilized. The source output is split into the probe and the reference signal. The probe signal is doubled followed by an active multiplier to bring the launching frequency up to 26-40 GHz (*ka*-band). The microwave launches from the outboard side along inverse the major radius direction on equatorial plane with slightly tilting angle. The polarization of launching wave is selectable on the ordinary mode or extraordinary mode. The returning wave is received and mixed with reference wave. The SSB modulator driven by 220 MHz (f_m) quartz oscillator shifts the frequency of the reference signal for the heterodyne I-Q detection. The suppression levels of image sidebands are less than -20dB in this system. The intermediate frequency (IF) signal is amplified and filtered by band pass filter (BPF) which the pass frequency component is 440±10 MHz. Then, the IF signal and the modulation signal are led to I-Q detection. The output signals of I-Q demodulator, which are described by $A\cos\phi$ and $A\sin\phi$, are acquired by real-time data acquisition system based on a compact PCI digitizer and the sampling rates are both 1 and 10 MHz during the whole plasma discharge. Also, the part of the IF signal is monitored by the spectrum analyzer for checking the frequency shift.

3. Experimental Results

Here, we show a preliminary experimental result of Doppler reflectometer with tilting angle antenna setup in the LHD plasma. At first, we investigate the direction of the back-scattered wave. When a LHD magnetic field direction is changed, the sign of Doppler shift frequency would be changed. Figure 2 shows complex frequency spectra obtained in two almost same plasma discharges. The Doppler shifted peak moves to the ion diamagnetic direction in both graphs. The estimated each poloidal velocity is about 5.8 (#99973) and 7.2 km/s (#100263). These values are quite reasonable compared with CXRS.

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