# Progress on collective Thomson scattering diagnostic in the Large Helical Device

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## Introduction

It is essential to understand the behavior of charged fusion products and related physics in burning plasmas. One of choices for diagnosing them is to employ an electromagnetic wave and their scattering. The collective Thomson scattering (CTS) technique has been developed in Large Helical Device [1-3]. The CTS diagnostic is required to measure bulk and fast ions in the Large Helical Device (LHD) quantitatively. A high power gyrotron with the frequency of 77 GHz has been equipped for electron cyclotron heating (ECH). The millimeter wave source is utilized as an incident probing beam for CTS diagnostic. For the receiver design and the spectrum analysis, we have calculated by using the CTS spectrum code (CTSsp), based on the scattering form factor introduced by Vahala et al. [4] and Hughes et al. [5].

In terms of the experimental results in the LHD, the measured CTS spectrum responded qualitatively to fast ions produced by neutral beam (NB) injections, and in some cases, the excited wave in plasmas is strongly related to the perpendicular fast ions, and is detected onto CTS spectrum in the lower hybrid wave range [3]. This is considered to be the same phenomena as that observed in Wendelstein 7-AS [6].

To obtain rigorous plasma parameters as a plasma diagnostic tool, the improvements for the mode purity of the probing beam [7], the receiver with their millimeter wave components [8], and the beam alignment for scattering volume have remained. We expect that the behavior of CTS spectrum must be understood clearly with these improvements. The spurious mode suppression from a probing beam enhances the sensitivity of CTS signals. The signal level of spurious radiations interferes with the detection signal, or overloads the detection system, even though it is usually much lower than that of the main radiation of the gyrotron. Therefore as for these spurious radiations, the gyrotron operation parameters have been optimized. But the optimized gyrotron operation degrades the output power, and it is not suitable for EC heating operation. For the correspondence of the various gyrotron operation conditions, we utilize a PIN switch and a notch filter for RF or IF line to reject spurious radiations. We have started fabricating the notch filters for 70 GHz range to reject them in the RF signal line [8].

New fast digitizer system has been installed into the CTS receiver, which is possible to resolve the fine frequency resolution in scattered spectrum. Other major improvement is the installation of fast scanning antenna system. The existing antenna for electron cyclotron heating is modified to search beam overlap.

The CTS technique has been used in JET, W7-AS, TEXTOR, and ASDEX Upgrade [9-11] and designed for ITER [9]. The CTS technique is focused onto fast ion diagnostics. In this case, the scattered radiation from bulk ions is of a several orders of magnitudes lower than that from fast ions, which is comparable to the background electron cyclotron emission (ECE). For the substantial understanding of CTS signals we start to discuss the measurement of bulk ions in this paper.

**Experimental setup and CTS spectrum measurement**

The CTS broad band receiver system is shown in Fig.1. The CTS diagnostic utilizes the ECH transmission lines of the LHD for the probing and the receiving beam detection. The scattered radiation from the cross volume on the probing and the receiving beams is collected by an ECH steering mirror, and passes through a transmission line into the CTS receiver front end. The receiver of a heterodyne system consists of mainly a notch filter for the rejection of a gyrotron stray light, a mixer with a local oscillator, and intermediate frequency (IF) amplifiers and diodes. The diode output is amplified by 100 times at the video amplifiers. The broad band receiver resolves the scattered signal into 32 channels. These signals are stored into the LHD database with a sampling rate of a hundred kHz. The sensitivity of the CTS receiver channels is calibrated by using the radiation from liquid nitrogen or an electron cyclotron emission combined with electron temperatures of non-collective Thomson scattering diagnostic.

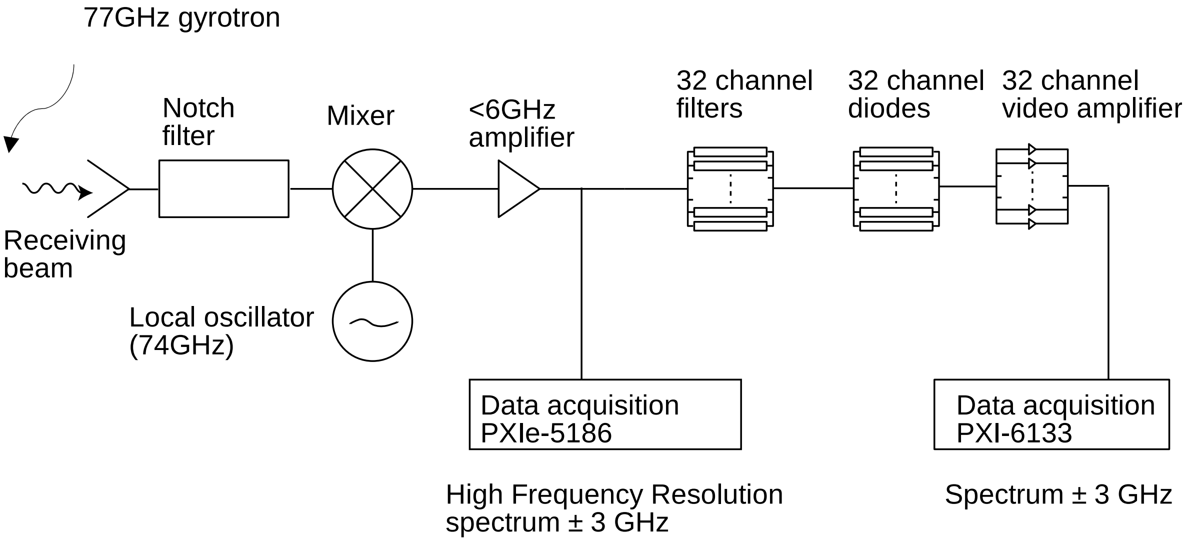


Fig. 1. Schematic diagram of the CTS broad band receiver and the fast digitizer systems. The probing beam of 77GHz gyrotron is used.

The fine spectrum is simultaneously measured by a fast digitizer, PXIe-5186 (National Instruments) data acquisition system, which is divided in the IF line [8]. The fine CTS spectrum after the subtraction of the ECE background spectrum is divided by the ECE background spectrum for the relative calibration. We verified that the calibrated signals for the broad band receiver are agreement with the fine spectrum except fine peak structures.

The probing beam from a 77 GHz gyrotron is modulated with 50 Hz to subtract the background electron cyclotron emission (ECE) from the detected signals. The scattered signals for both ON and OFF timings are averaged over a few ms before and after the trailing edge. Figure 2 shows the CTS spectrum measured by the fast digitizer. The high frequency side of the observed CTS spectrum in the bulk ion region near 77 GHz exists enough for fitting. From the fitting by a Gaussian curve, the center of the bulk CTS spectrum is 70.019 GHz, from which we can estimate the flow velocity. However the present data is difficult to give enough accuracy because of the lack of the data in the low frequency side. The monitored frequency of the gyrotron is 76.985 GHz. The both edges of notch filter are 76.85 GHz for low frequency side and 77.085 GHz, respectively. The lower frequency edge is desired to be shifted to a few MHz higher. The other strong peaks are also detected in the spectrum at less than 75 GHz and more than 79 GHz. These are spurious radiations from the gyrotron existing in the probing beam. These spurious radiations can be suppressed by the optimization of the gyrotron operation [7]. The detail analysis in CTS spectrum still required further for the ion temperature and the flow velocity.

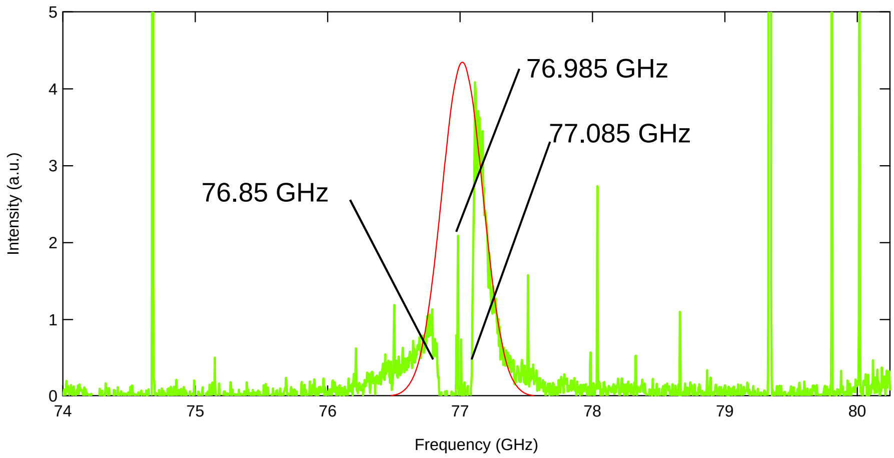


Fig. 2 Fine CTS spectrum measured by the CTS receiver with a fast digitizer for LHD#117125. The fitting curve is plotted in red.

For the quality improvement of the scattered signal, it is important to determine a scattering volume absolutely, where the probing and the receiving beams overlap each other. Before the last LHD experimental campaign, a fast scanning antenna system has been installed for the receiving antenna, which can be swept at about 18 degrees per second. Although the antenna-position alignments was carried out by a laser light relatively, it enables us to realize the in-situ alignment during a discharge. In LHD discharges, we look for the maximum CTS signal corresponding to a maximum beam overlap by scanning the receiving antenna direction to across the fixed probing beam.

After the alignment method, the temporal CTS spectra have been measured and been plotted in Fig. 3. The CTS spectrum for the bulk ion shows the qualitative response according to the increase of the ion temperature measured by Doppler broadening of an x-ray line of Ar XVII. The quantitative analysis is currently in progress.

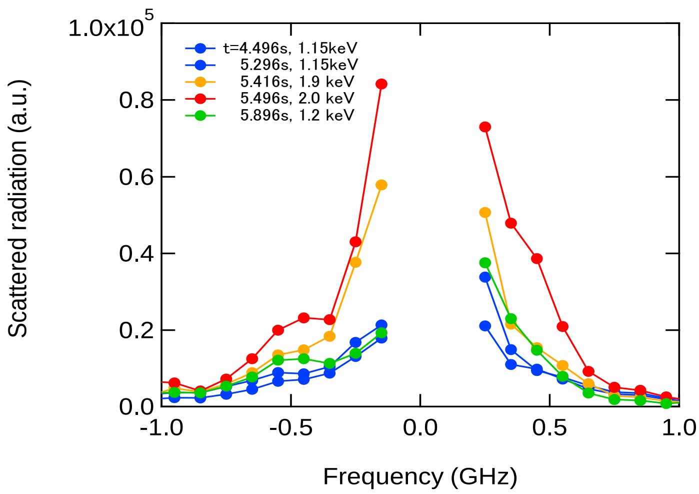


Fig. 3 Time evolution of CTS spectrum in bulk ion region.

## Summary

For the quantitative analysis measured by the CTS diagnostic, we have improved the hardware mentioned in the above. The CTS spectra behave qualitatively, and the quantitative analysis is currently in progress to obtain the ion temperature.


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