# §3. Direct Digitization of Signal of Microwave Frequency Comb Reflectometer in LHD

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Dynamic behavior of magnetized plasma has indicated limitations of a local diffusive picture of transport. Long distance correlation originated by plasma turbulence is considered to be one of the basic processes to produce non-local transport. The emergence of turbulence spreading, an avalanche process related to the self-organized criticality (SOC) models, and formation of macro-scale structures (the long-range modes [1]) are possible candidates to produce the long-distant correlation of turbulence. Observation of such long distance correlation between turbulence at distant locations and associated turbulence dynamics is one of the most challenging problems. We applied the microwave frequency comb technique to the Doppler reflectometry for edge plasma diagnostic [2] and the results made establish a research method of plasma turbulence transport.

Microwave frequency comb Doppler reflectometer is a possible candidate to measure the density and poloidal flow velocity fluctuations with high temporal and spatial resolution. In our system, the output from comb-generator (the repetition frequency of 0.31 GHz) is subsequently doubled followed by a frequency active multiplier in the ka-band (26 - 40 GHz). More than 30 frequency components can be simultaneously launched to the plasma by bistatic conical horn antennas with a lens. The reflected wave signal is down-converted by using a 24.8GHz local oscillator and directly transferred to the digital storage oscilloscope, which has a frequency band of 33 GHz (the sampling frequency is 80 GHz), so the waveform of the reflected signal is detected in the form of digital signal with very high temporal resolution. Doppler frequency for each comb frequency is obtained by using the FFT analysis and thus a multi-channel filter bank is not necessary in our system. This allows us to adjust the comb-frequency spectrum more flexible. Simultaneous multi-point measurement of turbulence is very useful to test the various non-local transport models.

Figure 1 shows a power spectrum of reflected wave neighborhood of a comb-frequency of 1.86 GHz. The O-mode cut-off layer is located at $r/a_{\mathrm{eff}} = 1$, where $a_{\mathrm{eff}}$ is the effective plasma radius. Experimental conditions are as follows: $R_{\mathrm{ax}}$ = 3.6 m, $B_{\mathrm{ax}}$ = 2.75 T, $T_{\mathrm{e0}}$ = 3.2 keV, $n_{\mathrm{e0}}$ = $1.35\times10^{19}$ m$^{-3}$, and NBI heated plasma. The Doppler shift of frequency (of the order of 10 kHz) is clearly demonstrated. The Doppler frequency is evaluated by the moment method quantitatively [3]. In the FFT analysis, the temporal resolution trades off the frequency resolution. We have assessed the accuracy of the Doppler shift and temporal resolution of the Doppler shift evaluation. Figure 2 shows temporal evolutions of the Doppler shift frequency, which depend on a number of data points used in FFT analysis, i.e. temporal resolution. When the temporal resolution is more than 0.01 ms, the similar behavior of the Doppler shift is obtained. However, when the temporal resolution is 0.01 ms, differences between others are observed. From these results, we value the optimum temporal resolution at 0.02 ms. From the temporal evolution of the Doppler shift, we can estimate a fluctuation of poloidal flow velocity.

Advanced digital signal processing techniques (e.g. Hilbert transform and convolution) allow us to observe density and flow velocity fluctuations in the edge region with high signal-to-noise ratio. Our reflectometer could be very useful to detect non-diffusive and non-local transport easily in many experimental devices.

[1] S. Inagaki et al., Phys. Rev. Lett. **107** 115001 (2011).
[2] T. Tokuzawa et. al., Plasma Fusion Res. **9** 1402149 (2014).
[3] G. D. Conway et. al., Plasma Phys. Control. Fusion **47** 1165 (2005)

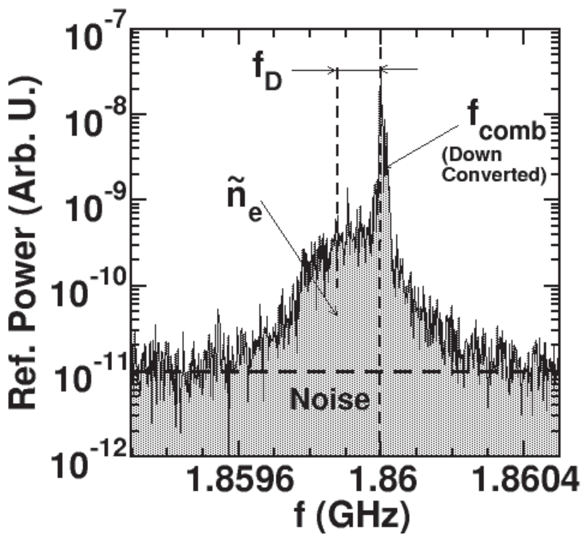


Fig. 1 Typical spectrum of Doppler reflectometer. The original comb frequency is 26.35 GHz.

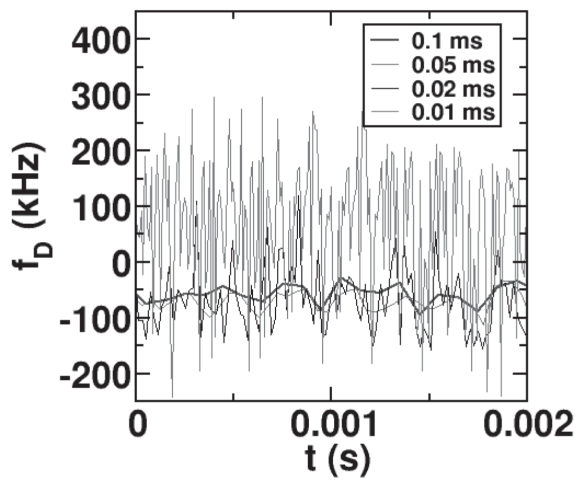


Fig. 2 Time traces of the Doppler frequency for the same comb component as Fig. 1 using the sliding FFT analysis method by changing the window width for FFT analysis.