§15. Development of a Microwave Frequency Comb Reflectometer for Multi-scale Turbulence Measurement

Kasuya, N., Itoh, S.-I., Fujisawa, A., Inagaki, S., Nagashima, Y., Sasaki, M., Lesur, M., Kosuga, Y., Mitsuzono, T., Miwa, Y., Nakanishi, K., Hattori, G., Fukunaga, K., Yamada, T. (Kyushu Univ.), Yagi, M. (JAEA), Fukuyama, A. (Kyoto Univ.), Sugita, S. (Chubu Univ.), Sugama, H., Kobayashi, T., Tokuzawa, T., Ida, K., Tamura, N., Ohdachi, S., Ido, T., Itoh, K., Toda, S., Yamada, H.

It is necessary to deepen our knowledge of plasma turbulence for improving the confinement in fusion plasmas. Nonlinear coupling in multi-scale turbulence is one of the keys in the transport mechanism, and dynamical changes of the mean and fluctuation profiles must be measured with high spatio-temporal resolutions for identifying the mechanism. In this research, development of a new experimental diagnostic for detailed fluctuation measurements is promoted with the integration of theoretical, simulation and experimental approaches. For that purpose, a reflectometer using microwave frequency comb has been developed [1]. Turbulence Diagnostic Simulator (TDS) [2], which is an assembly of simulation codes for numerical diagnostics in magnetically confined plasmas, is used as the platform for the development to accelerate the collaboration between the simulation and experiment. This was the first year of the research planned for three years, and the basis for the identification of multi-scale couplings was established both in the experimental and simulation parts.

The system of a microwave frequency comb reflectometer has been developed. An experimental test has been begun on the PANTA device [3] in Kyushu University, which will be applied to the LHD experiment [1]. The principal of the diagnostic is as follows. The comb signal with the frequency range of 12 - 27 GHz and the frequency interval of 0.5 GHz is injected and reflected in the plasma. Each Fourier component of the microwave has time delay in accordance with its reflected point, so the density profile can be reconstructed from the detected comb signal. The phase of the carrier wave is precisely controlled with respect to the shape of the envelope. The signals are directly transferred to the digital storage oscilloscope (DSO), which has a frequency band of 33 GHz (the sampling frequency is 80 GHz), so the waveforms of the incident and reflected signals are detected in the form of digital signals with high resolution. Our system enables simultaneous monitoring of fluctuation levels at more than 20 distinct spatial locations with high temporal resolution. Figure 1 illustrates the circuit used in the observations. Statistical noise can be eliminated by convoluting microwave pules. The time resolution for constructing the density profile is found to be on the order of 1 μs. Preliminary date has been also obtained in the LHD experiment by using the existing reflectometry system and the DSO. This experimental method is promising for the physics of plasma turbulence and transport.

For the reconstruction of the profiles, it is necessary to carry out a numerical simulation, so the routine to simulate the microwave frequency comb reflectometer has been developed in the TDS. The module of the ray tracing of the RF wave in the integrated simulation code TASK [4] is introduced for the wave analysis for the first step. The original routine is modified to adjust to the cylindrical magnetic field configuration and the incident comb signal for the linear device. Calculation of the ray and the phase delay gives the evaluated output signal in accordance with the plasma density profile. Figure 2 shows an example of the incident and detected waveforms. Different Fourier components have the different reflected points as in Fig. 2 (c), which gives the detected signal as Fig. 2 (b). This simulation gives the insight to experimental observations, and will be extended to analyze both simulation and experimental data in the same routine.

The development of the data analysis method is also important to identify the spatio-temporal structure, so the conditional averaging method has been developed to apply to both experimental [5,6] and simulation data [7]. This method is effective to clarify the characteristic responses of the turbulence, and will be applied to the reflectometory data.

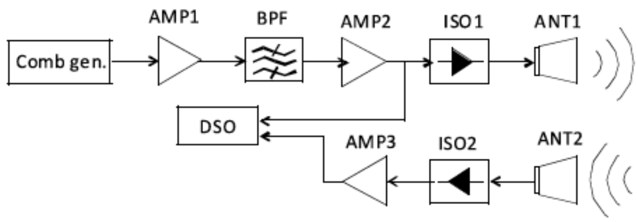

Fig.1: Block diagram of the microwave frequency comb reflectometer.

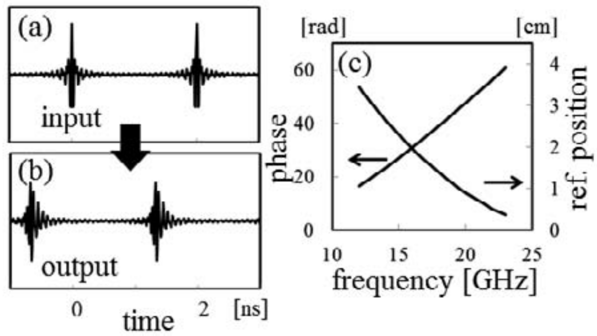

Fig.2: Simulation result of the (a) incident and (b) detected waveforms of the microwave frequency comb reflectometer. The phase delay in (c) gives the detected signal as (b). The incident comb signal has the frequency range of 12 - 27 GHz and the frequency interval of 0.5 GHz in this case.

1) Inagaki, S. et al.: Plasma Fusion Res. **8** (2013) 1201171.
2) Kasuya, N. et al.: Plasma Sci. Tech. **13** (2011) 326.
3) Oldenbürger, S. et al.: Plasma Phys. Control. Fusion **54** (2012) 055002.
4) Fukuyama, A.: http://bpsi.nucleng.kyoto-u.ac.jp/task/.
5) Inagaki, S. et. al.: Nucl. Fusion **53** (2013) 113006.
6) Kobayashi, T. et al.: Phys. Rev. Lett. **111** (2013) 035002.
7) Kasuya, N. et al.: Plasma Fusion Res. **8** (2013) 2403070.