§24. Conditional Averaging Method for Reducing Random Noise in Microwave Frequency Comb Reflectometer

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Microwave frequency comb reflectometer is a possible candidate to measure the density profile and density fluctuations with high temporal and spatial resolution. Thus, wide-band comb reflectometer by using ultra-high speed digital storage oscilloscope has been developed in the LHD and also in PANTA, which is a linear plasma device in Kyushu university. Here we report a new method for reducing random noise in the comb reflectometer in the PANTA. The reduction of noise is a common issue in magnetized plasma diagnostics and thereby the method developed in the PANTA can be applied to the comb reflectometer in LHD.

In the reflectometer, phase delay between an incident wave and a reflected wave is important. Usually, the phase relation is estimated from the power spectrum of the waves. Noise components in the power spectrum therefore will deteriorate the accuracy of estimation of the phase relation. Ensemble averaging is one of the conventional methods for reducing the random noise. While the lock-in technique increases the signal-to-noise ratio significantly. The repetition period in the frequency comb is well stabilized and the advantage of the ultra-high speed digitizing of our system [1] allows us to adapt a new lock-in technique [2].

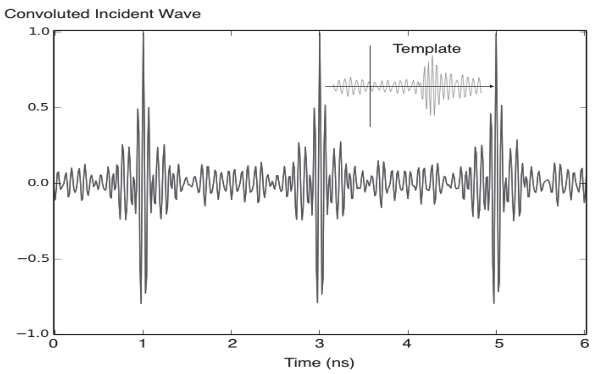

Fig. 1 Cross-correlation function between the template and raw signal. The initial template is also shown.

At the first, a template signal (a typical waveform in a periodical signal) is required in this technique. An initial template of the incident wave is obtained by using the inverse Fourier transform of ensemble averaged power spectrum. Next, periodical change in the incident wave is evaluated by calculating cross-correlation between the initial template (for one cycle) and raw signal of incident wave. Figure 1 shows the cross-correlation function (convolution integration between the template and raw signal). When a pattern similar to the initial template is found in the raw signal, mutual correlation becomes large. The frequency comb is very stable and thus the peak of mutual correlation is more than 0.9 and very sharp. Peaks are used as a basis of timing of frequency comb signal and thus this is called as trigger function. Based on each trigger, the incident wave is extracted and averaged for every 1 μs. Then new template is obtained. Usually iteration, i.e. recalculation of trigger function by using new template, is required to obtain a converged final template. In this case, the frequency comb is very stable and thus the initial template is found to be sufficient to obtain the trigger function. Finally, template of the incident wave and reflected wave signals are obtained as shown in Fig. 2. Power spectra are calculated from these signals.

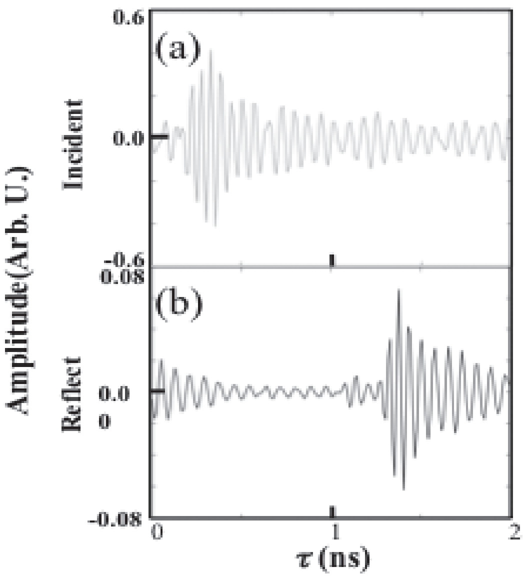

Fig. 2 Conditional averaged (a) incident wave and (b) reflected wave.

Figure 3 shows power spectrums of reflected wave obtained by two different methods (conditional averaging and usual ensemble averaging). The noise levels are evaluated from spectrums in the region of f <12 GHz and 26 < f < 33 GHz (cut-off frequency of oscilloscope) because no explicit external signal exists in this region. There are a few differences between spectrums in the region of 12-26 GHz (comb signal) and noise level is significantly reduced (~1/100) in the conditional averaging technique.

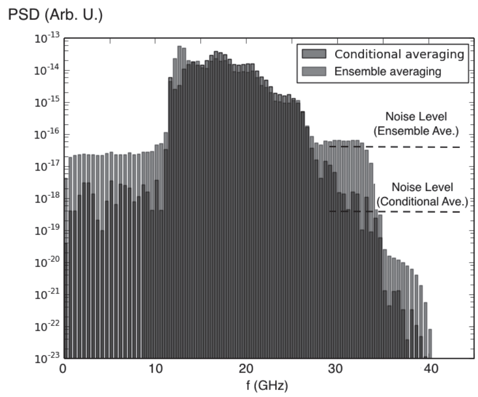

Fig. 3 Power spectrum of the reflect wave.

[1] S. Inagaki et al., Plasma Fusion Res. **9** 1201016 (2014).
[2] S. Inagaki et al., Plasma Fusion Res. **8** 1201171 (2013).