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Application of Microwave Frequency Comb for Plasma Diagnostics
プラズマ計測におけるマイクロ波周波数コムの活用

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Here we report a new microwave frequency comb reflectometer for measuring the density profile as a continuous function of radius with high temporal resolution. Direct simultaneous waveform detection with a ultra fast digital storage oscilloscope allows us to perform phase-sensitive convolution analysis of the reflected waves: convolution of pulses can eliminate statistical noise. The fundamental functions of the reflectometer are checked by a test-bench experiment. Initial results of plasma experiments on PANTA and the first attempt at reconstructing of the density profile are demonstrated.

1. Introduction

A statistical interpretation of plasma turbulence and transport has been developed [1]. For example, inhomogeneities in the mean plasma parameter are neither stationary nor smooth, but large-amplitude corrugations in the profile evolve dynamically [2–4]. To observe such corrugations, which can be essential to the dynamical response of turbulent plasmas, it is necessary to simultaneously measure the mean profile and its fluctuations precisely.

Microwave frequency comb technique is accelerated over the past few years and this technique is applied to the reflectometry for core plasma diagnostic in fusion plasma [5]. Microwave frequency comb reflectometer is a possible candidate to measure the density profile as a continuous function of radius with high temporal resolution [6]. For this challenging problem, we developed a new microwave frequency comb reflectometer. Experimental tests are carried out on the PANTA device.

2. Microwave frequency comb reflectometer

Figure 1 illustrates the circuit of our reflectometer. The output from com-generator (the repetition frequency of 0.5 GHz) is filtered by the

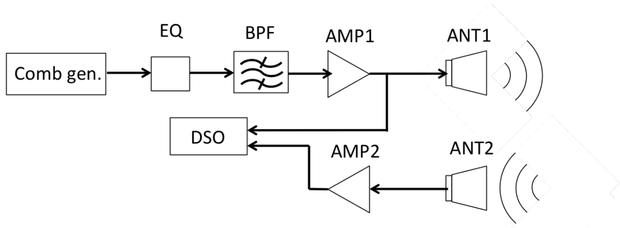

Fig. 1 Block diagram of the system.

dual-band (Ku- and K-band, i.e. 12-26 GHz) broad band-pass-filter (BPF), where the equalizer (EQ) is used to obtain the flat level of amplitude. The band-passed output is linearly amplified (AMP) and fed to the dual-band rectangular horn antenna (ANT) by the coaxial cable. The incident and reflected wave signals are directly transferred to the digital storage oscilloscope (DSO), which has a frequency band of 33/50 GHz (the sampling frequency is 80/160 GHz), so the waveforms of the incident and reflected signals are detected in the form of digital signals with very high temporal resolution. The O-mode cut-off densities of our system are in range of $1.8\text{-}8.4\times10^{18}$ m^{-3}, which can cover the typical density profile of the PANTA experiment. And thus our system enables simultaneous monitoring of density fluctuation levels at 29 distinct spatial locations with very high temporal resolution (eight channels in previous work [8]).

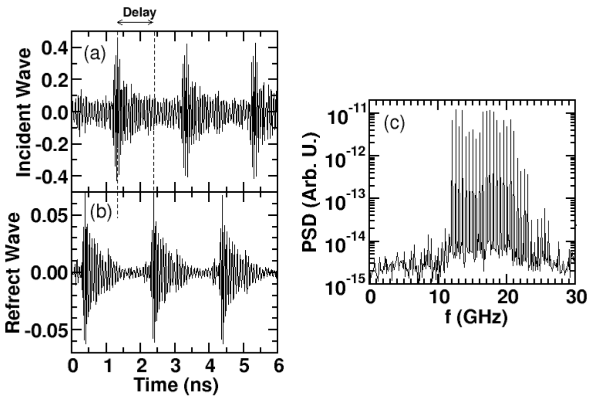

Fig. 2 Typical incident- (a) and reflect-microwave (b) and the power spectrum density of the incident wave (c).

3. Test bench experiment

The microwave frequency comb reflectometer is currently being tested. The microwave is launched aiming at the planer metal (SUS) reflector 10-20 cm away from the antenna. Figures 2(a)(b) show the typical incident and reflect microwave waveform and power spectrum of the incident wave. The repetition period is 2 ns (corresponding to a repetition frequency of 0.5 GHz). The delay between the envelope of the incident- and reflect-wave corresponds to the distance between the antenna and reflector. In a single frequency reflectometric measurement the phase of the microwave repeats itself at distance intervals equal to the wavelength. Thus, a phase delay $\delta\theta$ due to optical path difference between incident- and reflect-wave gives the same reflectometric measurement as ($2n\pi+ \delta\theta$), where n is an integer. This "fringe shift problem" makes the distance measurement difficult. One of the techniques for determining n is performing a reflectometric measurement at two or more frequency and comparing the phases for the different frequencies. In this case, the equivalent wavelength is defined as $\lambda_{eq} = (\lambda_1-\lambda_2)/\lambda_1\lambda_2$. In our case, this technique can be applied. Figure 3 shows frequency dependence of phase difference between incident- and reflect-wave. The slope of this plot gives the distance between the antenna and reflector. In this case, distance of 20 cm is correctly obtained. An estimation of the distance from the delay between envelopes is equivalent to what is done in the multi-frequency reflectometry. In our case, λ_{eq} becomes 0.6 m, which is longer than a diameter of the vacuum vessel of PANTA (=0.535 m).

If the target is switched from metal reflector to plasma, the dependence of phase delay shown in Fig. 3 is modified. From this modification the electron density profile can be estimated as a continuous function of radius. The conditional averaging technique is very useful to detect the delay time of the envelopes and frequency dependence of phase delay precisely. Averaging over 500 periods (1 period = 1/0.5 GHz = 2 ns) can suppress the 10 % noise in amplitude. The temporal resolution is evaluated to be 1 μs in this case.

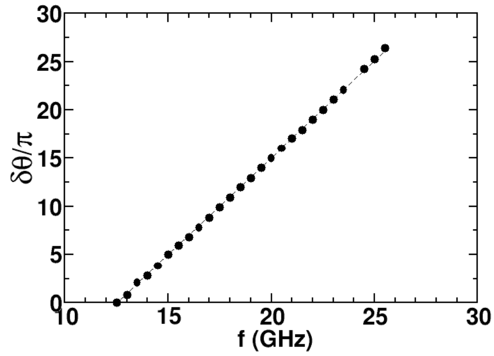

Fig. 3 Observed frequency dependence of the phase difference

5. Summary

We have developed a method to reconstruct the density profile as a continuous function of radius with a temporal resolution of 1 μs by using of a new microwave frequency comb reflectometer. This experimental method is very promising for developing the physics of plasma turbulence and transport.

Acknowledgments

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[1] S.-I. Itoh, J. Plasma Fusion Res. **86** (2010) 334.

[2] T. S. Hahm, et al., Plasma Phys. Control. Fusion **46** A323 (2004).

[3] X. Garbet et al., Phys. Plasmas **14** 122305 (2007).

[4] S. Sugita et. al., Plasma Phys. Control. Fusion **54** 125001 (2012).

[5] T. Tokuzawa et. al., Plasma Fusion Res. **9** (2014) in printing

[6] S. Inagaki et. al., Plasma Fusion Res. **8** (2013) 1201171