Application of Microwave Frequency Comb for Plasma Reflectometry

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Turbulence transport in magnetized plasmas is considered to be non-diffusive and thus plasma turbulence can generate large-amplitude corrugations in the profile which evolve dynamically [1,2]. In addition, the ballistic propagation of turbulence front is involved in such fine structure formation through an avalanche process related to the self-organized criticality (SOC) models [3, 4]. Observation of such corrugations and associated turbulence dynamics is one of the most challenging problems. Microwave refrectometry is now considered to be very useful tool to observe density profile and also density fluctuations. Thus a multi-channel reflectometer is the most promising to observe the fine structures and their dynamic behaviors simultaneously. We thus applied the microwave frequency comb technique to the reflectometry for core plasma diagnostic [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]. Here we report an initial experimental result measured with a new microwave frequency comb reflectometer in a linear device.

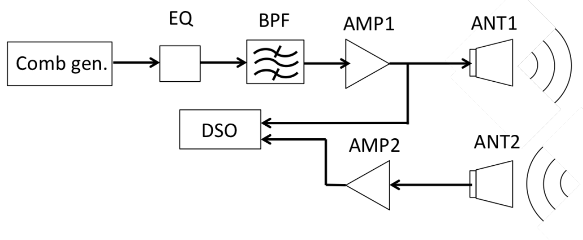

Fig. 1 Block diagram of the system.

Figure 1 shows a block diagram of the frequency comb reflectometer. In our system, the output from comb-generator (the repetition frequency of 0.5 GHz) is filtered by the dual-band (Ku- and K-band, i.e. 12-26 GHz) broad band-pass-filter, where the equalizer is used to obtain the flat level of output power. The band-passed output is linearly amplified and fed to the dual-band rectangular horn antenna by the coaxial cable. Figure 2 shows the typical power spectrum of the incident wave. A lot of frequency components (29 distinct peaks) are shown.

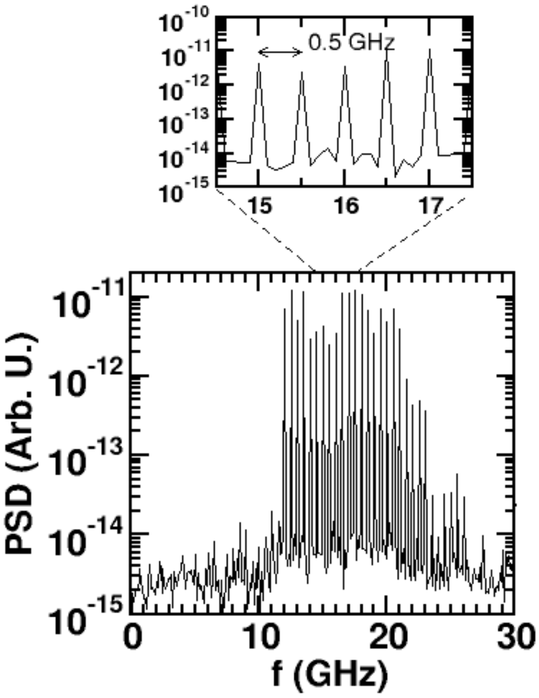

Fig. 2 Power spectrum density of output of comb generator.

In previous work [7], only eight peaks are used because of many micro-wave components, e.g. filter, power divider and mixer are needed. In this study, the incident and reflected wave signals are directly transferred to the digital storage oscilloscope, 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. Figure 3 shows the typical incident and reflect microwave waveform.

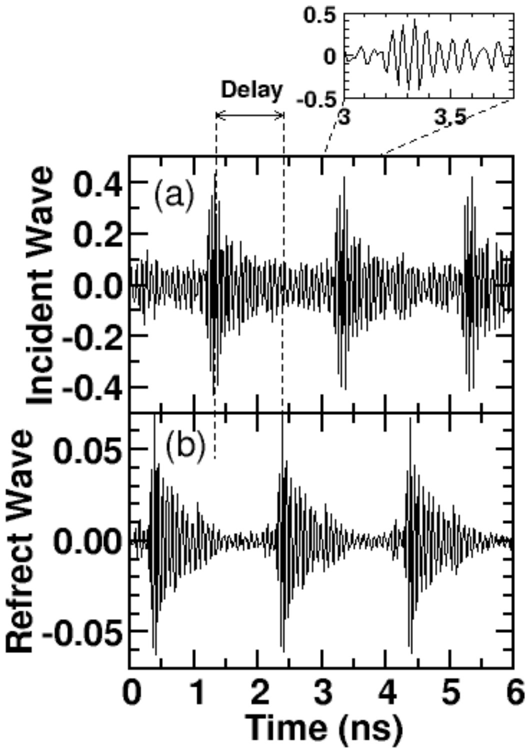

Fig. 3 Typical instantaneous incident- (a) and reflect- microwave (b) by direct signal acquisition

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. A phase delay $\delta\theta$ due to optical path difference between incident- and reflect-wave is obtained by using of the FFT analysis. Advanced digital signal processing techniques (e.g. Hilbert transform and convolution) allow us to apply ideal filters and improve the signal-to-noise-ratio. For example, the conditional averaging technique 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.

The microwave frequency comb reflectometer has been tested. The microwave is launched aiming at the planer metal (SUS) reflector 100-200 mm away from the antenna. The sensitivity of the phase difference is found to be 1.4 rad/mm. The target was switched from metal reflector to a linear magnetized plasma created by radio frequency wave (3 kW/7 MHz) in the PANTA device. The cylindrical vacuum vessel of PANTA has a diameter of 450 mm and a length of 4 m. Operational parameters are as follows; plasma diameter of about 120 mm, axial magnetic field of 0.09 T, and filling argon pressure of 3 mTorr. Typical central density and electron temperature are 1.0×10^{-19} m^{-3} and 3 eV, respectively. Probe measurement suggested that the electron density gradient is steep in the radius of r = 30-40 mm, and produces drift wave instability which propagates in the electron diamagnetic direction. The electron density fluctuation was also measured with a 64-channel poloidal probe array and evaluated from the ion saturation current fluctuations. 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 "ambiguity problem" makes the distance measurement difficult. One of the techniques for determining *n* is using two receivers. The simultaneous equation from two receiver can be solved by using integer linear programming. we reconstructed a density profile from the frequency comb reflectometer measurement and compared with the probe measurement. Both are consistent however the error bars of the frequency comb reflectometer measurement are large at this time. One of the candidates of large error bar is reflection from vacuum vessel. Recently, a new data processing technique based on time-frequency tomographic representation is developed [8]. It allows us to separate multiple reflection components. This technique will be applied on our system. Experimental tests are also carried out on toroidal devices (e.g. LHD).

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