§22. Developments of Advanced Microwave Diagnostics for Future Fusion Plasma Reactor Approaching by Time-Domain Spectroscopy Technique

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The electron density profile is one of the important parameters for controlling the operation of the future fusion plasma reactor. Especially, a Heliotron-type DEMO reactor (FFHR-d1)[1)] will operate on quite high density on the order of 10^{21-22} m^{-3}. In such high-density steady-state fusion plasma and under strong radioactive condition, robust diagnostic techniques are expected to measure the electron density profile and its fluctuation. One of the possible diagnostics is the radar technique using the electromagnetic waves. One of the big advantages is that it needs a small access for the measurements, since the accessibility is one of the challenging issues in fusion reactor.

For measurement of high-dense plasma by a radar technique, the desired frequencies reach the terahertz regime (0.1–10 THz). There is no example to apply the high temperature plasma in the world. It is completely new challenge. Therefore, we need to develop a wide frequency range diagnostics from microwave to THz wave. In this sense, a time-domain spectroscopy (TDS) has several attractive features[2)]. When a pulsed microwave - THz wave is used for burning fusion plasma, we can obtain several plasma parameters such as electron density profile, line-integrated density, magnetic field strength, etc. [3)]

For the demonstration of this idea in high temperature plasmas applying in GAMMA-10 central cell, we prepare the microwave time-domain spectroscopy. In this year, for applying the high temporal response, new TDS technique is developed and tested. Because the conventional TDS technique needs the variable delay line for sampling data acquisition, the short time measurement is difficult only in single shot measurement. Instead of mechanical variable delay line, asynchronous optical sampling (ASOPS) technique is applied shown in Fig. 1. Two sources are operated with different frequency (f1, f2). One output pulse launches to the plasma as a probe signal and another one is used for reference signal. Then, both signals are led to the detector. At the detector, the phase of both pulses is different caused by the plasma itself, which is the essential measurement quantity, and also the additional delay. This delay is controlled by the time sequence shown in Fig. 2. The time delay between both pulse operation times is changing according to the multiple of difference of time period ($\Delta t = |1/f1-1/f2|$). The maximum time window is equal to $1/\Delta f$ by the controlled operational clock. Here, $\Delta f = f1-f2$. The example of the detector output is shown in Fig. 3. Here, the operation condition is that f1 is 100 kHz and f2 is 99 kHz. The original pulse width of the generator output is around 1ns. In Fig. 3 the observed pulse width is 0.1ms and the time expansion is success by the sampling acquisition. The taking time of single measurement is only 1 ms and it is enough to the demanding temporal resolution. Therefore, this modified diagnostic system will apply near future for developing the fusion plasma experiment.

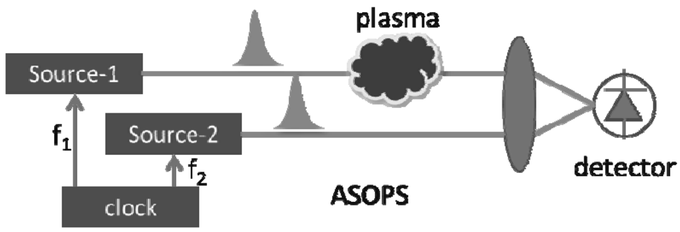

Fig. 1. Schematic drawing of ASOPS technique concept.

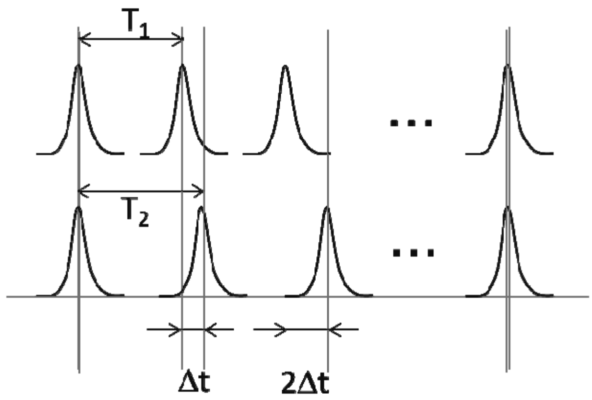

Fig. 2. Operation time sequence of two sources.

1) A. Sagara et al., Rev. Fusion Eng. Des. **87**, 594 (2012).
2) M. Hangyo, et al., PFR, **2**, S1020 (2007).
3) T. Tokuzawa et al., PFR, **8**, 2402063 (2013).

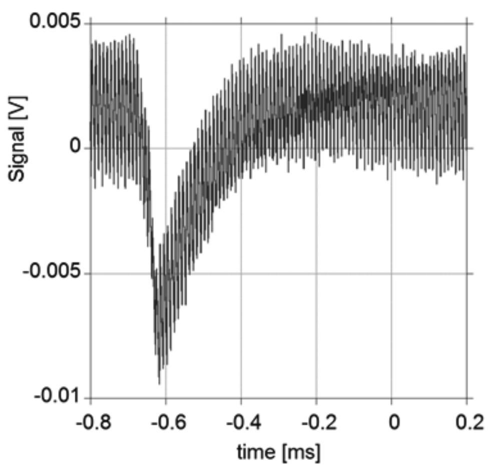

Fig. 3. Example of temporal waveform of detector output