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Enhanced Measurement of MHD and Turbulence Dynamics Through Electron Cyclotron Emission Imaging Diagnostics on KSTAR

Jaehyun Lee[1], Minho Kim[1], Dong-Kwon Kim[1,2], Gunsu S. Yun[2], Dongjae Lee[1], Minwoo Kim[1]
[1] Korea Institute of Fusion Energy, [2] Pohang University of Science and Technology
e-mail (speaker): jaehyun@kfe.re.kr

A novel diagnostic approach employing broadband electron cyclotron emission (ECE) measurements has been developed to probe the intricate structure and dynamics of small-scale turbulent fluctuations in KSTAR plasmas. This method combines a recently constructed high-speed digitizing system (Fig. 1) with a newly designed ECE imaging (ECEI) optical system (Fig. 2).
The ECEI detection system captures 2nd harmonic extraordinary mode (X-mode) ECE emissions within the 75-110 GHz (W-band) range, typically observed in KSTAR discharges. Given the challenges associated with signal processing at such high frequencies, the ECE signal is down-converted to lower frequencies prior to further analysis.

The ECEI heterodyne mixer combines the plasma RF signal with a coherent local oscillator (LO) signal to produce a beat signal at an intermediate frequency (IF). This linear mixing process enables the recovery of the RF signal's phase and ensures that the output IF power is directly proportional to the RF signal power. The heterodyne mixer boasts a broadband range (DC-20 GHz) and exhibits a 3 dB loss bandwidth.

The high-speed broadband digitizer features an impressive analog bandwidth of 6.5 GHz per channel, along with a sampling rate of 16 GSa/s. This advanced digitizer enhances radial resolution and extends measurement capabilities. With a storage capacity of up to 52 Gpts and 256 GB of acquisition memory, data can be retained for approximately 1.5 seconds, facilitating measurements of irregular or prolonged observations.

Traditionally, ECE radiometers or imaging diagnostics offer fixed spatial and temporal resolutions due to limitations imposed by analog electronics with fixed IF and video bandwidths. However, the KSTAR broadband ECE measurement system, leveraging high-speed digitization, enables the independent generation of local electron temperature fluctuation data through digitized signals and digital filtering. This flexible approach allows for the arbitrary adjustment of IF and video bandwidths, thereby optimizing spatial and temporal resolutions for investigating turbulence structure and dynamics. By tailoring resolutions to specific physical targets, external noise impacts are minimized, enabling focused examination of physical phenomena [1, 2].

The newly designed ECEI optical system in KSTAR provides local electron temperature fluctuation information with a spatial resolution of 1-2 cm in both poloidal and toroidal directions. The ECEI optics designed for the H-port feature a spatial resolution configuration of 2 (toroidal) × 12 (vertical) × 8 (radial) channels, and the high-speed digitizer subsystem has been extended to two toroidally adjacent views [3].

By correlating signals from various emission volumes, the system is expected to significantly enhance the analysis of turbulence characteristics by averaging out thermal noise in the ECE signal. The increased analog bandwidth provided by the high-speed digitizer reduces the lower limit of ECE sensitivity beyond the 600 MHz bandwidth used by the conventional ECEI system. The new H-port ECEI system's design and detection system adopt the Cooke triplet configuration of collection optics, allowing for adjustable focus positions and vertical zoom. These optics were designed using Code V software, and laboratory test results showed a close match with simulation results.

In conclusion, the broadband ECE measurement system, implemented with the newly designed high-resolution ECEI optics and the high-speed digitizing system (10 GSa/s), will be used in future KSTAR campaigns to provide precise measurement data for understanding turbulence behavior in plasmas. This advancement is expected to significantly enhance the study of plasma turbulence structure and dynamics, providing crucial insights for solving many challenging problems in plasma physics.

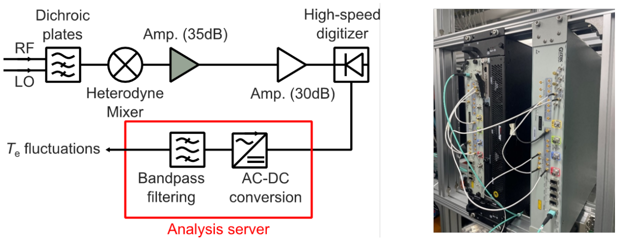

Figure 1. Block diagram of broadband ECE measurement (left), high-speed digitizers for broadband ECE measurement (right).

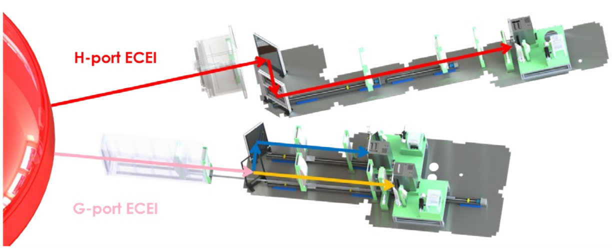

Figure 2. Configuration of the new KSTAR ECEI optical system.

References
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