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# Comparative Study of Ion and Electron saturation Currents for Density Fluctuation Measurements in Linear Magnetized Plasmas

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The characterization of plasma turbulence is critical for progress in fields such as magnetic confinement fusion, where turbulent transport is a primary driver of anomalous particle and energy losses. Langmuir probes are a foundational diagnostic for these studies, with fluctuations in the ion saturation current ($I_{is}$) traditionally serving as a proxy for plasma density fluctuations. The use of the electron saturation current ($I_{es}$) for this purpose is far less common. However, the significantly greater mobility of electrons compared to ions suggests that $I_{es}$ measurements may offer enhanced sensitivity to higher-frequency phenomena. Recent upgrades to experimental devices PANTA (Plasma Assembly for Nonlinear Turbulence Analysis), which allow for greater control over plasma radial profiles, necessitate a thorough re-evaluation of our fundamental diagnostic techniques [1].

This study, conducted in the PANTA linear magnetized plasma device, presents a direct, comparative analysis of $I_{is}$ and $I_{es}$ for the characterization of low-frequency fluctuations ($f$ < 20 kHz) to validate and understand the capabilities of $I_{es}$ based measurements.

To facilitate a direct comparison and minimize shot-to-shot variability, a novel square-wave bias was applied to two Langmuir probes mounted on a rotating manipulator. This technique allowed for the quasi-simultaneous measurement of both $I_{is}$ and $I_{es}$ within a single plasma discharge, ensuring that both currents were measured under identical plasma conditions. A rotating probe assembly was utilized to measure the phase difference of fluctuations between the probes at various angles, enabling the calculation of the waves' azimuthal and axial wavevectors.

Figure 1 shows preliminary results comparing the power spectra derived from $I_{es}$ and $I_{is}$. The overall power of the $I_{es}$ signal is higher than that of the $I_{is}$ signal, particularly at lower frequencies (below ~5 kHz) and higher frequencies (above 10 kHz). Coherent modes, with prominent peaks around 3~4 kHz, appear significantly enhanced in the $I_{es}$ spectra, while the two signals show closer agreement in the intermediate 5-10 kHz range. This general trend supports the hypothesis that higher electron mobility enhances the response to oscillations. Furthermore, the technique of inferring wavevectors from phase-shift analysis yielded more reliable results when using $I_{es}$ signals, particularly at the plasma edge where the $I_{is}$ signal-to-noise ratio diminishes.

However, the most significant finding of this work is a fundamental, unresolved discrepancy. The azimuthal wavelengths ($\lambda_\theta$) calculated from the $I_{es}$ data do not agree with those calculated from the $I_{is}$ data. This result indicates that while $I_{es}$ is not only a valid alternative but, in certain regimes, a superior diagnostic tool for fluctuation analysis, its use simultaneously uncovers a new scientific question regarding the different ways ions and electrons are observed by probes. This inconsistency points to the need for further investigation into the complex particle-sheath interactions that may be responsible [2].

Future work will focus on two primary areas. First, we will conduct experiments using a new probe to investigate the origin of this discrepancy. Second, we will focus on leveraging the new source in the PANTA device to systematically vary the plasma diameter and its gradients, thereby studying the dependence of plasma turbulence on these controllable parameters using the validated $I_{es}$ technique.

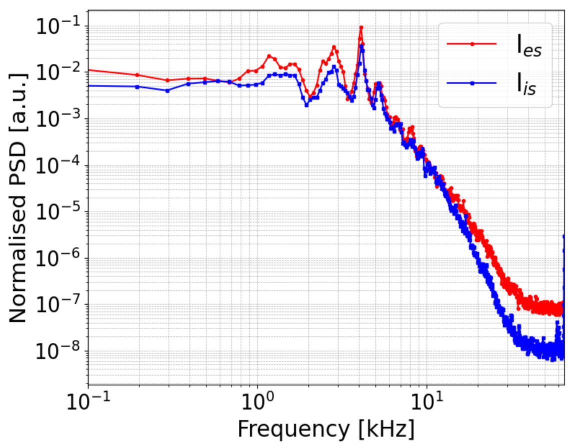


Figure 1. Comparison of normalized power spectra densities of electron and ion saturation current at $r$ = 2.5 cm.

References

[1] C. Moon, J. Plasma Fusion Res., Vol. **10**, p. 419 (2024).

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