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A high-k RF scattering diagnostic for measuring binormal wavenumber electron scale turbulence on MAST-U

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Plasma turbulence plays a key role in determining the spatial-temporal evolution of plasmas in astrophysical, geophysical and laboratory contexts. In particular, turbulence on disparate spatial and temporal scales limits the level of confinement achievable in magnetic confinement fusion experiments and therefore limits the viability of sustainable fusion power. MAST-U is a well-equipped experimental facility having instruments to measure ion-scale turbulence and electron scale turbulence at the plasma edge. However, measurement of turbulence at electron scales in the core is problematic, especially in H mode. This gap in measurement capability has provided the motivation to develop a high-k microwave scattering diagnostic for MAST-U. The turbulence is expected to be most significant in the binormal direction with scale ranges expected of order $k_{\perp e}$ ˜ 0.1 -> 0.4 (where k_{perp} is the binormal turbulence wavenumber and ρ_e the electron gyroradius) in the confinement region of the core plasma (0.5 < r/a < 1). We therefore propose a binormal high-k scattering diagnostic operating with near-perpendicular incidence to the magnetic field through the scattering region.
In this paper, the results of Gaussian wave optics and beam-tracing calculations [1] are presented that demonstrate the predicted spatial and wavenumber resolution of the diagnostic along with the sensitivity of the measurement, assuming a probe beam crossing close to the diameter of the MAST-U vessel in the equatorial mid-plane. The analysis considers the variation of magnetic pitch angle ($\alpha = tan^{-1}(B_\theta/B_\phi)$) as a function of plasma radius and its effect on the instrument selectivity function $F(r)$ as a function of scattering location and $k_\perp \rho_e$. The system we propose will operate in the collective scattering regime governed by the Bragg condition at a frequency close to 350GHz to maintain adequate $k_\perp \rho_e$ resolution over the range of interest whilst minimising beam refraction and maximising the detected signal to noise ratio. We conducted beam-tracing calculations [1] of the primary and scattered rays for a representative high-beta MAST-U equilibrium (results presented in figure 1). These were computed for the 3 scattering coordinates of 1.0m, 1.14m and 1.24m in major radius. In each case, we defined 4 equally spaced scattered beams up to a maximum scattering angle limited by a proposed 290mm x 250mm elliptical receiving window aperture centred 0.14m below the midplane. For a position midway between the magnetic axis and the pedestal (R_{scatt} = 1.14m) this gives a maximum measurable $k_\perp \rho_e$ of ˜0.33.
Using the $k_\perp$ data for each of the scattered components from the beam tracing simulations, we conducted an analysis of the instrument selectivity function using a methodology similar to that presented by Mazzucato et al. [2, 3]. We obtained a minimum localisation of 0.06m for a $k_\perp \rho_e$ of ˜0.33 at R_{scatt} = 1.14m. Assuming a source power of 100mW, 9dB of detection loss and a detector noise bandwidth of 10MHz this corresponds to a minimum signal to noise power ratio of 16. This can be improved further via narrowing of the detection bandwidth or upgrade of the transmitted power using a vacuum tube source.

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