3D full wave modelling of microwave interactions with plasma density fluctuations.

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The scattering of microwaves by density fluctuations in magnetised plasmas where the inhomogeneity scale length is comparable to the wavelength is not fully understood. Yet microwaves are used extensively in magnetically confined fusion plasmas not only to provide a wealth of information through diagnostics but for heating and current drive. To this end a 3D full-wave finite difference time domain code (EMIT-3D) has been designed to model the quasi-3D Doppler reflectometry data from a novel synthetic aperture microwave imaging diagnostic (SAMI) and to understand the scattering effects of turbulence on heating and current drive beams. SAMI illuminates the full poloidal and toroidal view of the plasma in a ±40 illumination from the mid-plane. A vast spatial grid is required to capture the inhomogeneous, curved plasma and magnetic geometry whilst considerable acquisition time is required for Doppler resolution. For this reason, EMIT-3D has been parallelised in 3D which is shown to scale well to large machines. EMIT-3D is shown to agree with the extensive benchmarking tests and demonstrates stability to large time iterations.

For collimated heating and current drive beams the largest scattering is expected to occur as the microwave beam propagates through the plasma edge where the turbulence fluctuations are largest. In light of this, a parameter scan has been conducted to characterise the scattering effect of a large range of turbulence parameter space and microwave beam properties. The scan discovered scaling laws for each parameter scan that were uncorrelated with changes in the other parameters. The time averaged effect of instantaneous scattering results in an effective beam broadening which, in the presence of large scattering, would result in a lower than expected heating and current drive efficiency as power is deposited outside of the target area. The broadening becomes more pronounced over the large propagation distances from the plasma edge to the absorption region which are typically $100 \rightarrow 200\lambda_0$. The broadening of microwave beams result in a lower than expected heating and current drive efficiency as power is deposited outside of the target area. This effect may cause the power requirements for the stabilisation of neoclassical tearing modes on ITER to substantially increase.

EMIT-3D has been applied to the case of electron cyclotron resonance heating (ECRH) deposition broadening in the DIII-D tokamak. Significant ECRH deposition broadening was measured in three different operating scenarios: L-mode, H-mode and negative triangularity. Each scenario corresponds to distinct turbulence characteristics in the edge region through which the beam must propagate. The turbulence is generated through the Hermes model in the BOUT++ framework which takes as input the measured time averaged electron density, temperature and magnetic field profiles for the specific shot in question. The simulated turbulence is constrained to match the experimentally measured (by use of the Beam Emission Spectroscopy (BES) and Doppler Back Scattering (DBS) systems) correlation length and normalised fluctuation levels. The predictions of the beam broadening from the simulations are found to agree very well with the experimentally observed broadening in all cases: L-mode, H-mode and negative triangularity. For the first time we have discovered a technique for predicting beam broadening in vastly different tokamak operating regimes which agree consistently with experiment.