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Theoretical and Computational Studies on the Scattering of Radio Frequency Waves by Fluctuations

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The practical and economic viability of tokamak fusion reactors depends, in a significant way, on the efficiency of radio frequency (RF) waves to deliver energy and momentum to the plasma in the core of the reactor. Among the various attributes of RF waves is their ability to heat magnetically confined plasmas, induce plasma currents in an effort to achieve steady state, and modify the current profile so as to control plasma instabilities like the neoclassical tearing modes. The RF electromagnetic waves, excited by antenna structures placed near the wall of a tokamak, have to propagate through the turbulent plasma in the scrape-off layer (SOL) along their path to the core plasma. While the propagation and damping of RF waves in the core is reasonably well understood, the same is not true for RF wave propagation through the SOL. In present day fusion devices, the radial width of the SOL is of the order of a few centimeters. In ITER and in future fusion reactors this width will be of the order of tens of centimeters. Any deleterious effects on RF waves due to plasma turbulence in the SOL could impact the efficient delivery of RF energy and momentum into the core. This paper is on a multi-pronged approach towards quantifying the effect of SOL plasma on RF waves. The SOL is composed of coherent filamentary structures and incoherent fluctuations. For coherent structures, a full-wave theoretical model has been developed and is used to benchmark computational codes. These codes are subsequently used to study the effect of a general distribution of filaments. For incoherent fluctuations, the theoretical modeling makes use of the Kirchhoff technique. This technique is based on physical optics and the wave fields at any point on a spatially varying surface are approximated to be the same as the fields on a tangent plane at that point. The results from the theoretical analysis are compared with full-wave numerical simulations for incoherent fluctuations. The final part of these studies is to construct the effective permittivity of a turbulent plasma that is a mix of coherent and incoherent fluctuations. Towards this end, the "effective medium approximation" is used to construct the permittivity of the plasma that will be used in full-wave studies of scattering. This cumulative research reveals new and important physical insights into the scattering of RF waves.

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