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Scattering of radio frequency waves by turbulence in fusion plasmas[1]

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In tokamak fusion plasmas, coherent fluctuations in the form of blobs or filaments and incoherent fluctuations due to turbulence are routinely observed in the scrape-off layer. Radio frequency (RF) electromagnetic waves, excited by antenna structures placed near the wall of a tokamak, have to propagate through the scrape-off layer before reaching the core of the plasma. While the effect of fluctuations on RF waves has not been quantified experimentally, there are telltale signs, arising from differences between results from simulations and from experiments, that fluctuations can modify the spectrum of RF waves. Any effect on RF waves in the scrape-off layer can have important experimental consequences. For example, electron cyclotron waves are expected to stabilize the deleterious neoclassical tearing mode (NTM) in ITER. Spectral and polarization changes due to scattering will modify the spatial location and profile of the current driven by the RF waves, thereby affecting the control of NTMs. Pioneering theoretical studies and complementary computer simulations have been pursued to elucidate the impact of fluctuations on RF waves. From the full complement of Maxwell's equations for cold, magnetized plasmas, it is shown that the Poynting flux in the wake of filaments develops spatial structure due to diffraction and shadowing. The uniformity of power flow into the plasma is affected by side-scattering, modifications to the wave spectrum, and coupling to plasma waves other than the incident RF wave. The Snell's law and the Fresnel equations have been reformulated within the context of magnetized plasmas. They are distinctly different from their counterparts in scalar dielectric media, and reveal new and important physical insight into the scattering of RF waves. The Snells law and Fresnel equations are the basis for the Kirchhoff approximation necessary to determine properties of the scattered waves. Furthermore, this theory is also relevant for studying back-scattering of waves from density fluctuations in the core – for example, for millimeter wave reflectometry used to determine the wave numbers of fluctuations. All of these studies apply to the scattering of RF waves in any frequency range and for arbitrary variations in density.

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