Full-wave test of analytical theory for fixed frequency fluctuation reflectometry

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Fluctuation reflectometry operating at fixed frequency can be used as a non-intrusive technique to measure plasma density fluctuations δn. Since density fluctuations all along the beam path contribute to the measured fluctuation of the signal phase $d\varphi$, the measurement is non-local and in general requires a full-wave analysis for interpretation.

If the fluctuation level is small enough so that only a single cut-off exists in the plasma, using the WKB approach, analytical integral formulae can be deduced [1]. Those link the measured phase fluctuation $d\varphi$ to the spatial distribution of the density fluctuation RMS amplitude δn_{rms} . The shape of the radial wavenumber spectrum $|\delta n_k|^2$ also plays a critical role, since each wavenumber k contributes to $d\varphi$ with a different efficiency. The analytical formulae can be simplified for a Gaussian or exponential spectrum $|\delta n_k|^2$, if δn_{rms} is homogeneous and if the refractive index squared changes linearly with the characteristic length L near the cut-off. In this case this well-known form is obtained

$$d\varphi_{\mathrm{rms}} = k_0 \sqrt{\frac{L}{k_{\mathrm{eff}}}} \, \frac{\delta n_{\mathrm{rms}}}{n_{\mathrm{cutoff}}}$$

including an analytical expression for k_{eff} , which is the effective wavenumber of the given spectrum. This result could be verified by O-mode full-wave simulations.

For an arbitrary profile of the refraction index, however, it is necessary to express the phase fluctuation $d\varphi_{\mathrm{rms}}$ with an integral formula, where the integration is carried out in radial direction, weighting the contributions of $\delta n_{\mathrm{rms}}(r)$ from different radial positions r. We verify this expression and explore its validity range by means of a full-wave code solving the Helmholtz equation for the wave electric field. Our model data is based on Tore-Supra measurements and we study O- and X-mode.

An inversion process can be set up in order to deduce the $\delta n_{\mathrm{rms}}(r)$ profile, if the $d\varphi_{\mathrm{rms}}$ were measured at different frequencies. We demonstrate this process numerically, assuming a constant spectrum shape in the probing zone, and discuss its results.

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[1] E. Gusakov and A. Popov, Plasma Phys. and Contr. Fusion **44** (2002), 2327.