Edge turbulence effects on core radial k-spectrum extracted from reflectometry data

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Introduction

Ultra fast radial sweeping reflectometry (UFSR) is a powerful tool for density profile reconstruction. Beside this it can provide an information about a plasma turbulence. Techniques to extract density perturbation properties from fluctuation of the signal phase were developed and applied to analyze experimental data[1]. These methods are based on iterative solution of inverse problem (turbulence k-spectrum extraction) with an assumption that the main part of the information coming from the cut-off area. Usually, due to simplicity and very high speed direct problem was solved with 1D Helmholtz equation solver. However this calculation do not take into account 2D effects such as real beam geometry, poloidal turbulence spectrum and others [2]. Instead of the 1D code one can use fast approximate solution based on the weighting function approach [3]. This model can be well applied the computation with small turbulence level($RMS(\delta n)/n_c < 2\% - 3\%$). Usual for tokamak discharges, strong edge turbulence can change the reflectometer response[2]. When the probing beam crossing density perturbation region it loose its coherency and suffer widening [4, 5]. However influence of the edge turbulence on core measurements was not studied well.

Strong edge turbulence effects on the core measurements(Slab geometry)

We have computed reflectometer response for O-mode probing wave. To check more realistic case we took 1 meter deep, slab, linear plasma profile with the plasma density up to $10^{19} m^{-3}$ We sweep probing frequency from $21 GHz$ to $26 GHz$. Turbulence consist of two Gaussian shape spectrum turbulence maps. First is the core turbulence map with constant RMS level of $0.5\% n_c$, and correlation length of 3.2 cm. Here n_c is the maximum cut-off density. Second turbulence map has the Gaussian envelop with the center near the point where density equals to $0.25 n_c$. Envelop length is equal to 10λ. where λ is the vacuum wavelength of maximum sweeping frequency. Reflectometer's phase spectrum was computed in 2D for different edge turbulence

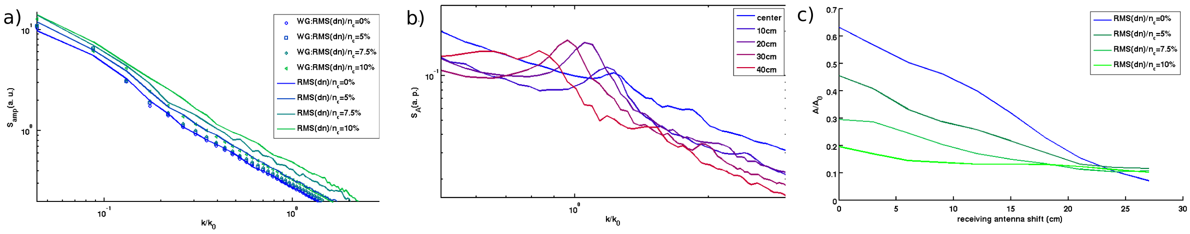

Figure 1: a) phase variation spectrum b) amplitude variation spectrum c) average received amplitude

amplitude both with IPF-FD3D full-wave code[6] and weighting function approach (Fig. 1(a)). One can see that with the increase of the edge turbulence level the phase fluctuation spectrum level also increases. But this increase can't be well estimated by weighting function method. However for $max(RMS(\delta n)/n_c) = 5\%$ discrepancy between full-wave computation and the weighting function method is below 30%. When the edge turbulence is strong and it changes the core measurements it is very important to have possibility to identify this case. For this we have used poloidal antenna array to analyze signal amplitude spectrum (Fig. 1(b)). On the figure we can see spectral peak. With the poloidal receiving antenna shift we see a movement of the spectral peak in the direction of smaller k-numbers. To be scattered to shifted receiving antenna probing beam first should make a turn. Deeper beam propagation inside the edge turbulence increases probability of this turn. Also deeper beam propagation means smaller k-number seen by shifted antenna. Moreover with antenna array it is possible to measure average signal amplitude decay with the antenna shift (Fig. 1(c)). Using theory [4, 5] it is possible to analyze this data to extract edge turbulence properties.

Core coherent mode observation

To check if it is possible to detect coherent core mode trough the strong edge turbulence layer we have simulated reflectometry experiment for the same plasma profile and edge turbulence $max(RMS(n)/n_c) = 10\%$. In the core, instead of homogeneous turbulence we placed one mode turbulence with Gaussian envelop. This Gaussian envelop has the same length as the edge turbulence envelop. It situated between edge turbulence and the highest frequency cut-off. Coherent mode k-number was chosen to match local Bragg scattering rule for middle frequency $k = 0.9k_0$. The coherent mode is tilted to the direction of the wave propagation by $15°$. On (Fig. 2(a)) one can see reflectometer's phase fluctuation spectrum. It is possible to notice that coherent mode spectral peak can be seen. However the spectral peak is doubled. Analyzing amplitude variation spectrum (Fig. 2(b)) it is also possible to see doubled peaks. Moreover with the receiving antenna shift higher k-number peak shifts to higher values, but smaller k-number

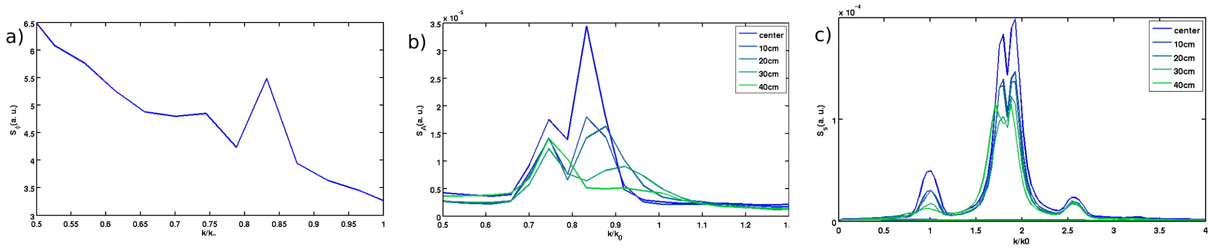

Figure 2: a) phase variation spectrum b) amplitude variation spectrum c) average received amplitude

peak stay on the same place. Using the complex reflectometer signal spectrum it is possible to distinguish spectral peaks by time of flight. (Fig. 2(c)) shows complex signal spectrum which consist of main peak which corresponds to cut-off position, and 2 peaks situated on the sides. One of these peaks amplitude stays constant with the antenna shift and other is not. This behaviour helps us to connect these peaks to amplitude variation spectral peaks. This means that higher k number peak connects to the first scattering from the coherent mode and second peak is scattering from the coherent mode after the cut-off reflection.

Real Tore-Supra 2D geometry

Curved 2D profiles of a real plasma can introduce more effects to the core turbulence measurements. In this case even without edge turbulence, probing beam is much wider and wave front is curved. To bring our computation closer to the experimental case we took the density profile, the turbulence spectrum, and the amplitude based on the interpretation of X-mode reflectometry data [1, 7]. Amplitude of the turbulence[1] was fitted to have possibility to change edge turbulence amplitude (Fig. 3). Turbulence map is isotropic and inharmonious. It consist of 3 turbulence maps with different wave-number spectral slope merged together using special envelops. First situated around $R = 3.1m$ with the slope of -1.52 second situated near $R = 2.9m$ with the slope -1.65 and last is near $R = 3.1m$ with the slope of -1.85. Phase fluctuation spectrum was computed for different edge turbulence amplitude (Fig. 4(a)). Even with small edge turbulence level we can see big change of the computed phase spectrum. Turbulence correlation length here is much smaller (6mm) then in slab model computation. This reduce wave coherency attenuation and increase widening of not coherent part of the beam[5, 2]. How-

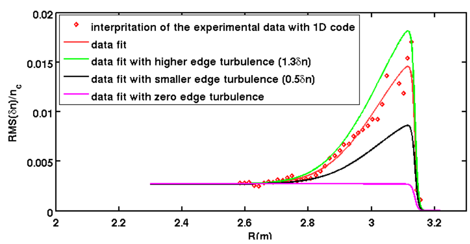

Figure 3: Turbulence amplitude envelop. Scattered experimental points and fitted lines with edge turbulence amplitude change

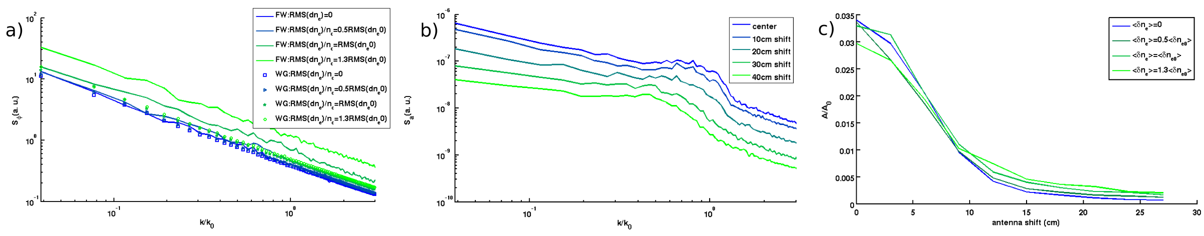

Figure 4: a) phase variation spectrum b) amplitude variation spectrum c) complex signal spectrum

ever small correlation length can be also the reason of the strong back Bragg-scattering. In this case average amplitude measurements will not show edge turbulence signature because main part of the beam keep its shape (Fig. 4(c)). But looking on the amplitude variation spectrum it is possible to see the edge turbulence signature spectral peaks. With the receiving antenna shift amplitude variation spectral peaks also moves in direction of smaller k-number. However this movement is not very strong. As most part of the wave do not suffer widening spectral peak movement is connected poloidal plasma curvature beam widening.

Conclusions

Strong edge turbulence is able to affect UFSR core measurements. This was shown both in the slab geometry and using 2D Tore-Supra profiles. However it is possible to detect such turbulence by analysis of the USFR amplitude variation spectrum. Additional information about turbulence could be achieved by using poloidal receiving antenna array. Analyzing average received amplitude decay with the antenna shift together with amplitude variation spectral peak shift one can get information about edge turbulence correlation length and amplitude. Core coherent mode observation is possible through the strong turbulent layer. But with the edge turbulence this coherent mode spectral peak is doubled. Even for curved plasmas weighting function method can give good results in spectral shape calculation. But due to probing beam wave front curvature in 2D geometry plasmas weighting function method is not good for specter amplitude description.

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