

Upper Hybrid Resonance RADAR Scattering Diagnostics of Small Scale Turbulence in Tokamak Plasmas

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Introduction.

Development of small scale turbulence diagnostics for tokamak experiments is important because of possible interconnection between density and magnetic field fluctuations and transport of energy and particles. The usual collective scattering fails to solve the problem of magnetic turbulence diagnostics because of low relative level of magnetic fluctuations, compared to the fluctuations of density. The cross-polarisation scattering (CPS) diagnostics utilising microwave probing perpendicular to the tokamak magnetic field is a feasible candidate for measuring the magnetic turbulence level in the hot plasma core because the density fluctuations do not contribute to the CPS signal in this experimental geometry [1]. This effect was used on Tore Supra [2], where the extraordinary to ordinary mode ($X \rightarrow O$) conversion was studied under conditions when the O-mode receiving antenna was protected from the higher level X-mode radiation forward scattered from the density fluctuations by the cut off and thick evanescent layer. The new diagnostic technique for study of spontaneous magnetic field and density turbulence, utilising RADAR microwave scattering in the Upper Hybrid Resonance (UHR), has been proposed recently [3]. The density component of the turbulence is diagnosed within the scheme using the Back Scattering (BS) signal, where as the magnetic component is estimated from the CPS signal. The expected merits of the approach under development are as follows: localisation of the CPS and BS from small scale fluctuations by the position of the UHR; wide fluctuation wave number spectrum available for diagnostics in the simple 1D probing scheme; possibility of fluctuation wave number measurements using experiments with time of flight resolution [4], based on linear dependence of the UHR scattering signal time delay on the fluctuation wave number; $X \rightarrow O$ and $O \rightarrow X$ CPS cross-section increase in the UHR [5]; suppression of the CPS caused by density fluctuations due to the perpendicular propagation of the incident wave in the UHR [5]; absorption in the UHR of the parasitic $x \rightarrow x$ radiation forward scattered from the density fluctuations; electron cyclotron absorption of the spurious O-mode component of the probing wave.

Experimental results.

The first results of the RADAR UHR scattering scheme application to study of density and magnetic turbulence in tokamak plasmas are given in the present paper. The experiment was performed at the FT-1 tokamak ($R=62.5\text{cm}$, $a=15\text{cm}$, $B_t=1\text{T}$, $I_p=30\text{kA}$, $n_e(0)=10^{13}\text{cm}^{-3}$, $T_e(0) \cong 400\text{eV}$) [6]. The probing extraordinary wave at frequency 28.05GHz, power 50W was launched into the plasma from high magnetic field side of the torus. A short (7ns) pulse amplitude modulation of the incident wave was used with repetition time of 70ns. The gate technique was utilized for the scattered signal time delay measurements. The near by standing X-mode receiving horn antenna and the O-mode antenna at the low field side were used to pick up the BS and CPS signals. The antennae diagram angular width was 15° , where as their mode selectivity was better than 10^{-2} .

The CPS spectra measured with time of flight resolution at magnetic field 9.9kGs ($r_{UH}=13.3\text{cm}$) are shown in Fig.1a for $t_d=5\text{ns}$ and 25ns . These spectra are quasi Lorentzian form. The width of the CPS line increases with the time delay of measurements. The maximal amplitude is decreasing with the time delay till saturation, which takes place at $t_d=30\text{ns}$ at the level $3\times 10^{-13}\text{W/Hz}$. This saturation level is determined by the continuous scattering of the probing wave, suppressed by the modulator to the -20dB level. Unlike the line maximum, the behaviour of the spectrum wings is not monotonic. At frequencies shifted by $|f_s-f_i|>0.3\text{MHz}$ the CPS signal first increases with time delay and then decreases Fig.1b.

Quite unexpectedly the X-mode scattered component was also observed at the low field side. The corresponding scattering spectra are shown in Fig.2a. The scattering line amplitude is comparable for this X and O-mode scattering components, where as the spectrum form is much different. Unlike O-mode, the X-mode spectra are triangular in the logarithmic scale and thus depend exponentially on the frequency shift. They are much broader, than those for the O-mode, at small time delays $t_d < 20\text{ns}$ and thus the level of the X-mode component with big frequency shift is typically a factor of 3 higher. The dependencies of the X-mode scattered signal on time delay are shown for different frequency shifts in Fig.2b. Unlike the O-mode case, all these dependencies are monotonic. The wide X-mode spectrum observed at the low field side is not likely to be generated by scattering in the UHR. Because of large width of the evanescent region it should be strongly suppressed. Most likely this X-mode is produced by depolarising reflection of the spurious incident O-mode at the wall. Its spectral broadening could be produced as a result of propagation in the turbulent zone between the wall and the X-mode cut-off. This supposition is supported by similarity of spectra observed for the X-mode (Fig.2a) and those, observed in the reflectometry mode in Fig.4a or for the X→O CPS in the absence of the UHR.

The UHR BS spectra observed at $H=9.9\text{kGs}$ are shown in Fig.3a. The amplitude of the BS line is smaller than that of the CPS one (Fig.1a), however its wings are much broader. These wings are very small at small time delay $t_d=0\text{ns}$, but they become much more pronounced for larger time delay, when the central part of the spectrum quickly decreases. The non-suppressed line at the incident frequency corresponds to the continuously acting part of the incident wave, attenuated by the modulator and directly coupled to the receiving horn antenna. When the UHR is not accessible at low magnetic field $H=6.9\text{kGs}$, the BS signal is measured in reflectometry scattering mode. It is a factor of 10dB larger than the signal in the UHR BS mode. The corresponding spectra are shown in Fig.4a. They are triangular, less broad than in Fig.3a, and their time evolution is very different. In the UHR mode the BS signal possess the well pronounced, sharp maximum at $t_d=10\text{ns}$ for all, but incident, frequencies (see Fig.3b). More than a 10dB variation of the BS signal is observed there. The maximal values of the BS signal exceed the corresponding values of CPS at the same frequencies by 3 – 10 dB. On contrary, the time delay behaviour of BS frequency components in the reflectometry mode is monotonic (see Fig.4b) and smooth.

Discussion.

The maximum shown in Fig.4a could be explained by the dependence of BS efficiency on the fluctuation wave number, which according to [7] possess a maximum, when $q_x = 2k_{conv} \equiv 2k_c \sqrt{c/v_{Te}}$, and BS takes place in the linear conversion point. For $T_e(r_{UH}) \approx 70\text{eV}$, $2k_{conv} = 96\text{cm}^{-1}$, close to the wave number $q=104\text{cm}^{-1}$, corresponding to $t_d=10\text{ns}$,

according the theoretical dependence [4] $t_d = 2q\omega_i \left/ \left| \frac{\partial\omega_{pe}^2}{\partial x} + \frac{\partial\omega_{ce}^2}{\partial x} \right| \right.$. Another interesting

peculiarity of the BS, as well as CPS, spectra is strong broadening with the growing time

delay or fluctuation wave number. The spectrum width is roughly proportional to the wave number, so that different spectra looks similar after compression of the frequency scale by the factor equal to the ratio of measurement time delays. One of the possible interpretations of the above observations could be given in terms of Doppler broadening of scattering spectra in the turbulent media [8]. The BS spectrum shape in this case should be determined by the distribution function of the turbulence velocity component. However this mechanism fails to explain different width of BS and CPS spectra, measured at the same time delay. Alternative explanation of the above peculiarities of BS and CPS spectra is based on the effect of growth of poloidal wave number of the incident X-mode in the UHR, which is roughly given for FT-1 by $k_\theta = \eta k_{\theta 0} k_r$, where $\eta = 0.15 \text{ cm}$, $k_{\theta 0}$ is initial value of k_θ in the ray tracing and k_r is the radial wave number. The BS frequency spectrum width in this model is determined by the Doppler broadening $\delta f = 2k_\theta v / 2\pi$ and in the case of gaussian antenna pattern $p_i^2 \propto \exp[-(k_{\theta 0} \rho)^2]$ is given by $p_{BS} \propto \exp[-(2\pi \delta f \rho)^2 / (\eta q v)^2]$, where $q = 2k_r$. The CPS spectrum width in this model is also determined by the Doppler shift effect, but the spectrum is proportional not to the probing wave diagram, but rather to the poloidal distribution of the receiving antenna field in the frontogenetic zone. Supposing it also gaussian $E_z^2 \propto \exp[-2y^2 / \rho^2]$ and using the linear approximation of the ray trajectory poloidal shift dependence on $k_{\theta 0} - y_{UH}(k_{\theta 0}) \approx \beta k_{\theta 0}$, one obtain the CPS spectrum as $p_{CPS} \propto \exp[-2(2\pi \beta \delta f)^2 / (\eta q v \rho)^2]$. Parameter β here is determined from ray tracing as $\beta = 7 \text{ cm}^2$. The ratio of the BS and CPS spectral width in this model is given by $2^{1/2} \beta / \rho^2 \approx 5$, in rough agreement with the experimental results. The poloidal velocity v , necessary for description of both spectra, $2.5 \times 10^5 \text{ cm/s} < v < 5 \times 10^5 \text{ cm/s}$ is close to the electron diamagnetic drift velocity, calculated for FT-1 edge plasma parameters [6] $v = 5 \times 10^5 \text{ cm/s}$. The experimental results for both BS and CPS are consistent with fluctuation wave number spectrum decreasing as q^{-3} . The rough estimation of the density and magnetic field perturbation, based on the q^{-3} dependence extrapolation to smaller scales and on FT-1 turbulence isotropy supposition results in values of $\delta n / n_{UH} \approx 1 \times 10^{-2}$ and $\delta B / B_0 \approx 4 \times 10^{-4}$.

Conclusions.

The comparative study of the UHR CPS and BS produced by spontaneous tokamak turbulence in FT-1 have confirmed the feasibility of the diagnostics under development. The CPS effect produced by magnetic turbulence component was observed and the CPS spectra were shown to be different from those produced by BS effect and by reflectometry scattering. The RADAR scheme was shown to be effective tool for carrying out the wave number resolved measurements. The mechanism of CPS and BS spectra broadening in the UHR, related to the increase of the poloidal probing wave number in the UHR was proposed.

References.

1. Gresillon D. et al. Proc. 12th EPS Conf. on Contr. Fusion and Plasma Physics, Budapest, 1985, II, 664.
2. Zou X.L. et al. Proc. 20th Conf. on Controlled Fusion and Plasma Physics, Lisbon, 1993, III, 1091.
3. Bulyiginskiy et al. Proc. 25th Conf. on Controlled Fusion and Plasma Physics, Prague, 1998, V.22C, 1546
4. Arkhipenko V.I., Budnikov V.N., Gusakov E.Z. et al. Plasma Phys. Control. Fusion, 1995, 37, A347.
5. Gusakov E.Z. Proc. 25th Conf. on Controlled Fusion and Plasma Physics, Prague, 1998, V.22C, 39
6. Bulyiginsliy D.G. et al. Plasma Physics and Controlled Nuclear Fusion Research, 1984, 1, 491.
7. Novik K.M., Piliya A.D. Plasma Phys. Control. Fusion, 1994, 36, 357.
8. C.Hanuse et al. Ann. Geophysicae 1993, 11, 29

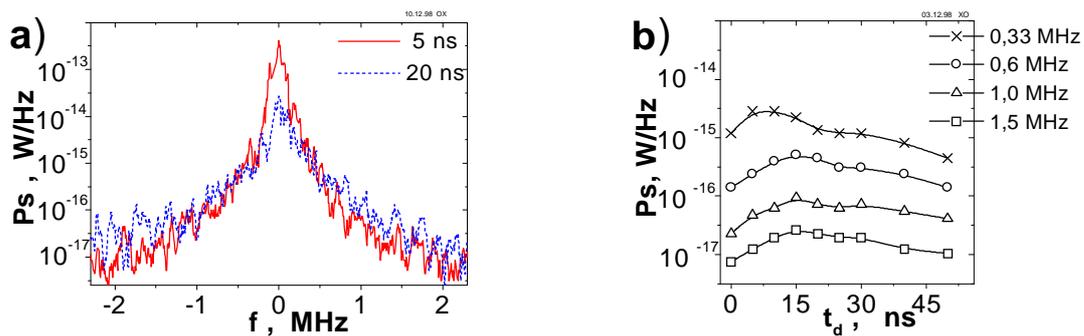


Fig. 1. The UHR CPS spectra – a) and signal dependence on the time delay for different frequency components – b)

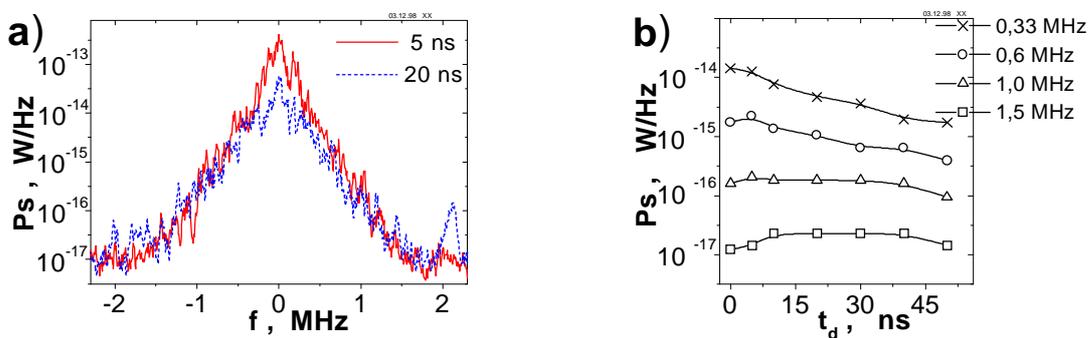


Fig. 2. The scattered X-mode spectra – a) and signal dependence on the time delay – b)

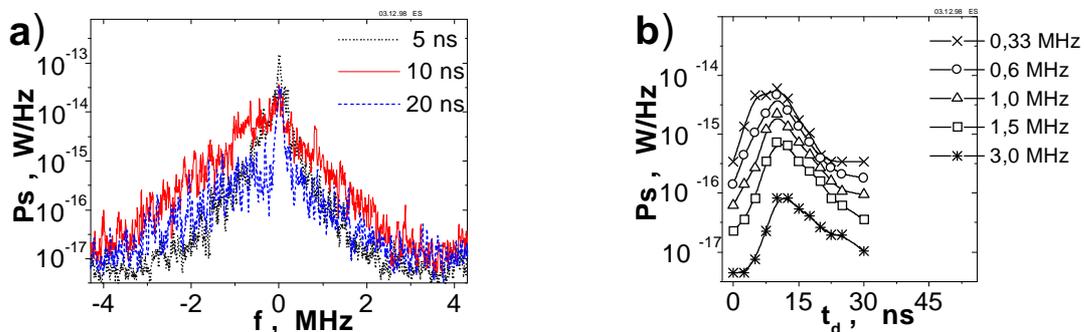


Fig. 3. The UHR BS spectra – a) and signal dependence on the time delay – b)

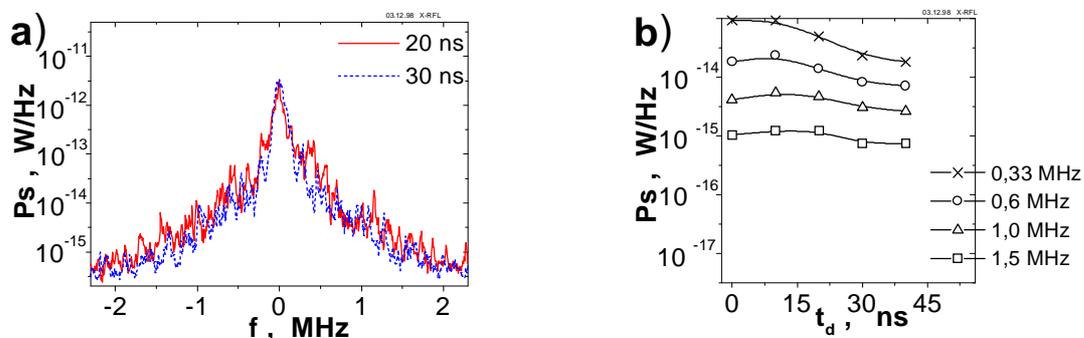


Fig. 4. The X-mode reflectometry spectra – a) and signal dependence on the time delay – b)