UKAEA-CCFE-CP(19)55

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This paper has been submitted to
14th International Reflectometry Workshop, Swiss Plasma Center of the Ecole Polytechnique Fédérale de Lausanne, Switzerland, 22-24 May 2019

Modelling the effects of misaligning the probe beam and magnetic field in Doppler backscattering measurements

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Introduction

The use of Doppler Backscattering (DBS) in spherical tokamaks is challenging since the magnetic pitch angle can be large (up to 35°, compared to 15° in standard tokamaks like JET). Moreover the pitch angle varies both spatially and temporally. Hence, the probe beam is generally not perpendicular to the magnetic field. This misalignment, which affects the backscattered signal, can be empirically optimised with 2D beam steering [1]. However, empirical optimisation is inefficient, requiring repeated pulses with different diagnostic settings, and may not always be possible. Hence, it is important to develop a model to quantitatively account for the effect of the misalignment on the backscattered signal, avoiding the need to optimise empirically.

We use beam tracing (Torbeam [2] as well as a newly written code) and the reciprocity theorem [3] to derive a model for the backscattered power and its dependence on the mismatch angle. Our model works for both the O-mode and X-mode in tokamak geometry.

Beam tracing and reciprocity

As presented in our previous work [4], we find that using the reciprocity theorem and the form of the electric field from beam tracing, we get

$$
\begin{aligned}
A_r = \int & \frac{A_{ant} K_{ant} g_{ant}}{2 i n_e} \left(\frac{\det[\mathrm{Im}(\boldsymbol{\Psi})_w]}{\det[\boldsymbol{\Psi}_w]} \right)^{\frac{1}{2}} \delta N_e(\mathbf{k}_\perp, \tau) \\
& \times \hat{\mathbf{e}}^* \cdot (\boldsymbol{\varepsilon}_{eq} - \mathbb{1}) \cdot \hat{\mathbf{e}} \, \exp(i \phi_B^{(0)} + i \phi_R^{(0)}) \exp\underbrace{\left(2is + i \int \mathbf{k}_\perp \cdot \mathbf{g}' \, d\tau \right)}_{\text{localisation}} \\
& \times \underbrace{\exp \left\{ -\frac{i}{4} [2\mathbf{K}_w + (\mathbf{k}_\perp)_w] \cdot \boldsymbol{\Psi}_w^{-1} \cdot [2\mathbf{K}_w + (\mathbf{k}_\perp)_w] \right\}}_{\text{mismatch}} \, d\tau \, d^2 k_\perp .
\end{aligned} \tag{1}
$$

Here A_r is the amplitude of the backscattered electric field, τ is a parameter that gives the position along the ray, $\mathbf{g}$ is the group velocity of the probe beam, $\mathbf{K}$ is the wavevector of the probe beam, $s(\tau) = \int_0^\tau K_g(\tau') g(\tau') \, d\tau'$, and $K_g(\tau) = \mathbf{K}(\tau) \cdot \hat{\mathbf{g}}(\tau)$ is the projection of the wavevector along the ray, $\mathbf{k}_\perp$ is the wavevector of the turbulence, $\hat{\mathbf{e}}$ is the unit polarisation vector, n_e is the equilibrium electron density, δN_e is the fluctuating electron density, $\phi_B^{(0)}$ and $\phi_R^{(0)}$ are the Gouy phases of the probe and reciprocal beams respectively, $\boldsymbol{\varepsilon}$ is the cold plasma dielectric tensor, and $\boldsymbol{\Psi}$ is a 2D symmetric matrix. The real part of $\boldsymbol{\Psi}$ is responsible for the curvature of the Gaussian beam, while its imaginary part gives the characteristic decay width of the Gaussian envelope. The subscript $_w$ indicates projection perpendicular to the group velocity of the beam, and the subscript $_{ant}$ means that the variable is evaluated at the antenna.

Effect of mismatch

We find that the effect of mismatch is

$$\frac{A_r(\theta_m)}{A_r(\theta_m = 0)} = \exp\left[-\theta_{m,s}^2 \frac{2K_s^2 W_{x,s}^{-2}}{K_s^2 R_{x,s}^{-2} + 4W_{x,s}^{-4}} \right], \qquad (2)$$

where $\sin\theta_m = \hat{\mathbf{K}} \cdot \hat{\mathbf{b}}$ is the mismatch angle, K is the beam wavenumber, R is the beam radius of curvature, W is the beam width, and $\hat{\mathbf{b}}$ is the unit vector of the magnetic field. The subscript $_s$ denotes that the variable should be evaluated at the scattering location, which is almost exactly at the cut-off. The subscript $_x$ indicates projection in the direction perpendicular to $\hat{\mathbf{b}}$ and in the plane of $\mathbf{g}$ and $\hat{\mathbf{b}}$. The derivation of this result is arduous, and will be presented in an upcoming paper.

We compare our model with MAST data [1] from the 55 GHz channel, for repeat shots 29904 – 29906 and 29908 – 29910, at 190ms. Equilibrium data from shot 29908 at 200ms, scaled by 1.05 so a cut-off exists, as confirmed by the signal. Preliminarily, our model indeed quantitatively accounts for the effect of mismatch (Figure 1), but further analysis for different frequencies and times is required.

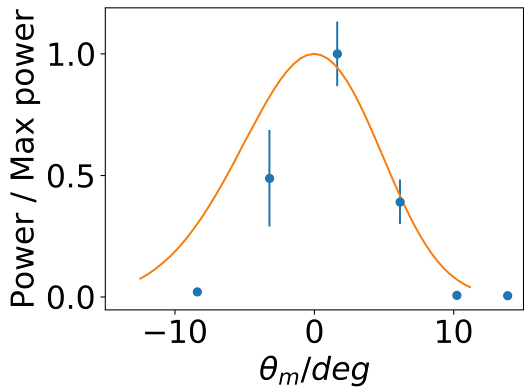

Figure 1: Comparison with MAST data from an earlier paper[1].

Conclusion

We have found an analytical expression of how the mismatch angle affects the backscattered signal. This effect only requires beam tracing, not a full wave code, to evaluate. Preliminary investigation shows agreement between our work and what has been observed experimentally.

Acknowledgements

This work has been funded by the RCUK Energy Programme [grant number EP/P012450/1]. In order to obtain further information on the data and models underlying this work, please contact PublicationsManager@ukaea.uk. V.H. Hall-Chen's DPhil is funded by a National Science Scholarship from A*STAR, Singapore.

References

[1] J.C. Hillesheim, N.A. Crocker, W.A. Peebles, H. Meyer, A. Meakins, A.R. Field, D. Dunai, M. Carr, N. Hawkes, and MAST Team, Nuclear Fusion **55** (7), 073024 (2015)

[2] E. Poli, A.G. Peeters, and G.V. Pereverzev, Computer Physics Communications **136** (1-2), 90-104 (2001).

[3] E.Z. Gusakov, and A.V. Surkov, Plasma Physics and Controlled Fusion, **46** (7), 1143 (2004).

[4] V.H. Hall-Chen, F.I. Parra, J.C. Hillesheim, Proceedings of the 45th EPS Conference on Plasma Physics (Prague) P5.1011 (2018).