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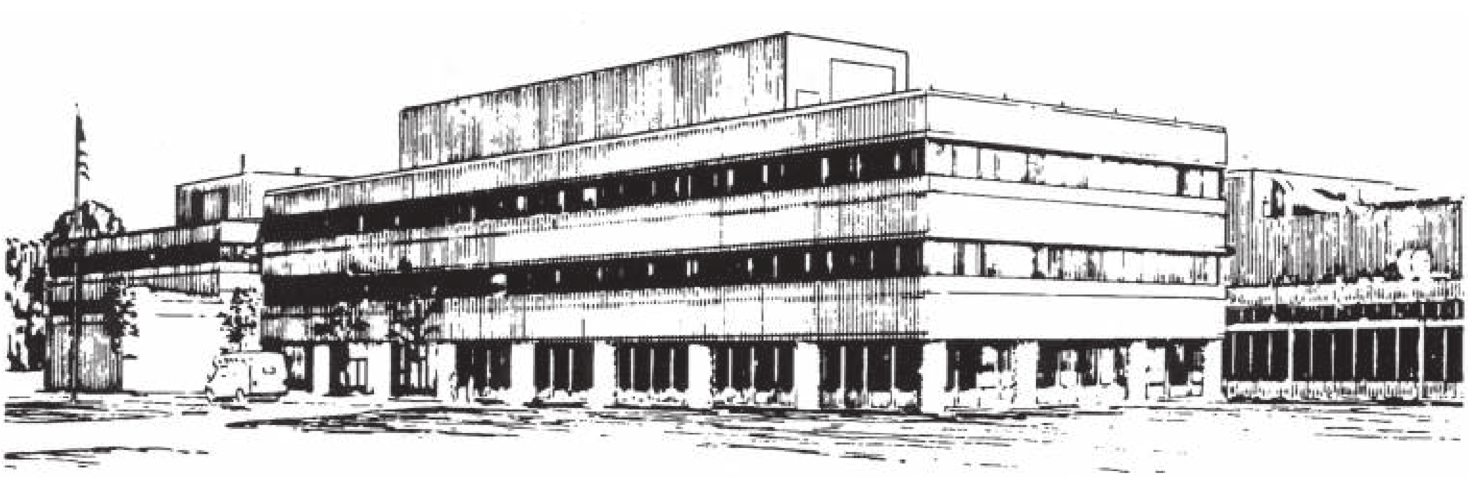

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Microwave Scattering System Design for ρ_e-Scale Turbulence Measurements on NSTX

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Abstract

Despite suppression of ρ_i-scale turbulent fluctuations, electron thermal transport remains anomalous in NSTX. For this reason, a microwave scattering system will be deployed to directly observe the ω and k spectra of ρ_e-scale turbulent fluctuations and characterize the effect on electron thermal transport. The scattering system will employ a Gaussian probe beam produced by a high power 280 GHz microwave source. A five-channel heterodyne detection system will measure radial turbulent spectra in the range $|k_r| = 0 - 20\ cm^{-1}$. Inboard and outboard launch configurations cover most of the normalized minor radius. Improved spatial localization of measurements is achieved with low aspect ratio and high magnetic shear configurations. This paper will address the global design of the scattering system, such as choice of frequency, size, launching system, and detection system.

I. INTRODUCTION

Recent theory work,[1] gyrokinetic simulations,[2,3] and Tore Supra experimental results[4,5] have highlighted the importance of electron thermal transport. In neutral beam heated NSTX[6] plasmas, beam power is expected to transfer preferentially to electrons, yet measured ion temperatures exceed measured electron temperatures.[7,8] Power balance analysis indicates ion thermal transport is at or near neoclassical levels while electron thermal transport remains anomalous. In addition, gyrokinetic simulations[9] predict low growth rates for ion temperature gradient (ITG) modes and trapped electron modes (TEM) with $k_\perp \rho_i \lesssim 1$ while electron temperature gradient (ETG) modes with $k_\perp \rho_i \gg 1$ have larger growth rates. These results point to the possibility that ETG modes drive the anomalous electron thermal transport observed in NSTX. High-k core turbulence measurements are needed to confirm the existence of ETG modes. Only the coherent scattering of electromagnetic radiation can probe such small scale fluctuations. In this effort, a microwave scattering system will be deployed on NSTX to investigate ρ_e-scale turbulence.

NSTX is well suited for ETG studies. ρ_i-scale turbulence, known to drive electron thermal transport, is believed suppressed due to $E \times B$ flow shear. Low magnetic field $B \sim .45\ T$ results in relatively large electron gyroradii of $\rho_e \leq 250\ \mu m$. Also, low aspect ratio and high magnetic shear configurations lead to improved spatial localization of measurements.[10,11]

Design criteria are addressed in Section II. The scattering system is described in Section III. A summary is given in Section IV.

II. DESIGN CRITERIA

Scattering systems are typically oriented for launch either in the poloidal cross section to measure primarily k_θ or in the toroidal midplane to measure primarily k_r, the scattering component relevant for radial transport. Due to port access, the NSTX scattering system will launch at a 5^o angle to the toroidal midplane and measure primarily k_r, but small k_θ, k_ϕ components are introduced.

Given an incident beam $\omega_i, \vec{k}_i$, a turbulent fluctuation $\omega, \vec{k}$ will scatter a small fraction of the incident power into a scattered beam $\omega_s, \vec{k}_s$ such that

$$\omega_s = \omega_i + \omega \tag{1}$$

$$\vec{k}_s = \vec{k}_i + \vec{k}. \tag{2}$$

The NSTX scattering system will employ a 280 GHz microwave source as described below. With $\omega/2\pi \lesssim 1\ MHz$, we can take $\omega_s = \omega_i$. This gives

$$k_i = k_s, \tag{3}$$

and therefore Eq. 2 describes an isosceles triangle.

The anisotropic fluctuations $k_\perp \gg k_\parallel$ of drift wave turbulence allow measurement localization beyond the mere overlap of the incident and "antenna" beams. Specifically, permissible fluctuation wave vectors are constrained to a plane defined by

$$\vec{k} \cdot \vec{B} = 0. \tag{4}$$

Variations in magnetic field orientation due to magnetic shear[10] and toroidal curvature[11] modify the instrument selectivity function which, in essence, constricts the volume observed by the detection receiver. The methods of Ref. 11 will be employed to calculate the scattering volume. An example is shown in Figure 1 with $k = 10\ cm^{-1}$.

The scattering system is designed with the flexibility to detect scattered signals with both $k_r > 0$ and $k_r < 0$ as shown in Figure 2. The outboard launch configuration has a tangency point $R = 1.38\ m$ and the five-channel detection system observes scattered signals with $k_r = -20.8,\ -15.3,\ -10.5,\ -6.0,\ -2.0\ cm^{-1}$. The inboard launch configuration has a tangency point $R = 1.11\ m$ and scattered signals with $k_r = 3.9,\ 8.0,\ 12.4,\ 16.1,\ 19.5\ cm^{-1}$ are observed. The sweep angle between inboard and outboard launch is 10.4^o. In this manner fluctuation measurements in regions with different gradient scale lengths is possible. In both scenarios the probe beam is launched 5^o below the midplane.

III. SCATTERING SYSTEM

The scattering system can be described in terms of four major components: microwave source, launch port, detection port, and data acquisition.

A. Microwave Source

A carcinotron source will supply 200 mW of microwave power at 280 GHz ($\lambda = 1.07\ mm$). Scattered signals of $5 \times 10^{-12}\ W$ are expected. With a detection system NEP of $2 \times 10^{-13}\ W$, the carcinotron source should be sufficient. However, if more microwave power is required, a 20 W, 354 GHz gyrotron source is available.[12] The higher frequency will also provide access to higher k_r.

Overmoded, corrugated waveguide will transport the microwave power to the launching port. Suitable optics will position the beam waist at the expected scattering region to minimize the scattering volume.

B. Launch Port

As shown in Figure 3, the probe beam enters the vacuum vessel through a water-free quartz window.[13] The window normal is oriented vertically and the beam enters 5^o off vertical. A transmittance of 0.84 is achieved with etalon optimization of window thickness as shown in Figure 4. The 5^o incidence of the beam shifts the optimized window thickness 40 μm. A turning mirror residing 4 cm above the midplane and oriented at 45^o to the beam redirects the beam for ordinary mode launch 5^o below the horizontal. The turning mirror can rotate about an axis 5^o off vertical providing access to inboard and outboard launch configurations.

Three neutral beam sources are directed towards the launch port as depicted in Figure 2. Previously, the vacuum vessel and port cover were protected by graphite neutral beam armor. To permit diagnostic access, a strip of armor centered on the midplane has been removed as noted in Figure 3. Three graphite neutral beam baffles and a fourth vacuum vessel graphite tile will be installed to protect exposed vacuum vessel, port cover, and diagnostic equipment from neutral beam site lines. In this manner, the port cover and diagnostic equipment can safely exist in the shadows of the baffles.

C. Detection Port

The detection port includes a collection mirror that reflects the scattered signals to five exit windows. The collection mirror is spherical with a 3 m radius of curvature and the mirror normal is pitched up 5^o to the horizontal. The mirror has limited rotation around a vertical axis to properly redirect scattered beams for the inboard and outboard launch configurations.

The scattered beams exit the vacuum vessel through five water-free quartz windows. The thickness of the exit windows is optimized in the same manner as the entrance window. To protect detection equipment when the system is not in operation, shutters will be installed on the vacuum side of the exit windows.

D. Data Acquisition

A five-channel heterodyne detection system will be employed. The local oscillator will be phase locked to the carcinotron source at an intermediate frequency $IF = 880\ MHz$. The scattered signals will be mixed with the local oscillator and the resulting signals demodulated with the IF. Digitizers will record the demodulator output.

IV. SUMMARY

ETG modes may drive anomalous electron thermal transport in NSTX. A microwave scattering system will be deployed to directly observe ρ_e-scale fluctuations. The carcinotron source should provide adequate power to produce observable scattered signals. Inboard and outboard launch flexibility allow radial turbulent measurements in the range $|k_r| = 0 - 20\ cm^{-1}$. Good spatial resolution is achieved due to toroidal curvature.

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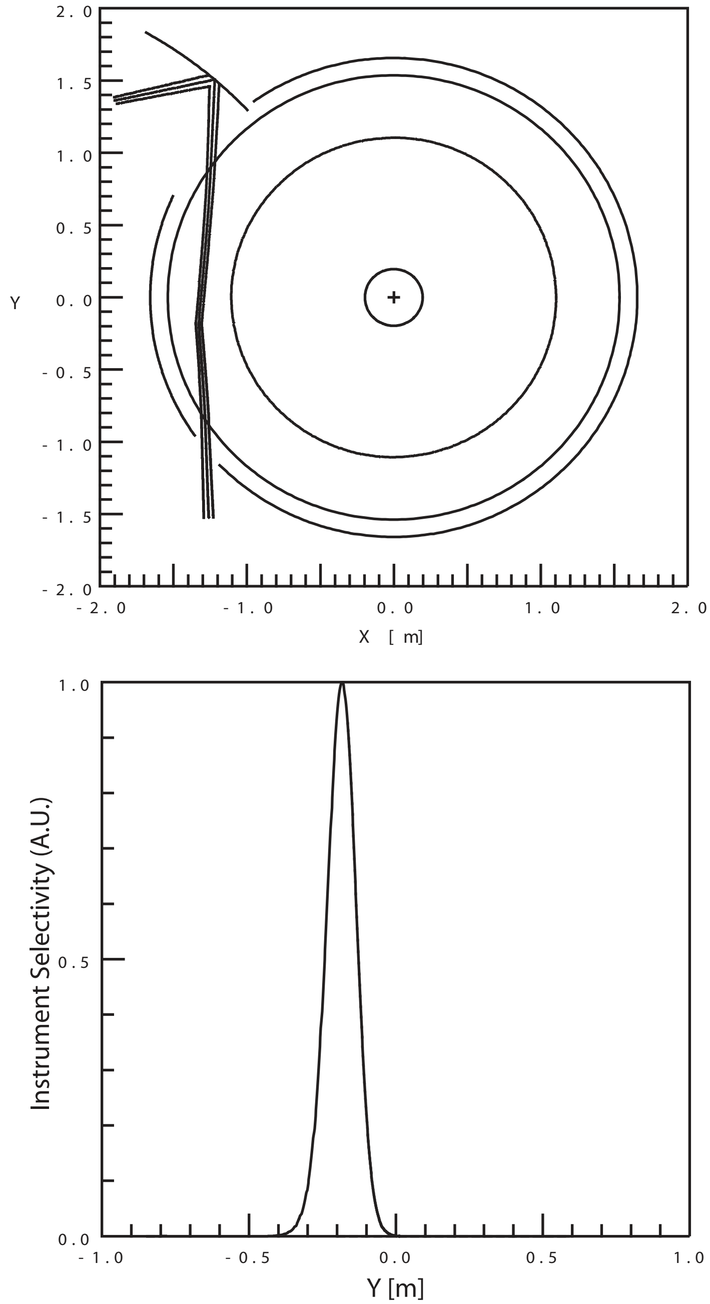

Figure 1: Instrument selectivity function for $k = 10\ cm^{-1}$.

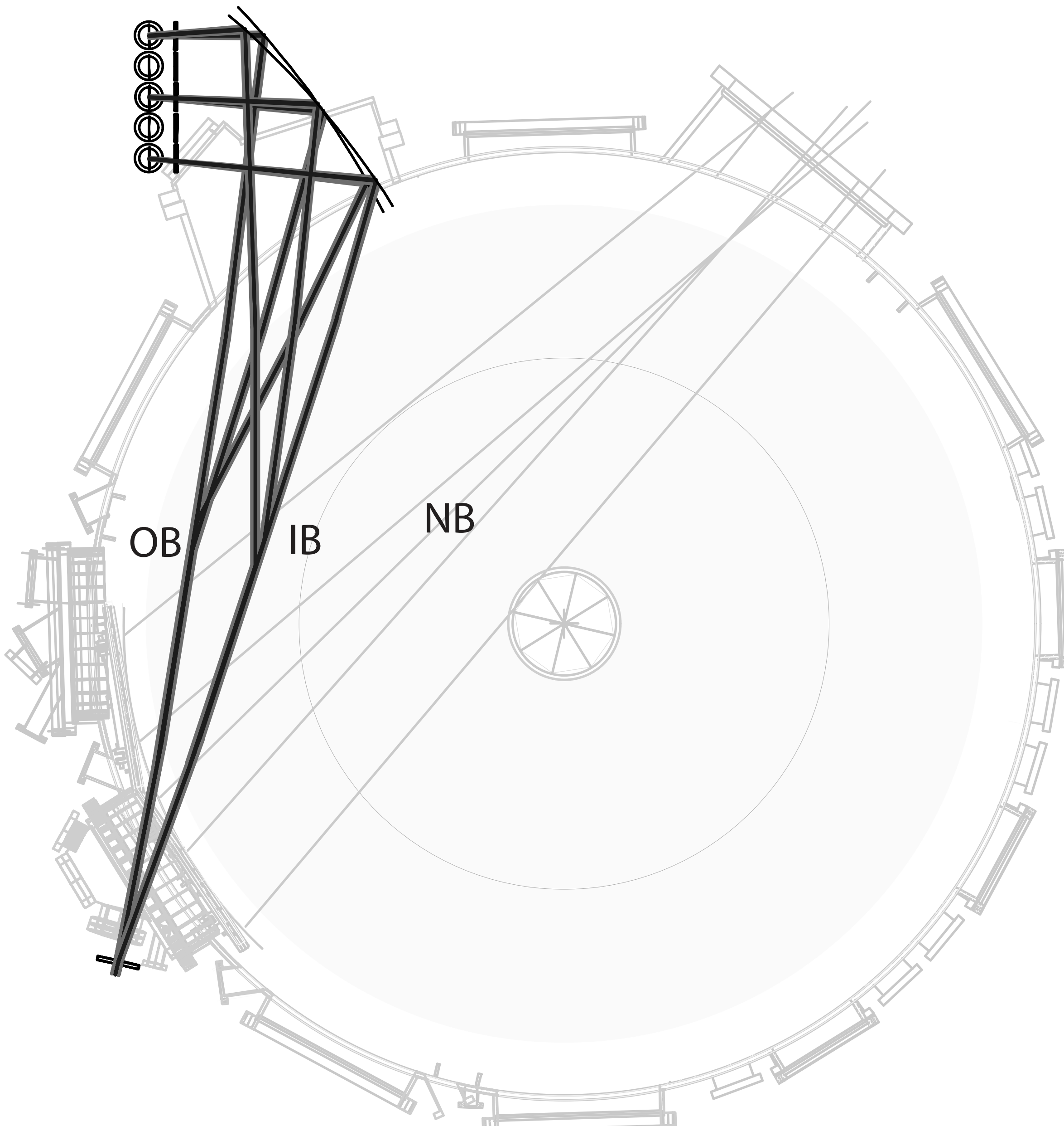

Figure 2: Overhead view of scattering system with inboard (IB) and outboard (OB) launch configurations and neutral beam sources (NB).

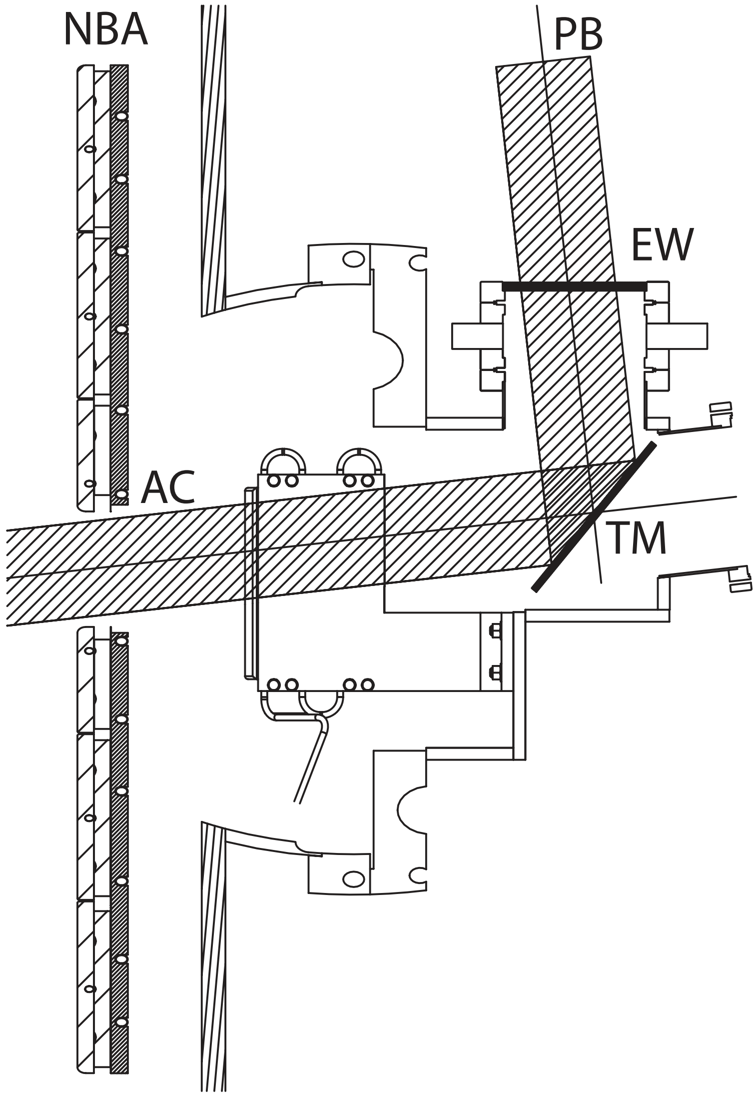

Figure 3: Launch port with probe beam (PB), entrance window (EW), turning mirror (TM), neutral beam armor (NBA), and neutral beam armor cut (AC). Plasma is to the left.

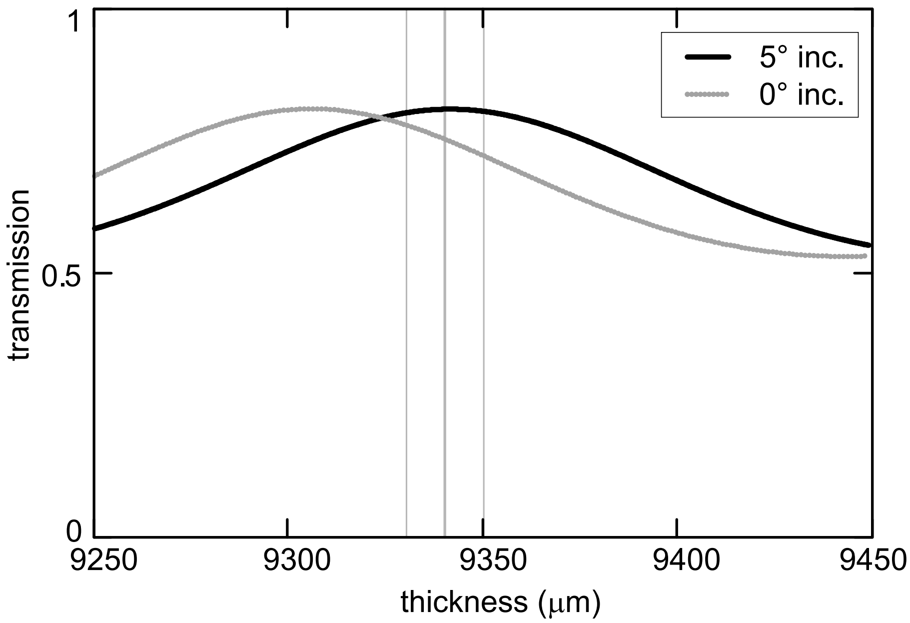

Figure 4: Etalon optimized transmittance vs. entrance window thickness for normal and 5° incident beams. Vertical lines correspond to manufacturer tolerance.

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