Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Experiment to Optimize the Conversion of EBWs to O-Mode on NSTX

OP-XP-309	**Revision: 3**	Effective Date: February 4, 2003 *(Ref. OP-AD-97)* Expiration Date: February 4, 2005 *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Title: Experiment to Optimize the Conversion of EBWs to O-Mode on NSTX **No.: 309**

1. Overview of Planned Experiment

The goal of this experiment is to measure electron Bernstein waves (EBWs) converted via the slow extraordinary mode to the ordinary electromagnetic mode (B-X-O emission) and to broaden the angular transmission window for B-X-O conversion in order to increase the effective conversion efficiency to > 80%. Discharges will be limited by the HHFW antenna structure in order to steepen the density gradient at the electron plasma frequency cutoff where transmission between the slow X-mode and the O-mode occurs at angles oblique to the magnetic field. The gap between the outer edge of the plasma and the front face of the HHFW antenna will be reduced to steepen the scrape off length at the HHFW antenna. The EBW emission will be measured by a microwave radiometer connected to a horn located between the HHFW antenna straps that incorporates a Boron nitride insert with a stepped wedge to direct the view towards the oblique B-X-O transmission window. The electron density profile near the plasma edge will be measured by an X-mode microwave reflectometer located at the same toroidal location as the EBW horn. This experiment will provide important information required to evaluate B-X-O conversion as a viable option for a future EBW heating and current drive system on NSTX.

2. Theoretical/Empirical Justification

The mode conversion and tunneling process between EBWs and the electromagnetic O-mode requires the coincidence of the X-mode and O-mode cutoffs [1-5]. This process has been studied extensively on Wendelstein 7-AS both for heating [6] and as a $T_e(R)$ emission diagnostic [7]. The B-X-O emission leaves the plasma through an angular window at an oblique angle with a transmission function given by [3,5]:

$$T(N_\perp, N_{//}) = \exp\left\{-\pi k_o L_n \sqrt{(Y/2)}\left[2(1+Y)(N_{//,opt} - N_{//})^2 + N_\perp^{\;2}\right]\right\} \quad (1)$$

where: k_o is the wavenumber, $N_{//,opt}^{\;2} = [Y/(Y+1)]$, $Y = (\omega_{ce}/\omega)$, ω_{ce} is evaluated at the cutoff and ω is the wave frequency. For NSTX this B-X-O emission window is located at about 55° from the direction of the magnetic field. The emission window has a width that increases with decreasing L_n at the O-mode cutoff. Figure 1 shows that the angular transmission window in equation (1) is broadened when L_n is reduced from 2 cm to 0.3 cm for fundamental EBW emission.

In a previous experiment on NSTX, XP-213, the conversion and tunneling of EBWs to the extraordinary mode (B-X conversion) was increased by a factor of four when L_n at the mode-conversion layer was shortened from ~ 2 cm to about 0.7 cm. In XP-213 the plasma was programmed to run with essentially no gap between the outer edge of the plasma and the

Boron nitride limiters in the HHFW antenna. The maximum conversion efficiency approached 50% when the outer gap was zero and L_n was reduced to 0.7 cm, in agreement with theoretical predictions that used the local L_n at the B-X conversion layer measured by X-mode reflectometry (Fig. 2) [8]. These EBW emission measurements were made using an existing microwave guide located between two of the HHFW antenna straps, viewing normal to the magnetic field. Recently, a modification was made to the microwave guide by installing a Boron nitride insert into the waveguide that includes a stepped wedge (Fig. 3(a)) that attempts to align the view with the peak of the B-X-O transmission window for frequencies around 12 GHz (Fig 3(b)).

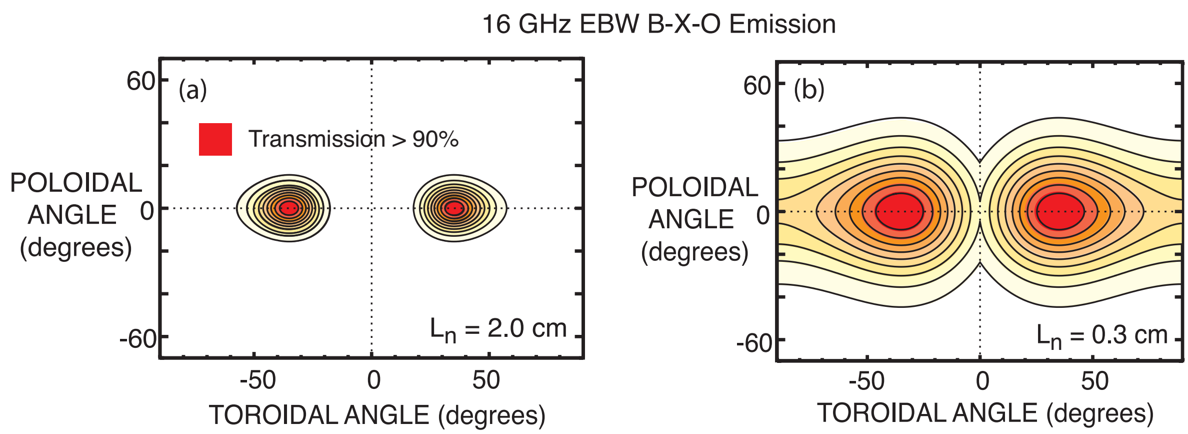

Figure 1 *Angular size of B-X-O transmission window, from equation (1) increases as L_n is shortened from (a) 2.0 cm to (b) 0.3 cm.*

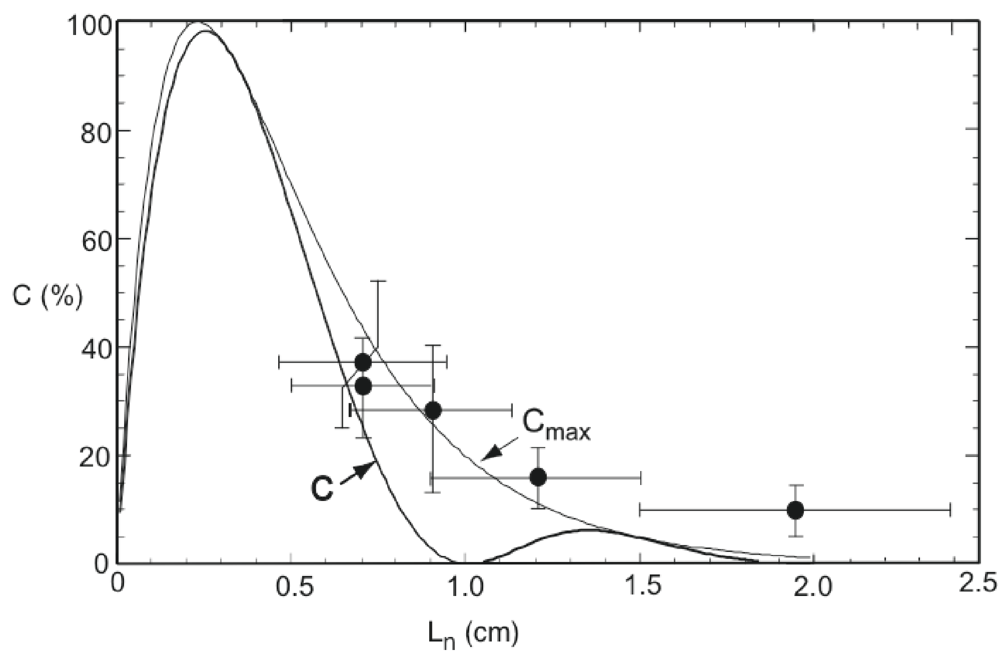

Figure 2 *Plot of theoretically expected B-X mode conversion efficiency versus density scale length (L_n) at the B-X conversion layer (lines) and the experimentally measured efficiency (T_{ebw}/T_e) and experimentally attained L_n measured by X-mode microwave reflectometry in XP-213.*

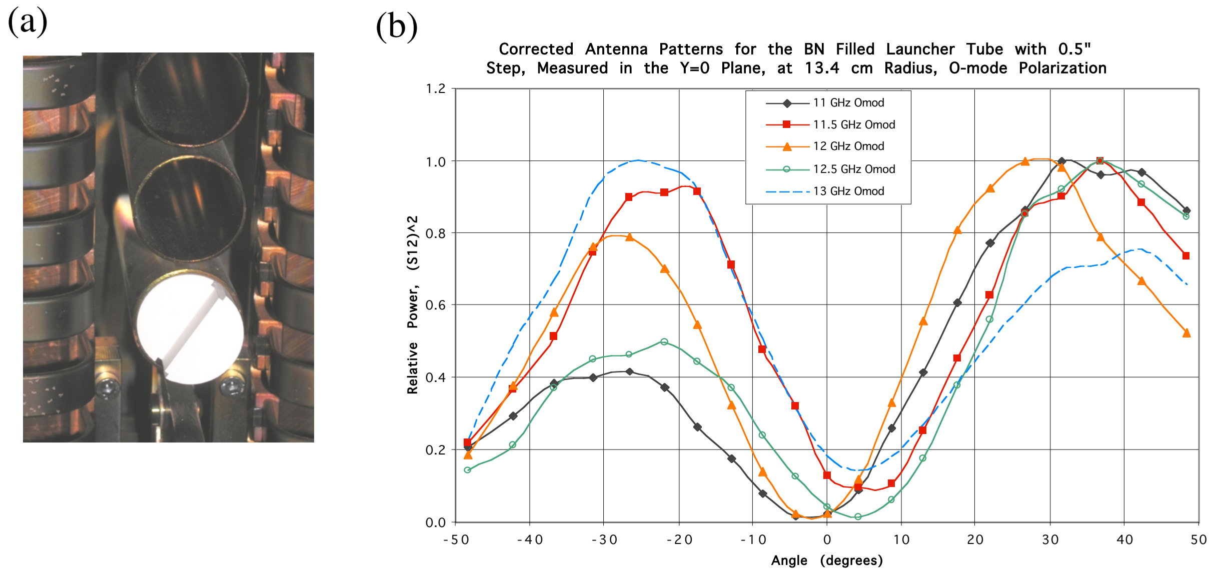

Figure 3(a) *Photo showing the Boron nitride insert installed inside one of the three microwave guides located between two of the HHFW antenna straps. A stepped wedge directs the view towards the B-X-O transmission window. The top two guides are used for X-mode reflectometry measurements of* L_n. ***(b)*** *Antenna pattern as a function of angle from the antenna axis for several frequencies between 11 and 13 GHz.*

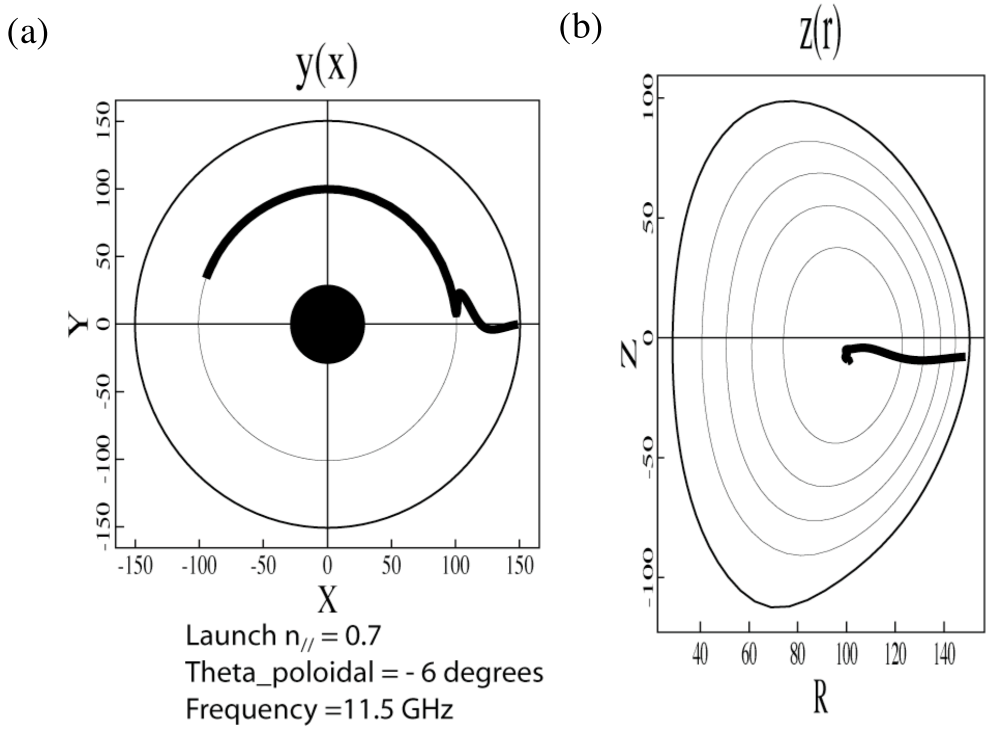

Figure 4 *EBW ray tracing for 11.5 GHz ray launched with* $n_{//}$*=0.7 to couple via B-X-O mode conversion. The results are for an EFIT equilibrium taken from shot 107975 at 300 ms. Ray damps very near the axis with* $n_{//} \sim 0$. ***(a)*** *Ray projected onto the a midplane toroidal cross section* ***(b)*** *Ray projected onto a poloidal cross section.*

This experiment will use a similar technique to XP-213. A sequence of discharges will be programmed to have increasingly smaller outer gaps. Based on our experience with XP-213 we will probably not be able to reach an L_n much shorter than 0.7 cm, so we would expect an angular emission window somewhere between the cases plotted in Figs. 1(a) and Fig. 1(b).

References:

[1] PREINHAELTER, J. and KOPÉCKY, V., J. Plasma Phys. **10**, 1 (1973).
[2] WEITZNER, H. and BATCHELOR, D.B., Phys. Fluids **22**, 1355 (1979).
[3] MJØLHUS, E., J. Plasma Phys. **31**, 7 (1984).
[4] NAKAJIMA, S. and ABE, H., Phys. Lett. A **124**, 295 (1987).
[5] HANSEN, F.R., et al., J. Plasma Phys. **39**, 319 (1988).
[6] LAQUA, H.P., et al., Phys. Rev. Lett. **78**, 3467 (1997).
[7] LAQUA, H.P., et al., Phys. Rev. Lett. **81**, 2060 (1998).
[8] TAYLOR, G., et al., "*Enhanced Conversion of Thermal Electron Bernsein Waves to the Extraordinary Electromagnetic Mode on the National Spherical Torus Experiment (NSTX)*", PPPL Report 3757 (October 2002).

3. Experimental Run Plan

Establish an ohmically-heated, deuterium plasma using the setup from shot 107975, an I_p = 800kA, B_o = 4kG, lower single null plasma. The experiment needs about 100 ms of I_p flattop without electron density glitches and a well-controlled shape. This XP will probably require about 10 shots.

a) Repeat same shot until the plasma conditions become reasonably reproducible and without significant MHD. Acquire MPTS $T_e(R)$ and $n_e(R)$ profile data during I_p flattop. Also obtain scrape off density profile at the HHFW antenna with ORNL X-mode microwave reflectometer. We would also like to get a density profile using the UCLA O-mode microwave reflectometer on the opposite side of the machine from the HHFW antenna. WE will use EFIT to determine Δ_{gap}, the distance between last closed flux surface and the front face of the HHFW antenna and adjust to ~ 4 cm.

b) Reduce Δ_{gap} to as close to zero as possible and repeat (a) for Δ_{gap} ~ 0 cm. Look for steepened scrape off density gradient on reflectometer data and enhanced EBW B-X-O transmission efficiency.

4. Required Machine, NBI, RF, CHI and Diagnostic Capabilities

No RF, NBI or HHFW required for this experiment, these are ohmically-heated discharges. See attached list of required diagnostics and machine parameter requirements. MPTS, ORNL reflectometer and EFIT equibria are essential for this experiment.

5. Planned Analysis

Compare measured B-X-O mode transmission efficiency (T_{ebw}/T_e) and the calculated transmission efficiency using the density scale length at the electron plasma frequency cutoff derived from the ORNL microwave reflectometer.

6. Planned Publication of Results

PPPL report and a journal publication in *Physics of Plasmas* if the results warrant it.

PHYSICS OPERATIONS REQUEST

Title: **Experiment to Optimize the Conversion of EBWs to O-Mode on NSTX** **XP No.: 309**

Machine conditions (indicate range where appropriate):

TF: Flattop (kG) 4.0 Flattop start/stop (s) 0.0 / 0.5

I_p: Flattop (kA) 800 Flattop start/stop (s) 0.2 / 0.4

Position: Outer Gap (m) 0-0.04 Z (m) 0 ~~Inner wall~~ / Single null / ~~Double null~~

Gas: He (inside gas feed) Puff yes, plus LDGFIS ? n_e.l programmed to avoid flat-top tearing mode

NBI: Power (MW) ______ Start / stop (s) ________ Voltage (kV) ______

RF: Power (MW) ______ Start / stop (s) ________ Frequency (MHz) ______

CHI: Off ~~/ Start-up / Ramp-up / Sustainment~~

If this is a continuation of a previous run or if shots from a previous run are similar to those needed, provide shot numbers for setup

Setup shot 107975, I_p = 800 kA, B_o = 4 kG, lower single null limited target plasma

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If shots are new and unique, sketch desired time profiles and shapes. Accurately label the sketch so there is no confusion about times or values. Attach additional sheets as required.

DIAGNOSTIC CHECKLIST

Title: **Experiment to Optimize the Conversion of EBWs to O-Mode on NSTX**

No. **309**

Diagnostic system	**Need**	**Desire**	**Requirements** (timing, view, etc.)
Magnetics	✓		
Fast visible camera		✓	
VIPS-1		✓	
VIPS-2		✓	
SPRED		✓	
GRITS		✓	
Visible filterscopes		✓	
VB detector		✓	
Midplane bolometer		✓	
Diamagnetic flux		✓	
Density interferometer (1mm)		✓	
FIReTIP interf'r/polarimeter		✓	
Thomson scattering	✓		Essential for EBW conversion efficiency
CHERS			
NPA			
X-ray crystal spectrometer			
X-ray PHA			
EBW radiometer	✓		Essential at HHFW location
Mirnov arrays		✓	
Locked-mode detectors			
USXR arrays		✓	
2-D x-ray detector (GEM)		✓	
X-ray tangential camera		✓	
Reflectometer (4 ch.)		✓	Scanning mode
Neutron detectors			
Neutron fluctuations			
Fast ion loss probe			
Reciprocating edge probe		✓	
Tile Langmuir probes			
Edge fluctuation imaging			
H-alpha cameras (1-D)			
Divertor camera (2-D)			
Divertor bolometer (4 ch.)			
IR cameras (2)			
Tile thermocouples			
SOL reflectometer	✓		ORNL reflectometer is essential