Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

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

OP-XP-404	**Revision: 0**	Effective Date: December 10, 2003 *(Ref. OP-AD-97)* Expiration Date: December 10, 2005 *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Title: Experiment to Optimize the Conversion of EBWs to X-Mode on NSTX — OP-XP-404

1. Overview of Planned Experiment

The goals of this experiment are twofold. First, to demonstrate the measurement of the electron temperature on NSTX using mode-converted EBW's in support of an ongoing DoE plasma diagnostic initiative to develop an EBW electron temperature profile diagnostic for overdense ($\omega_{pe} > \omega_{ce}$) plasmas. Second, to demonstrate a B-X conversion efficiency ≥ 80% on NSTX as a prerequisite for installing an EBW heating and current drive system. A new EBW antenna with two radially adjustable carbon limiters (Fig. 1) has been installed on NSTX to measure extraordinary electromagnetic mode emission converted from electron Bernstein waves (EBWs) (B-X emission) and to optimize the B-X conversion efficiency with a local limiter. The new EBW antenna has two quad-ridge horns that will be used for both EBW radiometery and O-mode reflectometry. The electron density scale length (L_n) at the B-X mode conversion layer is an important parameter in determining the B-X conversion efficiency. The O-mode reflectometer will measure L_n at the B-X mode conversion layer in front of the EBW antenna.

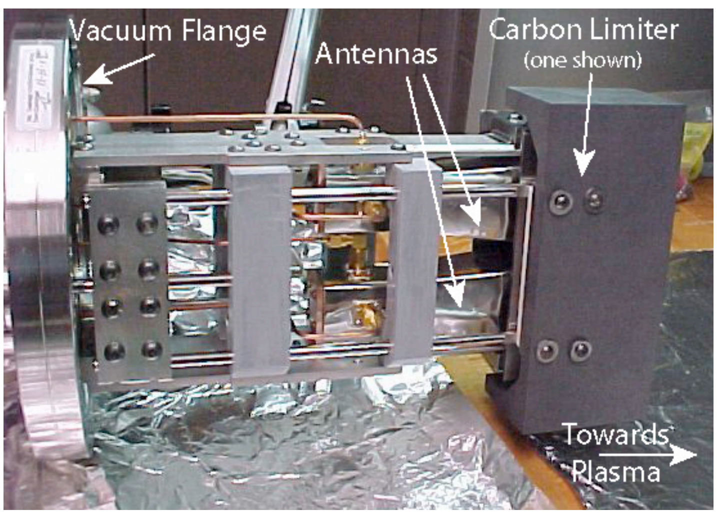

Figure 1 *Photograph showing a side view of the NSTX EBW B-X antenna assembly with radially adjustable carbon limiters. The two carbon limiters can be moved independently over a major radial distance of about 3 cm. The assembly has two quad-ridged horn antennas. In addition to EBW radiometry the horns will be used by an O-mode reflectometer to measure L_n at the B-X conversion layer. The antenna includes a port for a gas injection valve.*

2. Theoretical/Empirical Justification

Fundamental EBWs convert and tunnel to the fast X-mode at the upper hybrid resonance (UHR) that usually surrounds the NSTX plasma just outside the last closed flux surface (LCFS) [1-3]. EBWs first convert to the slow X-mode at the UHR. A cutoff-resonance-cutoff triplet formed by the left hand cutoff of the slow X-mode, the UHR, and the right hand cutoff of the fast X-mode allows the slow X-mode to tunnel through the UHR to the fast X-mode. The mode conversion efficiency (C) for $k_{//} = 0$ is given by [3]:

$$C = 4e^{-\pi\eta}\left(1 - e^{-\pi\eta}\right)\cos^2(\phi/2 + \theta) \qquad (1)$$

where $cos^2(\phi/2+\theta)$ is a phase factor relating to the phasing of the waves in the mode conversion region and the term preceding this is the maximum mode conversion efficiency. Here η is a tunneling parameter, which for magnetic scale lengths much greater than the density scale length at the UHR [3], is given by:

$$\eta \approx \left[\omega_{ce} L_n / (c\alpha)\right]\left[(1+\alpha^2)^{1/2} - 1\right]^{1/2} \qquad (2)$$

where L_n, the density scalelength, and $\alpha = \omega_{pe}/\omega_{ce}$ are evaluated at the UHR layer and c is the velocity of light. From these equations it can be seen that the B-X conversion efficiency is very sensitive to changes in L_n at the UHR layer where the wave frequency, $\omega = \omega_{UHR}$.

B-X mode conversion is particularly well suited for ST plasmas since the UHR layer for fundamental EBW conversion lies in the scrape off layer outside the LCFS where L_n can be modified without affecting plasma performance. On NSTX the maximum mode conversion efficiency for fundamental EBWs occurs for L_n ~ 0.3 - 0.6 cm.

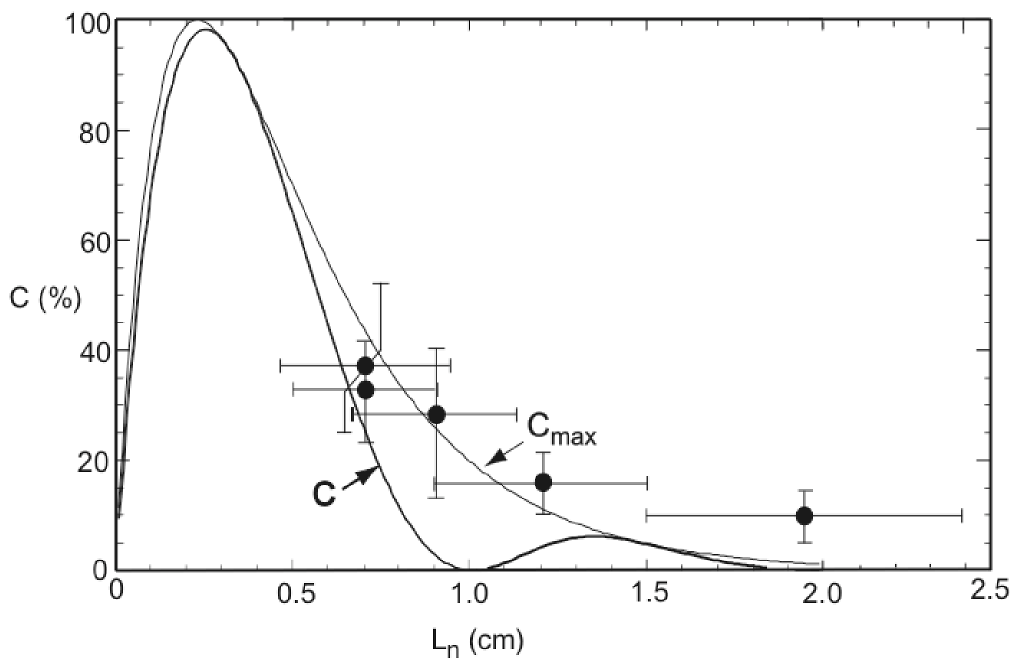

Figure 2 *Plot of theoretically expected B-X mode conversion efficiency for fundamental EBW from the NSTX core versus density scale length (L_n) at the B-X conversion layer (lines) and the measured efficiency (T_{ebw}/T_e) and attained L_n measured by X-mode microwave reflectometry in XP-213.*

In a previous experiment on NSTX, XP-213, the 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 (Fig. 2) [4]. 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. To reach ≥ 80% B-X conversion L_n needs to be reduced to about 0.3 cm. In XP-213 the minimum attainable L_n was limited by the connection length along the magnetic field lines between the Boron nitride tiles. The new EBW antenna was designed to have a connection length that can be made short enough to produce $L_n \sim 0.3$ at the UHR layer.

References:

[1] NAKAJIMA, S. and H. ABE, Phys. Rev. A **38**, 4373 (1988).
[2] SUGAI, H., Phys. Rev. Lett. **47**, 1899 (1981).
[3] RAM, A.K., and SCHULTZ, S. D., Phys. Plasmas **7**, 4084 (2000).
[4] TAYLOR, G., et al., Phys. Plasmas **10**, 1395 (2003).

3. Experimental Run Plan

Dedicated run time for this experiment will be requested only after the new EBW antenna has been fully commissioned with the UCLA O-mode reflectometry operational on the antenna and providing routine measurements of the scrape off density profile. Remote operation of the radially adjustable carbon limiters is also a prerequisite for this experiment. A gas feed is available at the EBW antenna if the electron density is not high enough to make the plasma overdense near the front face of the antennas. The following run plan requires about 20 plasma shots.

I. L_n Scan for Optimum B-X Conversion (run EBW radiometer dwelling at one frequency ~ 11.5 GHz (i.e. EBW emission from near the plasma axis):

a) Establish an ohmically-heated, helium plasma using the setup from shot 107975, an I_p = 800 kA lower single null plasma, with B_o = 4 kG. The experiment needs about 150 ms of I_p flattop without electron density glitches and a well-controlled shape. Five minutes of He GDC will be performed between shots. The experiment will begin with both the B-X antenna limiters A and B fully extended towards plasma (see Fig. 3(a)). Here we define the displacement of A and B limiters as Δ_A and Δ_B, respectively. Where a displacement of 0 cm is fully retracted and 3 cm is fully extended towards the plasma. **(5 shots)**

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. Acquire data on two similar shots. Obtain scrape off density profile in front of the EBW antenna with the UCLA O-mode microwave reflectometer in swept mode. Measure L_n at the B-X conversion layer and EBW T_{rad}/T_e, where T_e is measured by MPTS. **(2 shots)**

b) Move limiter B away from the plasma so that Δ_B = 2, 1 and 0 cm, two shots at each position. Measure L_n at B-X conversion layer and EBW T_{rad}/T_e. **(6 shots)**

c) Set Δ_B = 3, move limiter A back from plasma so that Δ_A = 2, 1 and 0 cm, two shots at each position. Measure L_n at B-X conversion layer and EBW T_{rad}/T_e. **(6 shots)**

(a) (b)

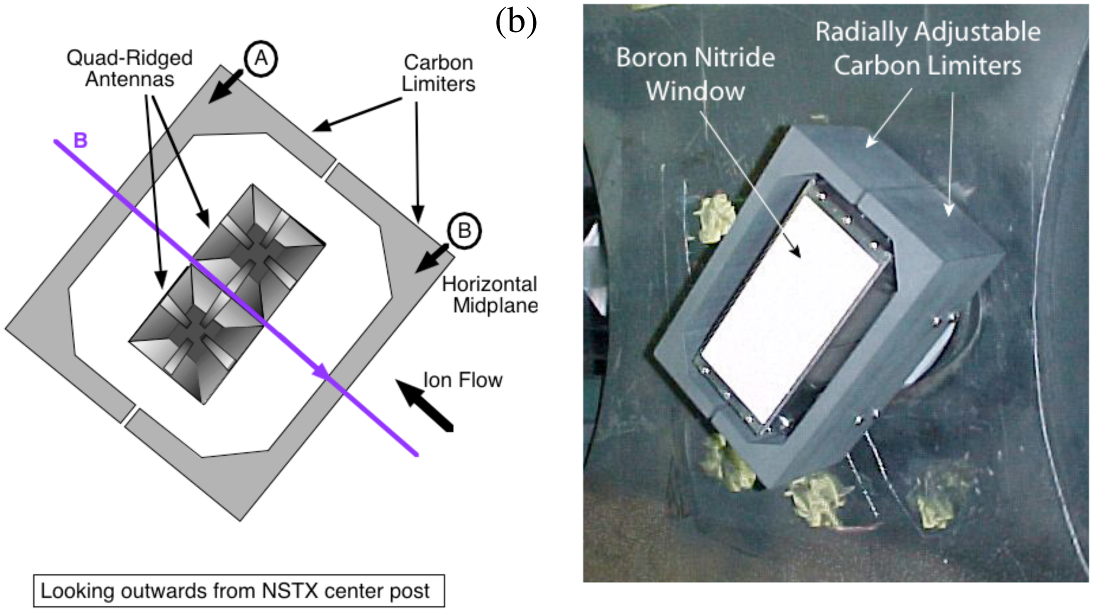

Figure 3(a) *Schematic showing the EBW B-X antenna with radially adjustable carbon limiters. The two limiters are labeled A and B. Limiter A is on the electron flow side and limiter B is on the ion flow side of the antenna.* ***(b)*** *Photograph showing the new EBW antenna installed inside NSTX. The antenna has a white Boron nitride window covering the two quad-ridged horns. The antenna is rotated to orient the ridges to be parallel and normal to the edge magnetic field.*

II. Run EBW radiometer in swept frequency mode (8-12 GHz) at maximum B-X conversion:

Set Δ_A and Δ_B for maximum B-X conversion and obtain and EBW T_{rad}/T_e vs radius where T_e is measured by MPTS on two similar shots. **(2 shots)**

III. Attempt to use HHFW to Suppress Edge Fluctuations:

It has been noted on NSTX in the past that edge density fluctuations can be reduced or suppressed when HHFW power is coupled to the plasma. Plan to couple 1-2 MW of HHFW power into some of the shots during the last 50 ms of the current flat top to assess the effect of HHFW on edge density fluctuations and EBW B-X conversion. **(run piggyback)**

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

No NBI is required for this experiment. HHFW at ~ 2 MW is required for some discharges. See attached list of required diagnostics and machine parameter requirements. The X-mode EBW radiometer at Bay I/J, MPTS, UCLA O-mode reflectometer at Bay I/J and EFIT equilibrium are essential for this experiment. The ORNL X-mode reflectometer at the HHFW antenna is desired to monitor the outer gap and to look for a decrease in edge density fluctuations with HHFW.

5. Planned Analysis

Compare measured B-X mode transmission efficiency (T_{ebw}/T_e) and the calculated transmission efficiency using L_n at the B-X conversion layer derived from the UCLA O-mode 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 X-Mode on NSTX** **OP-XP-404**

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 / 0.35

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.I programmed to avoid flat-top tearing mode

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

RF: Power (MW) 2 Start / stop (s) 0.3 – 0.35 Frequency (MHz) 30

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, an I_p = 800 kA, lower single null plasma, but with B_o = 4.0 kG

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

Experiment to Optimize the Conversion of EBWs to X-Mode on NSTX **OP-XP-404**

Diagnostic	Need	Desire	Instructions
Bolometer – tangential array		✓	
Bolometer array - divertor			
CHERS			
Divertor fast camera			
Dust detector			
EBW radiometers	✓		Essential at EBW antenna bay I/J location
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy			
Fast lost ion probes - IFLIP			
Fast lost ion probes - SFLIP			
Filtered 1D cameras			
Filterscopes		✓	
FIReTIP		✓	
Gas puff imaging			
Infrared cameras			
Interferometer - 1 mm		✓	
Langmuir probe array			
Magnetics - Diamagnetism		✓	
Magnetics - Flux loops	✓		
Magnetics - Locked modes			
Magnetics - Pickup coils	✓		
Magnetics - Rogowski coils	✓		
Magnetics - RWM sensors			
Mirnov coils – high frequency			
Mirnov coils – poloidal array			
Mirnov coils – toroidal array			
MSE			
Neutral particle analyzer			
Neutron measurements			
Plasma TV		✓	
Reciprocating probe		✓	
Reflectometer – core (UCLA)	✓		Essential at EBW radiometer bay I/J
Reflectometer – SOL (ORNL)		✓	
RF antenna camera			
RF antenna probe			
SPRED		✓	
Thomson scattering	✓		Essential for EBW conversion efficiency
Ultrasoft X-ray arrays		✓	
Visible bremsstrahlung det.		✓	
Visible spectrometers (VIPS)		✓	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray PIXCS (GEM) camera			
X-ray pinhole camera		✓	
X-ray TG spectrometer		✓	