Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: HHFW Power Deposition by RF Modulation		
OP-XP-412	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(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: HHFW Power Deposition by RF Modulation **OP-XP-412**

1. Overview of planned experiment

The goal is to measure where HHFW power is deposited in the plasma for a number of rf and plasma conditions. The Ultra-Soft X-ray (USXR) diagnostic will be used to obtain good time-resolved data of temperature and impurity profile evolution during the heating. The HHFW power will be square-wave modulated to provide a good time-dependent signal from the USXR for the modulation studies.

The first day of this XP, which is the only one described here, is an exploratory one. We will attempt to obtain good USXR data and do preliminary scans of plasma parameters and rf properties to determine what parameters give good analyzable data.

If the technique proves successful, we can use it to study electron power deposition and transport over a wide range of plasma conditions, including reversed shear scenarios.

2. Theoretical/ empirical justification

A few shots with HHFW modulation were taken in piggyback mode in January 2003. Modulation was clearly observed on the low-energy USXR channels. Inversion of the modulated signal was possible and indicated the source of the modulated signal was in the outer half of the plasma; this was probably caused by density or impurity changes. The high-energy array, which is sensitive to T_e changes near the center of the plasma, showed remarkably little modulation; analysis of the data from one shot indicated that $\Delta T_e/T_e \leq 1\%$, which is significantly less than calculations predict. However, the signal/noise ratio with the arrays was good, and the emission profiles appear up/down symmetric. This should allow for good inversion of the chord-integrated signals with high time resolution.

Prior measurements of HHFW power deposition were attempted using Thomson scattering, and firing the two lasers with a short (but variable) time separation (in the 1 to 10 ms range). Results using the 10-channel version of the Thomson scattering system were inconclusive, probably due to limited spatial resolution and very limited (2 points) time resolution. The USXR system provides significantly higher time resolution (down to 5 μs) and should provide good spatial resolution with 30 up/down and 18 in/out detectors at Bay G and another 15 in/out detectors at Bay J.

The results indicate that the USXR arrays can act as sensitive diagnostics to measure changes of the electron temperature near the plasma center ($r/a \leq 0.6$), and will be useful tools to look for the predicted centrally-peaked power deposition, *if* it is not obscured by possible anomalous transport effects (e.g., grad-T limiting of profile steepness).

3. Experimental run plan

We are searching for experimental plasma conditions that will show central power deposition in agreement with rf theory. This experiment can be run in piggy-back mode initially to look for modulation of $T_e(0)$ for a variety of plasma conditions. **This XP is written assuming that sufficient operation of the HHFW system with modulation has been done to identify plasma regimes where central T_e modulation can be observed.** If this is not the case, then a day or part-day experiment can be done using several plasma conditions to look for T_e modulation.

Initial plasma conditions

Initial plasma conditions will be similar to shot 109758 (4.5 kG, 600 kA, He discharge, LSN, avg. density = 3 - 4 x 10^{19} m^{-3}, $T_e(0)$ = 1.5 – 2 keV). He operation is chosen because it tends to prevent H-mode operation; while H-mode is desirable eventually, the development of the technique and initial analysis may be made easier if it is avoided.

Initial RF conditions

Power: RF power will be set at about 2.5 MW. We may start at lower power (~1 MW) prior to the plasma becoming diverted, and increase the power after that to prevent power trips.

Phasing: Initial phasing will be –90° (co-CD). During the experiment we will plan to take data at –90°, +90°, and 0π0π0π phasing, with others possible for later runs.

Modulation: A significant part of the experiment will be to determine the best modulation conditions. Initially, we will start with about 50% power modulation, using square-wave modulation frequencies of50 Hz ($\tau_E \approx$ 20 ms during similar conditions).

Shot list:

We will determine the initial shot conditions based on results from piggyback experiments, which must be run before the dedicated day. Nevertheless, the general concept of density, current, power, and phase scans should be the same.

1. Set up initial conditions, get 2 shots alike, check X-ray signals. Need enough power to get $T_e(0)$ > 1 keV, then need to check X-ray signals. Take 2 shots with 50-Hz modulation and two with 25-Hz modulation. (**6 shots, including setup).**
2. Reduce power level to just enough so that good signals are obtained on USXR detector and obtain data at that power. (**3 shots**)
3, Change phase to 0π0π0π, get 2 shots alike (**3 shots**). Choose power level based on results from steps 1 and 2.
4. Decrease the density to1-2x 10^{19} m^{-3}. Use phase, power, and modulation frequency from steps 1 – 3 that looks most promising (**6 shots**).
5. Change to Ip = 900 kA. Repeat phase scan at two density levels (**12 shots).**

During several shots in above run, T_I measurements will be done using beam blips and the CHERS diagnostic. In addition, the MPTS lasers will be adjusted to have a small time interval between firing of the two lasers (1 ms initially, increasing to 5 ms if no change in T_e profile is measurable with the 1-ms separation) during a subset of the shots in order to look for changes in T_e during the modulation. For most shots the MPTS lasers will be fired at the normal (16.7 ms) interval.

Deleted: to 5 ms

Deleted: , depending on observations

4. Required machine, NBI, RF, CHI and diagnostic capabilities

HHFW system operational with reliable 2-3 MW power. Good control of plasma, particularly inner and outer gaps.

Diagnostics:

USXR arrays.

SPRED and visible spectroscopy for relative impurity fraction and influx

FireTIP channels for monitoring electron density changes

Magnetics and EFIT analysis

MPTS (see above for operation with small Δt between lasers)

Possibly, Ar puff with X-ray spectrometer for ion temperature measurements.

CHERS with 10-ms beam blips for T_i measuremennts on some shots.

5. Planned analysis

Initial analysis will be observation and inversion of modulated and unmodulated signal components from the USXR arrays. Software to do this has been written and tested.

If modulation is observed, MIST modeling of the USXR data to determine the Te and impurity profile changes. This requires EFIT and MPTS/FireTIP electron density data for the shots as input to the analysis. It is anticipated that the density and impurity profiles will not change on the time scales of the electron power deposition measurement, which will simplify analysis. However, initial results will be analyzed to determine whether this a good assumption.

If reasonable data is obtained, the experimental measurements will be compared to power deposition codes of various flavors (e.g., TORIC, CURRAY, AORSA).

6. Planned publication of results.

Preliminary presentations might be made at the EPS meeting and/or APS meeting. Eventually, publication in a peer-reviewed journal comparing measured power deposition and rf modeling results will be done.

If the USXR measurements are successful, a second paper will be published in PPCF or PoP on these measurements and analysis.

PHYSICS OPERATIONS REQUEST

Title: HHFW Power Deposition by RF Modulation **OP-XP-412**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **52 kA (4.5 kG)** Flattop start/stop (s):

I_P (MA): **600 kA and 900 kA** Flattop start/stop (s): **0.150 / 0.500**

Configuration: **LSN**

Outer gap (m): **0.05** Inner gap (m): **0.05**

Elongation κ: _____, Triangularity δ: _____

Z position (m): **0.00**

Gas Species: **He** Injector: **Outboard**

NBI - Species: **D**, Sources: **C**, Voltage (kV): **?**, Duration (s):**0.01**

ICRF – Power (MW):**2-3**, Phasing: **CD**, Duration (s): **0.3**

CHI: **Off**

Either: List previous shot numbers for setup: **109758**, except n ≈ 3 – 4 e19.
Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

Title: HHFW Power Deposition by RF Modulation **OP-XP-412**

Diagnostic	Need	Desire	Instructions
Bolometer – tangential array	✔		
Bolometer array - divertor			
CHERS	✔		
Divertor fast camera			
Dust detector			
EBW radiometers		✔	
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		✔	
Reflectometer - SOL		✔	
RF antenna camera		✔	
RF antenna probe		✔	
SPRED			
Thomson scattering	✔		
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			