Electron Bernstein Wave Experiments in an Overdense Reversed Field Pinch Plasma

P.K. Chattopadhyay*, J.K. Anderson*, T.M. Biewer*, D. Craig*, C.B. Forest*, R.W. Harvey† and A.P. Smirnov**

**Department of Physics, University of Wisconsin, Madison WI 53706*
†*CompX, Del Mar, California 92014*
***Moscow State University, Moscow, Russia*

INTRODUCTION

Here we report the observation of blackbody levels of emission in the ECRF range of frequencies from an overdense MST reversed field pinch plasma. We speculate the emission is a result of mode conversion of EBW to electromagnetic wave through the XB process[1]. It has previously been proposed and theoretically shown that EBWs may be suitable for driving current and heating in RFP[2] provided a technique for coupling to the waves can be found. By reciprocity, the observation of emission shows that it is possible to couple to these waves and possibly drive current. We also present results from a coupling experiment in which rf is injected into waveguide antenna; under certain conditions related to the edge density gradient, low reflected power is observed.

EMISSION EXPERIMENTS

The experiments were performed in the MST[3] reversed field pinch (major radius (R) = 1.5 m, minor radius (a) = 0.52 m). Emission was measured by a broadband double-ridge horn antenna (aperture 5 cm$\times$ 5 cm), with an antenna gain of 13-17 dB ($\Delta N_{||} = \pm 0.34 - \pm 0.22$) over the bandwidth 3.8-8.2 GHz, located 19^o above the toroidal mid-plane. The antenna views the plasma radially and is rotatable to receive radiation with $\mathbf{E}_{rad} \parallel \mathbf{B}$ or $\mathbf{E}_{rad} \perp \mathbf{B}$. The emission was detected by a 16 channel absolutely calibrated homodyne radiometer.

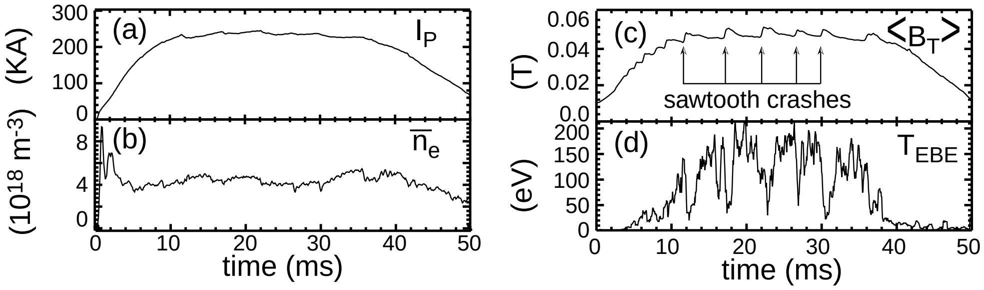

FIGURE 1. Time histories of the plasma current (I_P), line averaged plasma density density ($\overline{n}_e$), average toroidal magnetic field and radiation temperature of EBE at 5.75 GHz.

Black-body emission is observed from over-dense RFP plasmas as seen in Fig. 1. The radiometer signal [trace (d)] corresponds to the frequency $f = 5.75$ GHz, and should be associate with emission from the core. The line average electron density is $\overline{n}_e \sim 4\times\ 10^{18}\ \mathrm{m}^{-3}$. The plasmas are clearly over-dense and do not support propagating electromagnetic waves at this frequency. Emission drops dramatically at 'sawteeth', flux generation events which sustain the poloidal current in the edge of the RFP. This is largely due to the influence of the edge density profile on the mode conversion efficiencies; the sawteeth strongly modify the edge density profile.

The observed spectra for both O ($\mathbf{E}_{rad} \parallel \mathbf{B}$) and X mode ($\mathbf{E}_{rad} \perp \mathbf{B}$) are shown in Fig. 2 (a). These spectra represent an ensemble average of approximately 25 sawteeth during the period between sawtooth crashes. The radiation temperatures for both polarizations are comparable to the electron temperature as measured by Thomson scattering and are therefore of blackbody levels. The X-mode polarization, however, has a measurably higher radiation temperature. The difference between the radiation temperatures for the two polarizations is attributable to the differences in the mode conversion efficiencies from EBW to O-mode and X-mode, the dependence of the mode conversion efficiencies on angle, and the antenna pattern. Fig. 2(b) shows the radiation temperature measured by the radiometer (T_{EBE}) mapped to plasma radius. Ray tracing calculations are used to determine the emission location and include the Doppler shift from the cold EC resonance as described in Ref. [2]. For frequencies higher than 5.75 GHz, harmonic overlap occurs; core emission from the fundamental resonance is absorbed at the second harmonic near the edge. The observed levels of emission are consistent with emission from the 2nd harmonic at the edge.

Comparisons of the temperature as measured by Thomson scattering ($T_{Thomson}$) with

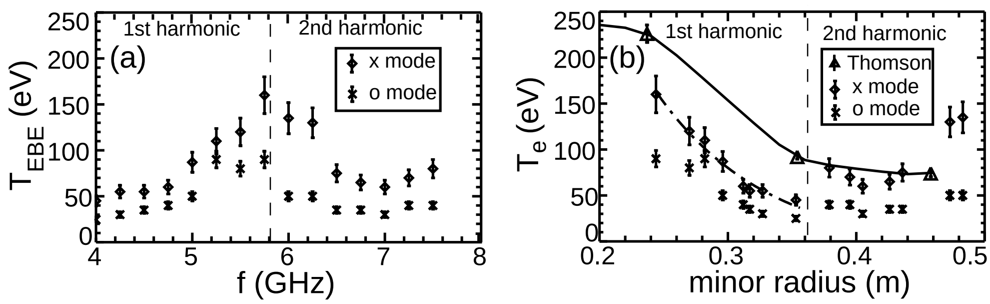

FIGURE 2. (a) Measured O and X mode radiation temperature vs frequency. (b) Spectrum for O and X mode EBE radiation temperature mapped to minor radius. Also shown is the electron temperature measurements from Thomson scattering. The vertical dashed lines at 5.8 GHz separate two cyclotron harmonics.

T_{EBE} the mode-conversion efficiency can be inferred from the ratio $T_{EBE}/T_{Thomson}$ at a given position/frequency and can be compared to the theoretical value as given in [1] $C = 4e^{-\pi\eta}(1-e^{-\pi\eta})$, where $\eta = \frac{1}{\alpha}(\omega_{ce}L_n/c)\sqrt{\sqrt{1+\alpha^2}-1}$, $\alpha = \omega_{pe}/\omega_{ce}$ and $L_n = n/|\frac{\partial n}{\partial r}|$ is the density scale length. All quantities are evaluated at the UHR layer where the mode conversion process takes place. In MST, for line average electron density $\overline{n}_e \sim 4\times 10^{18}$ m^{-3}, the density scale length (measured with triple Langmuir probe) $(L_n)_{UHR}$ ~1.4 cm, $\alpha = 2$ for 5.75 GHz giving η = 0.46. The theoretical maximum mode conversion efficiency $C_{max} \sim$ 70%, experimentally we find the efficiency is 75%.

COUPLING EXPERIMENTS

Experiments have also been performed to actively launch power into MST. We have performed coupling experiments using an unterminated S-band waveguide in the frequency range of 2.8-3.8 GHz with ~1 watt of power. From the measured forward and reflected power, the reflection coefficient at the end of the waveguide can be inferred and is shown in Fig. 3.

Pulsed poloidal current drive (PPCD) discharges were used to actively control the edge density gradients during the coupling experiment. PPCD discharges are obtained by applying an inductive poloidal electric field; these plasmas are characterized by steep edge density gradients and improved energy and particle confinement. During PPCD a substantial decrease of reflected power is observed. A strong correlation between the edge density and the reflected power is observed. Finally, the reflection decreases with frequency. The precise dependence of reflection with the edge density is under

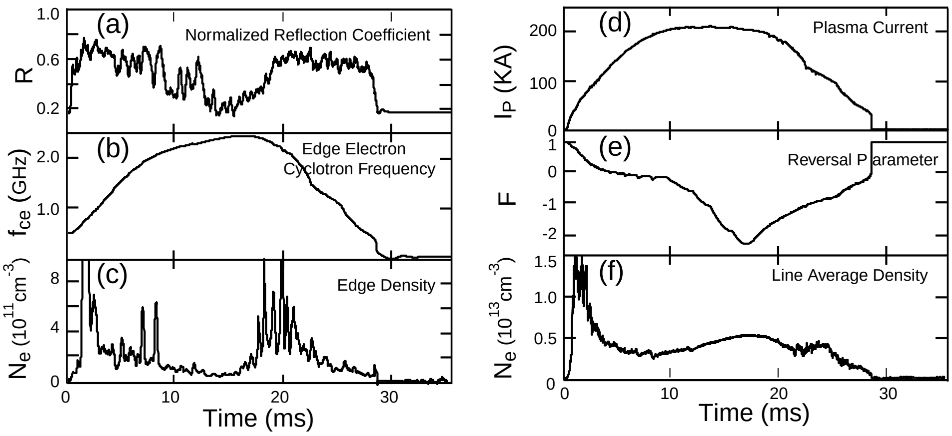

FIGURE 3. Time histories of the reflection coefficient(R), edge cyclotron frequency (f_{ce}), edge density (N_e), plasma current (I_P), reversal parameter (F) and line average density (N_e). 1 watt of rf power at 3.8 GHz is applied to the plasma.

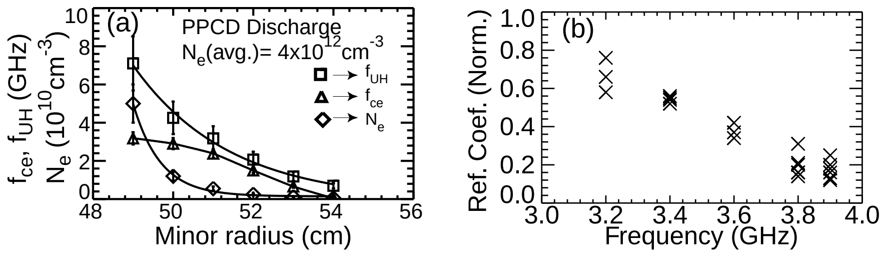

FIGURE 4. (a) Edge profiles for cyclotron frequency (f_{ce}), upper hybrid frequency (f_{UH}) and electron density (N_e), (b) normalized reflection coefficient (R) vs frequency of applied power (f). The profiles correspond to the time ** in fig. 3.

investigation.

The authors are grateful for helpful discussions with Abhay Ram, Stewart Prager and Mark Carter. This work was supported by the U.S. Department of energy.

REFERENCES

1. Ram, A., and Schultz, S., *Phys. Plasmas*, **7**, 4084 (2000).
2. Forest, C. B., Chattopadhyay, P. K., Harvey, R. W., and Smirnov, A. P., *Phys. Plasmas*, **7**, 1352 (2000).
3. Dexter, R. N., Kerst, D. W., Lovell, T. W., Prager, S. C., and Sprott, J. C., *Fusion Technol.*, **19**, 131 (1991).