Accessibility of electron Bernstein modes in over-dense plasma

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Abstract. Mode-conversion between the ordinary, extraordinary and electron Bernstein modes near the plasma edge may allow signals generated by electrons in an over-dense plasma to be detected. Alternatively, high frequency power may gain accessibility to the core plasma through this mode conversion process. Many of the tools used for ion cyclotron antenna design can also be applied near the electron cyclotron frequency. In this paper, we investigate the the possibilities for an antenna that may couple to electron Bernstein modes inside an over-dense plasma. The optimum values for wavelengths that undergo mode-conversion are found by scanning the poloidal and toroidal response of the plasma using a warm plasma slab approximation with a sheared magnetic field. Only a very narrow region of the edge can be examined in this manner; however, ray tracing may be used to follow the mode converted power in a more general geometry. It is eventually hoped that the methods can be extended to a hot plasma representation. Using antenna design codes, some basic antenna shapes will be considered to see what types of antennas might be used to detect or launch modes that penetrate the cutoff layer in the edge plasma.

INTRODUCTION

Electron Bernstein Waves (EBWs) propagate in over-dense plasmas where direct accessibility of the extraordinary (X) and ordinary (O) modes is not possible. Mode conversion of the X and O modes to EBWs can occur near the X and O mode cutoffs for very precise launch angles [1,2]. This mode conversion leads to the possibility that microwave power at moderate frequencies can penetrate through the density cutoffs near $\omega = \omega_{pe}$ where ω is the microwave frequency and ω_{pe} is the electron plasma frequency. In this paper, we explore the possibilities for designing a microwave antenna that can couple to the EBWs in NSTX. Such an antenna could be used to detect electron cyclotron emission from within the plasma, or it could couple power to the plasma if it can launch waves that efficiently undergo the mode conversion process.

In the first section, we discuss the general plasma response for mode conversion to EBWs, and the codes and parameters used for these calculations. Next, we consider a low field launch from the outboard side of NSTX which would occur during low plasma current operation such as plasma initiation. This case considers EBW accessibility to the $\omega = \Omega_e$ resonance. Next, we consider high plasma current operation where the poloidal magnetic field in NSTX becomes comparable to the toroidal field on the outboard side. High current operation results in a geometry that allows outboard launch from a high magnetic field, allowing access of EBWs to the $\omega = 2\,\Omega_e$ resonance deep within the plasma. Finally, we summarize the preliminary results for a phased array of waveguides or straps that may be able to couple to EBWs.

PLASMA RESPONSE FOR EBWs IN NSTX

Fig. 1 shows magnetic field strengths (|B|) on the equatorial plane that could be expected in NSTX for both low and high plasma current operation. A frequency of 7.5 GHz was chosen for the low current case with accessibility to the $\omega = \Omega_e$ resonance. A frequency of 11.2 GHz was chosen for the $\omega = 2\,\Omega_e$ case to move the non-Doppler shifted absorption/emission region close to the bottom of the magnetic well. The same density and temperature profiles were used in both cases to simplify the analysis; however, these values are more reasonable for the case of high plasma current operation. The plasma response and mode conversion was studied using the GLOSI code [3], which solves Maxwell's equations for a sheared plasma slab using a warm plasma dispersion relation retaining second order terms in $k_\perp\rho$. Thus, it can be used to study EBWs propagating between the $\omega = \Omega_e$ and $\omega = 2\,\Omega_e$ resonances.

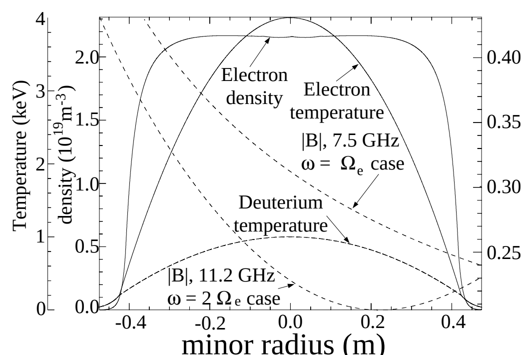

FIGURE 1. Plasma parameters used for NSTX.

Launch from the low field side, as shown in Fig. 2, can be considered during periods of low current operation such as for start-up. A problem with outgoing boundary conditions in the GLOSI code prevented a full calculation including resonant absorption. This problem is being investigated, and may have occurred because of a polarization change at the RL=PS surface[4] for the parameters considered. However, outgoing boundaries that appear to be correct could be used between the $\omega = \Omega_e$ resonance and the mode conversion layer. The modeling presented here gives a reasonable picture of the low field EBW launch if complete absorption occurs at the $\omega = \Omega_e$ resonance.

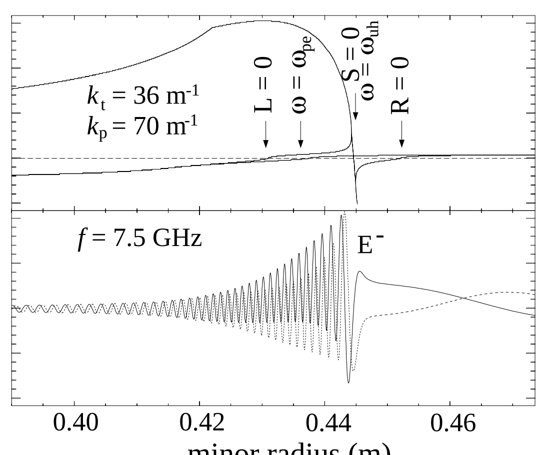

FIGURE 2. Mode conversion for low field launch to damp at $\omega = \Omega_e$.

The polarization in the high plasma current regime for NSTX is mixed because of the sheared field and the large angle of the magnetic field at the launcher. In Fig. 3, we show a case with mode conversion and absorption at the $\omega = 2\Omega_e$ resonance. The outgoing boundary condition again assumes that any power propagating beyond the $\omega = 2\Omega_e$ resonance will be absorbed at the $\omega = \Omega_e$ resonance located on the inboard side of the torus. This case is further complicated numerically because the large Doppler shift can substantially move the resonance over the range that is scanned.

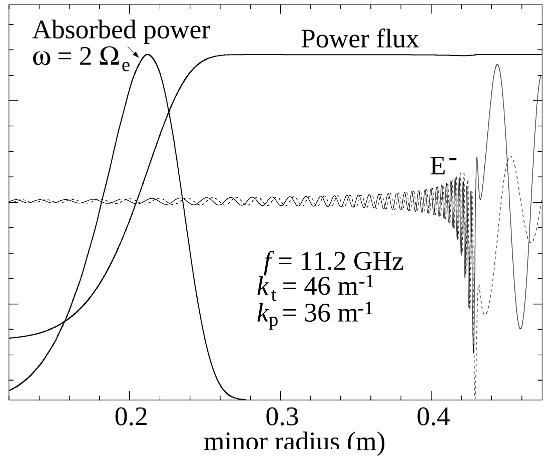

FIGURE 3. High field launch from the outboard side of NSTX with EBW absorption at $\omega = 2\ \Omega_e$ can couple when plasma current and/or β are high.

POWER COUPLING

Fig. 4 shows contours for the power coupled through the plasma/vacuum interface by two different incident polarizations in the low field launch case. The contours are generated by the RANT3D code [5] using a very small current loop to excite a broad range of poloidal and toroidal wavelengths with specified polarization. From Fig 4. it is clear that an effective launcher must excite only a very narrow range of wavelengths in roughly circular bands of toroidal (k_t) and poloidal (k_p) wave numbers; however, electron cyclotron emission should be detectable through these modes. The sensitivity of this band to changing plasma conditions remains to be investigated.

In the high field launch case, the static magnetic field does not change significantly between the launch and cutoff such that the launch polarization remains fairly pure. This calculation is still in progress, but preliminary results shown in Fig. 5 indicate that O mode launch couples substantially better than X mode launch. Note, however that a much narrower range of launch angles were performed than for the low field launch because of the numerical difficulty caused by the Doppler shifted resonance.

SUMMARY

Coupling to EBWs is possible over a very narrow range of wavelengths in NSTX via either X or O mode incoming polarization. Coupling to the $\omega = \Omega_e$ resonance shows promise for low β and low plasma current operation. High plasma current or high β operation can lead to conditions where high field launch to the $\omega = 2\ \Omega_e$ resonance is possible from the outboard side of the torus. In either scenario, efficient coupling occurs only for very restricted and somewhat isolated angles of propagation. Designing a launcher to couple high power to the plasma core using this mode conversion process appears to be difficult because very precise control of the spectrum is needed; however, a reflecting plate could allow many bounces to make penetration through the cutoff layers more efficient. A measure of electron cyclotron emission may also be possible because of this mode conversion process. Studies to determine sensitivity of the accessible modes to plasma parameters are needed to see if the operational range for such a launcher is practical.

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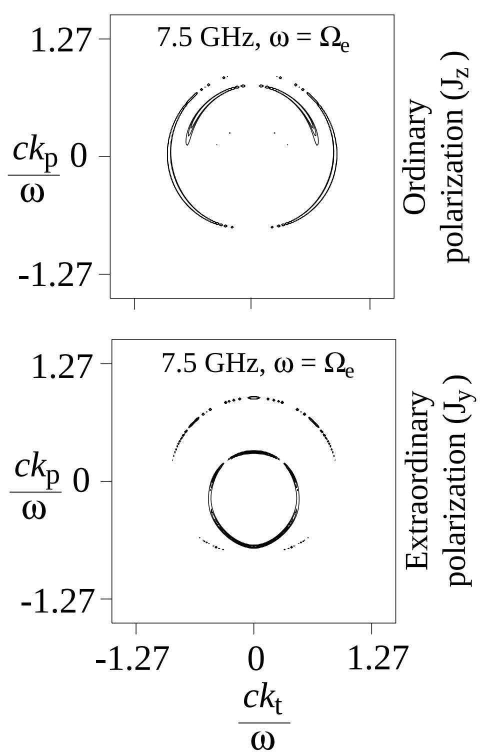

FIGURE 4. Contours of power coupling for low field launch with J_z and J_y excitation shows EBW accessibility for very restricted launch angles.

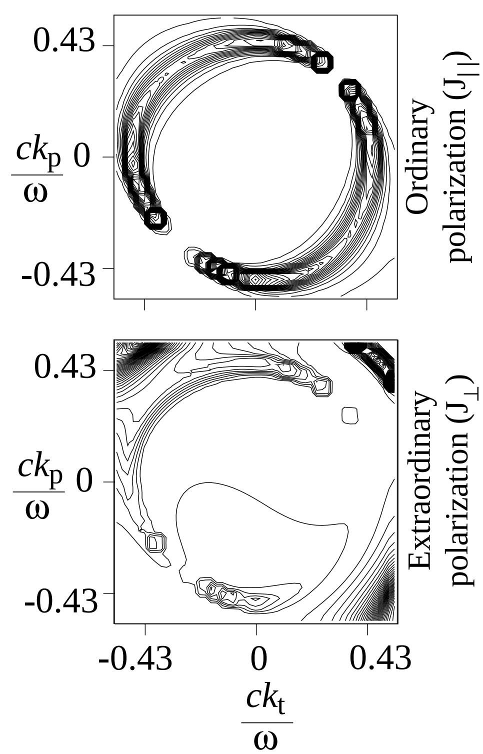

FIGURE 5. Contours of power coupling for high field launch with $J_{\|}$ and $J_{\perp}$ excitation. Polarization is somewhat mixed by sheared magnetic field.