Coupling of Electron cyclotron Harmonic Waves with Electron-beam induced Plasma Waves near the Upper Hybrid Frequency

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In several experimental works dealing with electron-beam - plasma interaction, the observations of energetic plasma electrons and the presence of high-frequency instabilities associated with the "cold-theory" plasma waves have been shown to be related in frequency ranges near the electron cyclotron harmonics /1,2 /. On the other hand it has been shown experimentally that noise-emission from a quasi-Maxwellian plasma is strongly enhanced near the electron cyclotron harmonics when a small electron beam is fired through the plasma /3/; these results have been ascribed to the presence of longitudinal electron cyclotron harmonic plasma waves (Bernstein waves). The present investigations have shown that the wave phenomena quoted above, can appear simultaneously and are in fact coupled with each other under the condition that the upper hybrid frequency is close to the second electron cyclotron harmonic.

The plasma is produced in the positive column of a low-pressure Argon glow-discharge /4/ and a separate continuously generated electron-beam ($\varnothing$ = 6 mm, 1 kV, 10 mA) is injected axially and parallel to the homogeneous magnetic field. The emission signals are detected with small cylindrical antennas outside the beam region, and received with a Spectrum Analyser and a Radiometer.

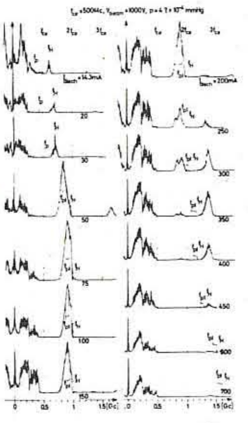

Fig. 1

Emission spectra measurements were performed with a fixed magnetic field and constant electron-beam conditions, with the discharge current($\sim$ plasma density) as variable parameter (fig. 1, emission amplitude in log.scale vs.frequency). At low- and for increasing discharge currents, the emission peak (f_H) is shifted progressively to higher frequencies and as far as $f_H \lesssim 2f_{ce}$ can be identified with the upper hybrid frequency branch of the beam-induced plasma waves /1,3 /. Moreover, when the emission signals appeared just below the 2nd harmonic, ion-saturation current measurements showed a relative increase of the plasma density of 50 % and more; this suggests that the beam-induced emission is accompanied by an additional heating, which in our plasma system corresponds to an extra-ionization. Therefore we have limited the analysis of the emission spectra to the case when: $f_{ce} < f < 2f_{ce}$.

With measurements of the radial amplitude dependence of the noise-emission, we could verify that in this frequency range the beam-generated wave-signals have dispersion properties wich are identical to the well known Bernstein waves which propagate perpendicularly to the magnetic field /5/. These results are summarized in fig.2 together with the transmission-comparision measurements /4/.

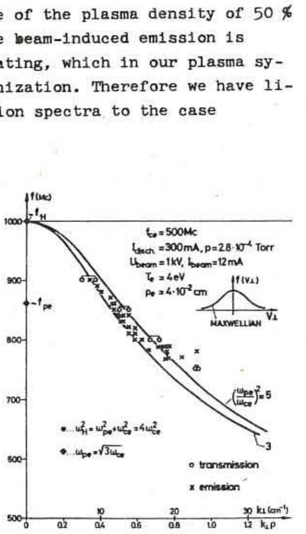

Fig. 2

Spatial phase correlation measurements were also performed between two antennas movable in the r- and z-direction. The emission signal detected by each antenna is mixed through an interferometric-like system (fig.3), one arm of which is used as reference signal and the other arm is connected to the antenna which is swept and the frequency is selected at the receiver. The measured phase differences are a function of the distance between the r- and z-antenna. Typical results (fig.3a) appear when the r-antenna is fixed and the z-antenna varied parallel to the beam. The parameter Δ l corresponds to the variable coaxial delay-line inserted between both arms. We see that the parallel wavelengths satisfy the Cherenkov-synchronism relation ($\omega = k_{//} v_{beam}$). In the other case when the r-antenna is moved and z-fixed (with the position of the z-antenna as parameter as shown in fig. 3a) we can conclude from these measurements: (fig. 3b, 3c)

1) the "parallel" and "perpendicular" phase-components of the observed waves are linearly correlated;
2) the "perpendicular" phase velocity component of the Beam-generated Bernstein waves is directed towards the axis of the beam-plasma system;
3) the "perpendicular" phase component is space dependent in the outer region of the plasma profil, until the limit layer corresponding to the local upper hybrid frequency is reached (fig. 3c); wheras, close to the beam-axis no variation of the phases can be observed when varying the external delay-line (Δ l);
4) the phase correlation measurements, perpendicular to the magnetic field, corroborate the results of the radial amplitude dependence of the emission signals: the beam-induced, Bernstein waves propagate across the radially density-inhomogeneous plasma profile with wavelengths which are only determined by the local plasma parameters (density, temperature).

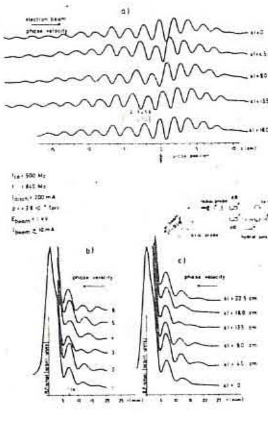

Fig. 3

So far our experimental results agree with the theoretical predictions, in /6/, about the coupling conditions between the Upper Hybrid and the Bernstein wave modes. However, the enhanced plasma heating which has been observed in the same frequency range, is believed to be a consequence of the coupling of both waves parallel to the electron beam, because Bernstein waves with a wave component parallel to the static magnetic field are Landau damped /7/.

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