EXPERIMENT ON THE EXCITATION OF BUCHSBAUM-HASEGAWA-RESONANCES

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In a hot inhomogeneous plasma column in a magnetic field resonances known as Buchsbaum-Hasegawa-modes [1] can be observed at the low frequency side of the electron cyclotron harmonic frequencies. They are attributed to electrostatic electron plasma waves which can propagate perpendicular to the magnetic field (Bernstein waves [2]). If $\omega_p^2 > \omega_{pH}^2 = \omega^2 - \omega_c^2$ (= hybrid density), then for frequencies $\omega/\omega_c = n - \Delta\ (\omega/\omega_c)$, where the B-H-resonances are observed, these waves propagate as backward waves. This implies that in an inhomogeneous plasma column and for ω near $2\ \omega_c$, these waves can only exist in the dense core of the column bounded by the hybrid layer. Within this dense core these oscillations form a standing wave pattern, which manifests itself in the resonances whenever the phase condition

is fulfilled [1,3,6]. $\int_{r_H}^{0} k(r)\,dr = (m + \alpha)\pi$; $m = 1, 2, 3 \ldots$

It is generally assumed that the Bernstein waves, which lead to the oscillations, are coupled to the electromagnetic field at the hybrid layer [4]. This implies that in an inhomogeneous cylindrical plasma column the group velocity of the thus excited waves should be directed radially inward, from the hybrid layer towards the higher density region. However, Gruber and Bekefi [5] report the observation of just the opposite direction of propagation which would require another excitation mechanism instead of a local coupling at the hybrid layer. They propose a continous coupling throughout the volume where the waves propagate.

In a steady state experiment [6] where the waves have been excited by means of an externally applied high frequency capacitor field, we obtained results which are contrary to the findings of Gruber and Bekefi. In such a steady state experiment, however, the group velocity of a wave cannot be measured directly. Therefore, a short microwave pulse ($\approx$ 2o nsec, 94o MHz) was applied to the capacitor plates and the transient plasma wave response was observed with an antenna inside the plasma. Fig. 1 shows the experimental arrangement. Fig.2 shows a set of recorded probe signals for different probe positions between the axis of the column and the wall. We see, expecially for 4 mm $< r <$ 8 mm, four clearly separated pulses arriving at the probe which indicate that the excitation is mainly a local one. The first one of the pulses is due to capacitive coupling from the capacitor plates to the probe. It is an electromagnetic signal which arrives without appreciable time delay. The second and third pulses are the Bernstein wave pulses which are excited on both sides of the plasma column in the region of the hybrid layer (at $r \approx \pm$ 12 mm). It is seen from fig. 2 that the wave pulses travel radially inward with a considerable time delay.

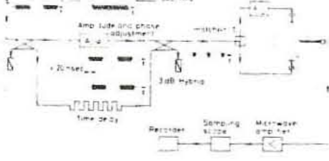

Fig. 1
Experimental arrangement

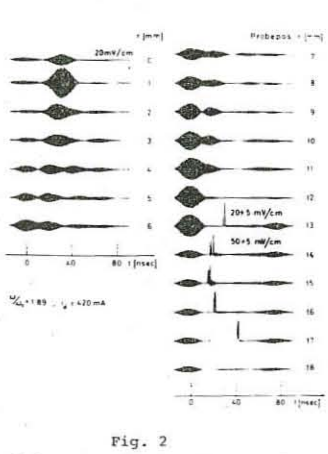

Fig. 2
Pulse records at various probe positions, $\omega/\omega_c = 1.89$; $\omega_{po}^2/\omega^2 = 2.4$; different sensitivities

This direction is identical to the direction of the group velocity of the excited Bernstein waves in a steady state experiment, i.e. away from the hybrid layer towards the higher density region. From the dispersion relation we can calculate the group velocity $v_{gr} = \partial\omega/\partial k$ as a function of density. The time delay assuming excitation at the hybrid layer then is:

$$t(r) \approx \int_{r_H}^{r} \frac{1}{v_{gr}(\rho)}\, d\rho$$

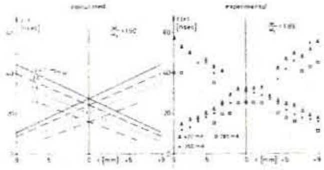

Fig. 3
Comparison between measrued and calculated timedelays

Fig. 3 shows a comparison between measured and calculated time delays. When the two wave pulses travel just once across the plasma column and reach the hybrid layer at the opposite side of the column they couple out to the electromagnetic vacuum field which we again detect at the probe without appreciable time delay. This is the fourth pulse we see in fig. 2. His time delay is just twice the time delay of the pulse at r = o. With the probe situated outside the dense core, we could detect up to 4 coupled out pulses, which are due to mulitple reflection of the Bernstein wave pulses inside the dense plasma core. One set of measurements is presented in fig.4. We see how with increasing peak plasma density (or discharge current), the time delay of the coupled out pulses increases due to the increasing diameter of the hybrid layer in the column. From the relative amplitudes of successive coupled out pulses we can estimate the coupling coefficient:

$$\alpha \approx 1 - \frac{1}{\sigma} \cdot \frac{N_{n+1}}{N_n}$$

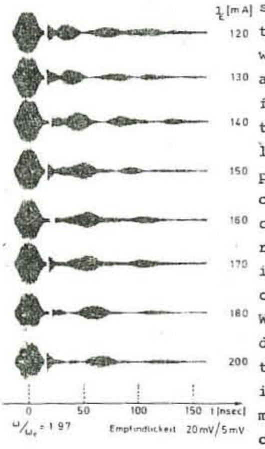

Fig. 4
Records of coupled out pulses for various densities, $\omega/\omega_c = 1.97$

σ represents a damping of the pulse during one transit time from a hybrid layer to the opposite one. In fig. 5 the dots show experimental results neglecting damping, i.e. for $\sigma = 1$. The heavy lines in fig. 5 correspond to the results of Kuehl [7], who has calculated this coupling coefficient for excitation of the Bernstein waves by an extraordinary wave in an infinite inhomogeneous plasma. Taking Kuehl's parameter n_{ex}^2 ($x \to \infty$) (refractive index of the extraordinary wave for $x \to \infty$) equal to n_{ex}^2 (r = o) in our experiment, we obtain the dashed line in fig. 5, representing the coupling coefficients expected in our experiment. We find agreement within an order of magnitude. Matching our experimental results to this theoretical line would give a reasonable value of o.65 for the neglected damping term σ.

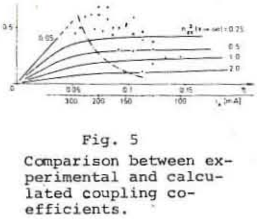

Fig. 5
Comparison between experimental and calculated coupling coefficients.

These observatious, together with the results in [6] show that Buchsbaum-Hasegawa-resonances can be well understood in terms of Bernstein waves excited mainly in the vicinity of the hybrid layer.

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