Proceedings of the Research Institute of Atmospherics,
Nagoya University, vol. 18 (1971)

EXPERIMENTAL RESULTS OF ION CYCLOTRON HARMONIC WAVES IN SIMULATED SPACE PLASMA

Katsunori KURAHASHI, Tetsuo KAMADA
and Susumu TOKUDA

Experiments to detect ion cyclotron harmonic waves in a low density and temperature plasma were made in the space chamber belonging to the Institute of Space and Aeronautical Science, University of Tokyo. This was an explanatory experiment before doing an experiment on high-frequency parametric excitation by ion cyclotron harmonic waves.

The space chamber consisted of a stainless steel cylinder ($2\ \mathrm{m}\phi \times 3\ \mathrm{m}$) with several ports and diffusion pumps. A plasma gun of a back diffusion type was placed at one end of the chamber. The plasma density and the pressure of He gas used were $10^4 \sim 10^6 \mathrm{cm}^{-3}$ and $10^{-4} \sim 10^{-5}$ Torr, respectively. The magnetic field was supplied by an Hermholz coil wrapped around the chamber. A block diagram showing the experimental arrangement is shown in Fig. 1. For a transmitting antenna a probe of $5\ \mathrm{cm}\phi$ was used. Two receiving antennas were used: a whip of 60 cm length and a loop of 4 turn ($30\ \mathrm{cm}\phi$) which were set about 1.3 m distant from the transmitting antenna. Every antenna was arranged carefully such that their center points coincided with the center line of the chamber. A 2 volt, 20 KHz sine wave signal was applied to the transmitting antenna. The magnetic field was applied by a sawtooth current so as to obtain a continuous magnetic field variation from zero to 30 Gauss. Frequency and magnetic field range values were selected so that resonance and cutoff points of plasma waves other than ion cyclotron harmonic waves would not appear. Also the effects caused by the volume of the chamber and the characteristic length of the plasma, and the problem of wave damping were considered.

The 20 KHz signal was detected by the receiving whip and loop antennas through the plasma. These results are shown in Fig. 2. In Fig. 2, the curves A and B show the variation of magnetic field intensities, and the received signal pattern detected by the whip antenna, respectvely. From curve B, it is clearly seen that the signal pattern of the ascending time of a magnetic field differs from the descending time. As it is seemed to be due to effect of hysteresis of the induction coil, only the signal pattern of the ascending time of a magnetic field is considered in the following discussion. The received signal levels increase gradually with an increase of magnetic

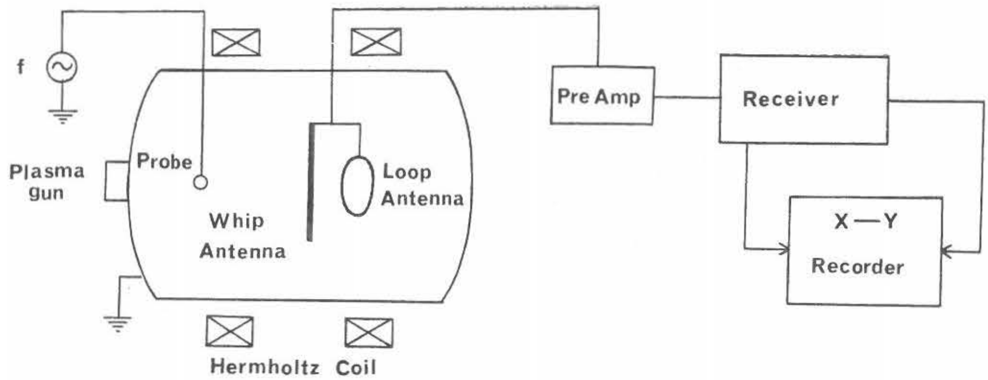

Fig. 1. Block diagram of experimental arrangement.

field except in the regions of a, b, c, ... and f noted in curve B of Fig. 2. These variations are interpreted to be the result of variations of antenna impedance. The variation of antenna impedance in the vicinity of the ion cyclotron harmonic waves is shown in Fig. 3. This was calculated under assumptions of which the direction of wave vector of the ion cyclotron harmonic waves is a perpendicular to the magnetic field and the wave number of them has a real value. Fig. 3 shows that, in the region of $f_{Bi} < nf_{Hi} < f_0$, the antenna impedance decreases as nf_{Hi} rises, where f_{Bi}, f_{Hi} and f_0 are: the frequency of ion cyclotron harmonic wave; the cyclotron frequency of ion; and the received signal frequency, respectively. Therefore, the received signal levels increase with an increase of magnetic field. However, when the frequencies nf_{Hi} coincide with the frequency of ion cyclotron harmonic wave f_{Bi}, the antenna impedance increases, then the received signal levels decrease. The regions of a, b, c .... and f in Fig. 2 seem to correspond to the regions of ion cyclotron harmonic wave. The same experiment was repeated with the loop antenna, but the absorbed regions corresponding to a, b, c, ... and f were not measured. This fact is evidence for an ion cyclotron harmonic wave, because this wave is a longitudinal plasma wave and does not exhibit electromagnetic coupling.

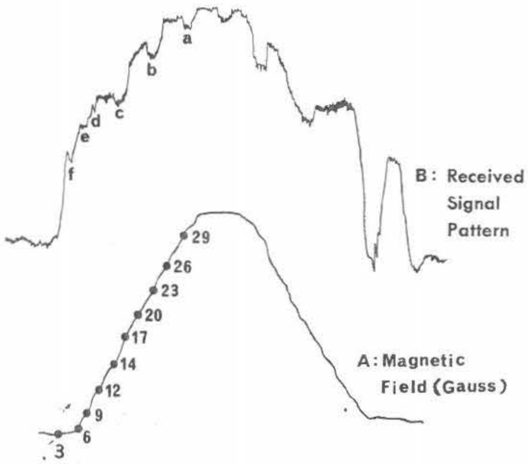

Fig. 2. The variation of magnetic field intensities and the received signal.

Therefore, these waves were not detected from the loop antenna.

The dispersion relations of cyclotron harmonic waves in the plasma are calculated by many workers (for example, Crawford 1965; Tataronis, Crawford 1970). From these results, both the upper and the lower limits for the perpendicular propagation of ion cyclotron harmonic waves were obtained for our experimental conditions. These limiting points exist on the dotted line A and B shown in Fig. 4, respectively. The circle points on those curves indicate both the upper and lower limit for each mode of the ion cyclotron harmonic waves which is excited by a 20 KHz signal. Then, in our experiment, an ion cyclotron harmonic wave are allowed to propagate only in the region between the upper and lower limit point of each mode. The gyro-frequencies which were calculated from the absorbed regions of a, b, c, ... and f in Fig. 2 were in the enclosed region of the arrow sign in Fig. 4. Then, the absobed points of a, b, c, ... and f in Fig. 2 seem to correspond to a higher order mode of ion cyclotron harmonic wave. By the characteristics of antenna impedance shown by Fig. 3, these absorptions of ion cyclotron harmonic wave points ought to be larger than our experimental results; We consider for this reason such that the wave number of each mode in our experiments took a complex value and then, the antenna impedance of their mode had a finite value.

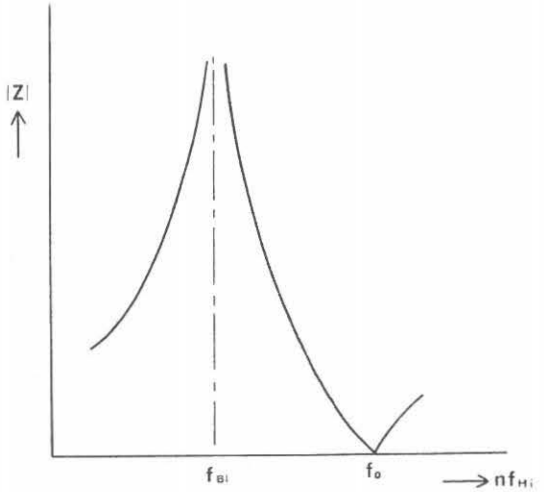

Fig. 3. The variation of antenna impedance.

As mentioned at the first, this experiment was made as an explanatory experiment to examine parametric excitation in the simulated space plasma, and so, we did not intend to examine the character of the ion cyclotron harmonic waves. Thus, we did not make more detailed measurements at that time. It would be of interest to do more detailed experiments on the ion cyclotron harmonic waves itself in simulated conditions of space plasma.

Acknowledgements — This work was carried out under the collaborating research problem at the Institute of Space and Aeronautical Science, University of Tokyo. We wish to express our thanks to Prof. K. Hirao, Prof. T. Obayashi and Dr. T. Itoh, University of Tokyo, and also thanks to Dr. I. Kimura, Kyoto University and Dr. H. Ikegami and Dr. H. Ikeji, Institute of Plasma Physics, Nagoya University for their useful suggestions. Finally we deeply appreciated Mr. Kawahara and Mr. Tamata, Chamber Laboratory for their contribution to this experiment.

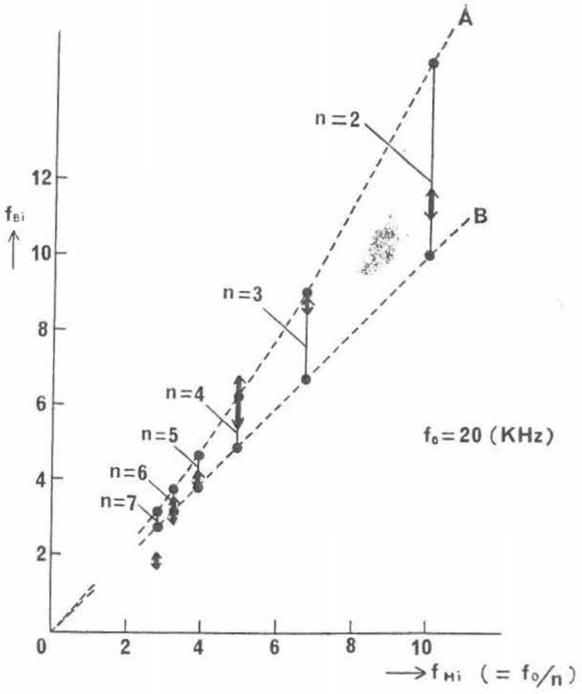

Fig. 4. Both theoretical regions and experimental results of the ion cyclotron harmonic waves.

References

Crawford, F. W.: Cyclotron Harmonic Waves in Warm Plasmas, Radio Scie., **69D**, 789-805 (1965).

Tataronis, J. A. and F. W. Crawford: Cyclotron Harmonic Wave Propagation and Instabilities, 1. Perpendicular Propagation, Journal of Plasma Physics, **4**, 231-248 (1970).