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ABSTRACT

The turbulence induced by a current drawn in a low density Argon plasma is investigated by microwave scattering and correlation techniques. The azimuthal 30 GHz scattering system uses a newly designed variable waveguide in order to detect the scattered signal at any angle between 0^0 and 90^0. Both diagnostic methods show that the turbulence is dominated by low frequency waves propagating perpendicular with respect to the current. A comparison of these two important diagnostic methods for turbulent plasma is presented.

I INTRODUCTION

Plasma turbulence is an interesting and still developing topic in plasma physics. Many problems are far from being solved. Those not yet solved are the detailed measurement of the frequency spectra, wave spectra and the angle of propagation of the tubulence. Futhermore, little is known about the different wave-wave and wave-particle interactions in turbulent plasmas and as well as about the saturation mechanism.

Different diagnostic techniques have been applied in various experiments. Probe measurements are the most popular method. However, it is well known that probe techniques suffer from several drawbacks. The plasma, and therefore the turbulence to be observed, may be strongly modified by induced perturbations due to the presence of probes. Furthermore, instabilities arising from currents drawn from the plasma by the probe may itself induce misleading data on basic turbulence quantities such as frequency spectra [1]. Many different type of probes have been designed in order to minimize these two main disadvantages [2,3]. In spite of this, correlation measurements, which provide the most powerful analysis of plasma tubulence, are performed using small Langmuir probes [4,5,6].

Microwave scattering represents an alternative diagnostic technique [7]. The major advantage of this method is its non-perturbing nature and possible use in high temperature plasmas, while the main disadvantages are its poor spatial resolution and its relatively complex arrangement.

In the present paper we apply, to our knowledge for the first time, probe measurements and microwave scattering on the same experiment to diagnose independently the turbulent state.

II. EXPERIMENT

1. Plasma production

The plasma was created in a 3m long Pyrex tube by negatively biased hot filaments, which were positioned at each end of the device (Fig. 1). The plasma is immersed in a steady magnetic field of 30 Gauss. The experiment was performed in an Argon plasma with a neutral pressure of typically 5×10^{-4} Torr, the base pressure being 8×10^{-7} Torr.

An electron density of about 10^{10} cm^{-3} and electron temperature of around 2-5 eV have been measured. The ratio T_e/T_i is approximately 10 to 15. The turbulent state is driven by a current established between the two biased plasma sources. Typical basic plasma parameters obtained on axis along the column for a bias voltage V_g = 50 V are shown in Fig. 2. The microwave scattering system and the two small Langmuir probes are placed at the same axial position indicated by an arrow in Fig. 2. Within this region density fluctuations $\delta n/n$ of about 30 % have been detected.

2. Correlation measurements

Correlation measurements were carried out using an analog cross-power spectrum analyzer similar to that designed by Harker and Ilic [4]. Minor modifications to their original design have been made. The basic circuit of the cross power spectrum analyzer is drawn in Fig. 3. At the output of the correlator the real and imaginary parts of the cross power spectral density are obtained. By appropriate adjustment of the local oscillator (LO), the cross power spectral density at the chosen frequency can be found. By changing the position of one probe with respect to the other, phase contours in the plane swept by the two probes are obtained. From these maps the parallel and perpendicular wavelength can be determined. The direction of wave propagation can be determined using the same cross power spectrum analyzer, by introducing a small phase change in one of the channels [8].

For the present measurements, carefully designed, cylindrical Langmuir probes have been used. The tip consists of a wire of diameter 0.3 mm and length 2 mm. The rest of the wire was fitted into a 200 mm long silver painted ceramic tube (diameter 0.5 mm) and covered by a thin layer of ceramic. No part of the stainless steel holder of the probe was immersed in the plasma. With such probe systems no detectable perturbation of the plasma and the turbulence could be observed. For the correlation measurements, these probes have been biased slightly above the local plasma potential in order to detect the density fluctuations.

The phase contours have been obtained from measurement of the real part of the cross power spectral density such as presented in Fig. 4. Contours of constant phase of the cross power spectral density in the r-z plane for three different frequencies are shown in Fig. 5, 6, 7. Parallel wavelength $\lambda_{\parallel}$ of the order of 20 to 30 cm or even longer could be noted. The perpendicular wavelength $\lambda_{\perp}$ is found to be of the order of a few centimeters. Furthermore Fig. 8 shows that the unstable wave at 100 kHz propagates radially outwards. It was found that the turbulence is dominated by low frequency waves ($f < fpi/4$) with large $k_{\perp}$ and small $k_{\parallel}$ values. Identical behaviour of the plasma turbulence was found in a previous experiment, performed in similar geometry but with a stainless steel vessel [9].

3. The microwave scattering measurements

Scattering technique provide a powerful tool for the diagnostic analysis of turbulent plasmas. Recently, laser [10] and microwave scattering [7] have been successfully used to study ion wave turbulence in current driven plasmas. For detecting low frequency and relatively long wavelengths, the use of microwaves is more suitable than short wavelength laser light [7].

The optimal choice of the microwave frequency is determined by the wavenumber spectrum of the turbulence to be studied and a convenient choice of the range of the scattering angle. These are related through the well-known scattering relation

$$k = 2\, k_i \sin \frac{\theta s}{2}$$

where k_i is the incident wavenumber, k the wavenumber of the unstable wave, and θ_s the scattering angle (Fig. 9).

For our experiment, a 30 GHz microwave scattering system was constructed using a newly designed variable waveguide in order to detect the scattered signal at any angle between 0^0 and 90^0 (Fig. 10). A gun diode with an output of 100 mW at 30 GHz was used as the microwave source. The experimental arrangement is shown in Fig. 11. The conventional homodyne method of detection was utilised. The power spectral density $I(k,\omega)$ was then obtained from a commercial spectrum analyzer, whose output could be plotted on an x-y recorder.

The geometry of the scattering system must be determined from the spectral density of the turbulent plasma to be studied. In our case, previous correlation measurements demonstrated that the dominant unstable waves have a low frequency and propagate perpendicular to the electron drift velocity with large values of $k_\perp$. Therefore the scattered signal has to be detected azimuthally with respect to the plasma discharge current. To date, azimuthal measurements have been performed at discrete angles either by using an array of antennae installed around the plasma column or with a single horn at a fixed angle. In order to significantly improve azimuthal scattering measurements, an azimuthal microwave structure that allows precise variation of the scattering angle has been designed. With this system, continuous measurement of the scattered wave between 0^0 and 90^0 can be performed.

The newly designed microwave structure consists of two interconnected parts. The first, into which the incident power is introduced, is a fixed curved section containing a longitudinal groove. The second part is able to slide along this groove, the two parts combining to form a curved microwave guide section. The sliding part is driven by an electric motor combined with angle controlling electronics. The standing wave ratio (VSWR) ratio measured at 356 GHz is found to be 1.3.

The transmitted microwave beam is focused on the plasma by the use of a PTFE lens (Fig. 12). With this arrangement, the instrumental broadening is estimated to about 12^0 obtained from measurement of incident beam divergence by the detection horn (Fig. 13). This corresponds to a frequency resolution of roughly 23 KHz, as observed in other experiments [7]. Typical measurements of the cross power spectral density are presented in Fig. 14. Signal broadening larger than the instrumental resolution is observed. This broadening is attributed to the turbulent state of the plasma.

III CONCLUSION

The dispersion relation of the turbulence obtained by the two different methods is shown in Fig. 15. Good agreement is found between the data obtained from the microwave scattering diagnostic and these obtained from the phase contours of the correlation measurements. Therefore, in conclusion, the non-perturbing microwave scattering and the probe measurements reveal the same physical behaviour of the turbulent state of the plasma. Using in combination probe measurements and the correlation technique a very detailed picture of the turbulent state can be obtained.

However, it should also be noted that microwave scattering is a straight forward method for determining the power spectral density which characterizes the turbulence. A continuously driven sliding microwave structure, which to our knowledge has never been used before, could be adapted to less accessable geometries. In addition, this system may be used in a direct transmission configuration to yield a measurement of density.

AKNOWLEDGEMENTS

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REFERENCES

[1] R.L. Stenzel, Phys. Fluids 21, 93 (1978) and 21, 99 (1978)

[2] J.R. Roth and W.M. Krawczonek, Rev. Sci. Intr. 42, 598 (1971)

[3] J.A. Schmitt, Rev. Sci. Instr. 39, 1297 (1968)

[4] K.J. Hawker and P.B. Ilic, Rev. Sci. Instr. 45, 1315 (1974)

[5] D.B. Ilic, K.J. Hawker and F.W. Crawford, Phys. Lett. 54 A, 265 (1975)

[6] W. Gekelman and R.L. Stenzel, Phys. Fluids 21, 2014 (1978)

[7] A. Mase and T. Tsukishima, Phys. Fluids 18, 464 (1975)

[8] Ch. Hollenstein, P.J. Paris (to be published)

[9] Ch. Hollenstein and M. Guyot (to be published)

[10] R.E. Sluster and C.M. Silver, Phys. Fluids 23, 472 (1980)

[11] C.B. Wharton and J.H. Malmberg, Phys. Fluids 11, 2655 (1965)

FIGURE CAPTIONS

Fig. 1 : Schematic of the experimental triple plasma device.

Fig. 2 : Main parameters of the steady state argon plasma along the z axis. The arrows show the position of the microwave scattering system and of the probes.

Fig. 3 : Block diagram of the analog cross power spectrum analyzer. A_1 preamplifier (for $f > f_0$, narrow band turned amplifiers), F_1 variable pass band filters, Mi Mixers, LO local oscillator, F_2 narrow IF bandpass quartz filters (fo = 6 MHz), A_2 amplifier, Mu multiplier, PS 90^0 phase shifter, A_3 amplifier.

Fig. 4 : Typical measurements of the cross power spectral density, for 100 kHz. The radial probe is at fixe position z = 0 mm, and moves from $\Delta R = -106$ mm to + 106 mm. The position of the longitudinal probe is given by Δz from 5 mm to 505 mm.

Fig. 5 : Contours of constant phase (fine line for minima, large line for maxima) of the cross power spectral density in the r-z plane at frequency 50 kHz.

Fig. 6 : Identical as 5 but frequency 100 kHz.

Fig. 7 : Identical as 5 but frequency 150 kHz

Fig. 8 : Radial time-position diagram for maxima (large line) and minima (fine line) of the cross power spectral density at 100 kHz. The reference probe is on the axis of the device at fixe position Δz = 8 cm. The wave propagates radially in the negative Δr direction.

Fig. 9 : Plot of the scattering relation. Schematic of the geometrical figure of the scattering procedure; λ_i is the incident wavelength, λ is the wavelength of the wave to be detected, λ_s is the scattered wave. The same indexes are valid for the k values. θ_s is the scattering angle.

Fig. 10 : Mechanical design fo the azimuthal 30 GHz scattering system.

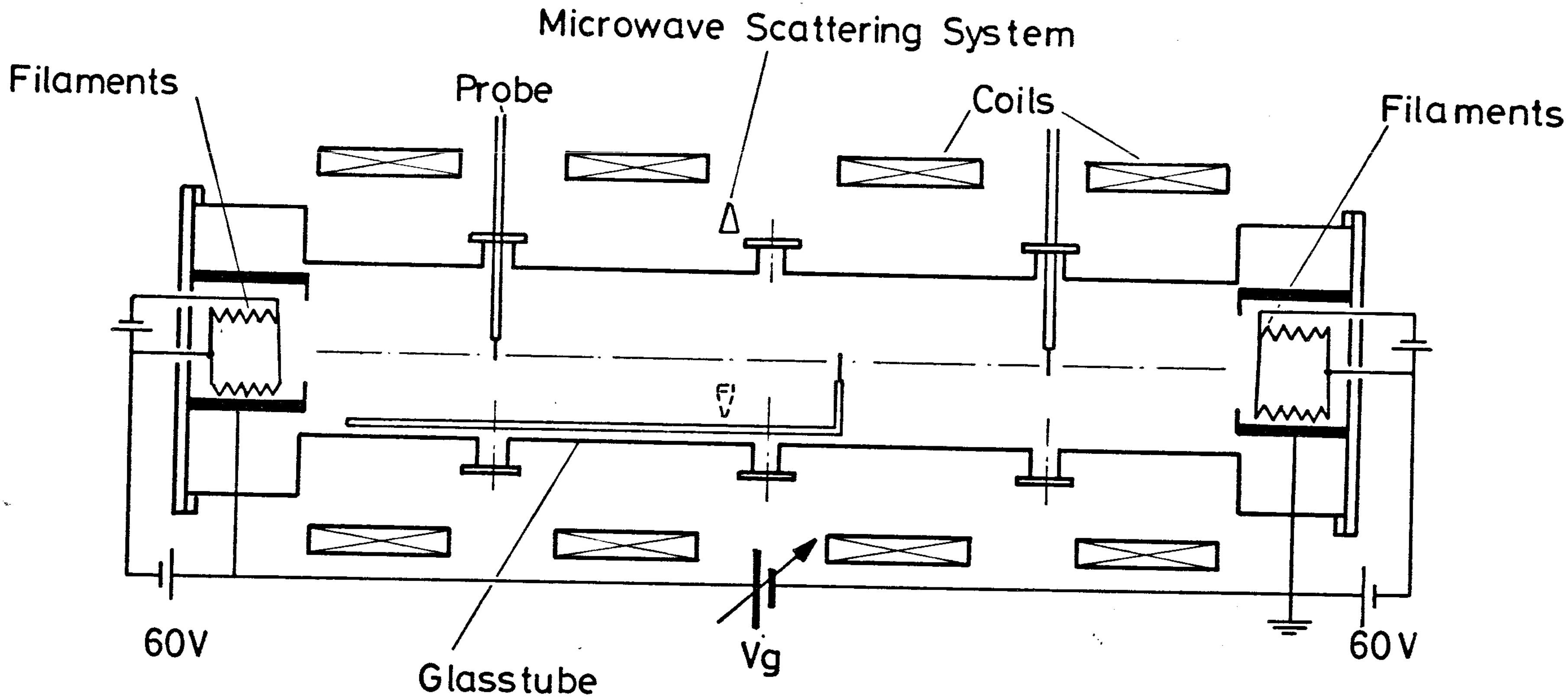
Fig. 11 : Schematic of the experimental configuration.

Fig. 12 : experimental set up and equipement for detection of scattered wave.

Fig. 13 : Measurement of the divergence of the incident electromagnetic beam detected by the receiving horn. This allow us to determine at half of the transmitted power the instrumental resolution angle as 12^0.

Fig. 14 : Typical measurements of the analysed scattered signal at different angles. The frequency is measured on the frequency spectrum anlyser and plotted on X-Y recorder. The dash lines represent measurements without plasma.

Fig. 15 : Dispersion relation obtained by both methods, the circles represent the scattering detection and the dots, the correlation technique. The phase velocity v_p is of the order of 1,6 10^5 cm s^{-1}.



NESSIE II

FIG. 1 EXPERIMENTAL DEVICE

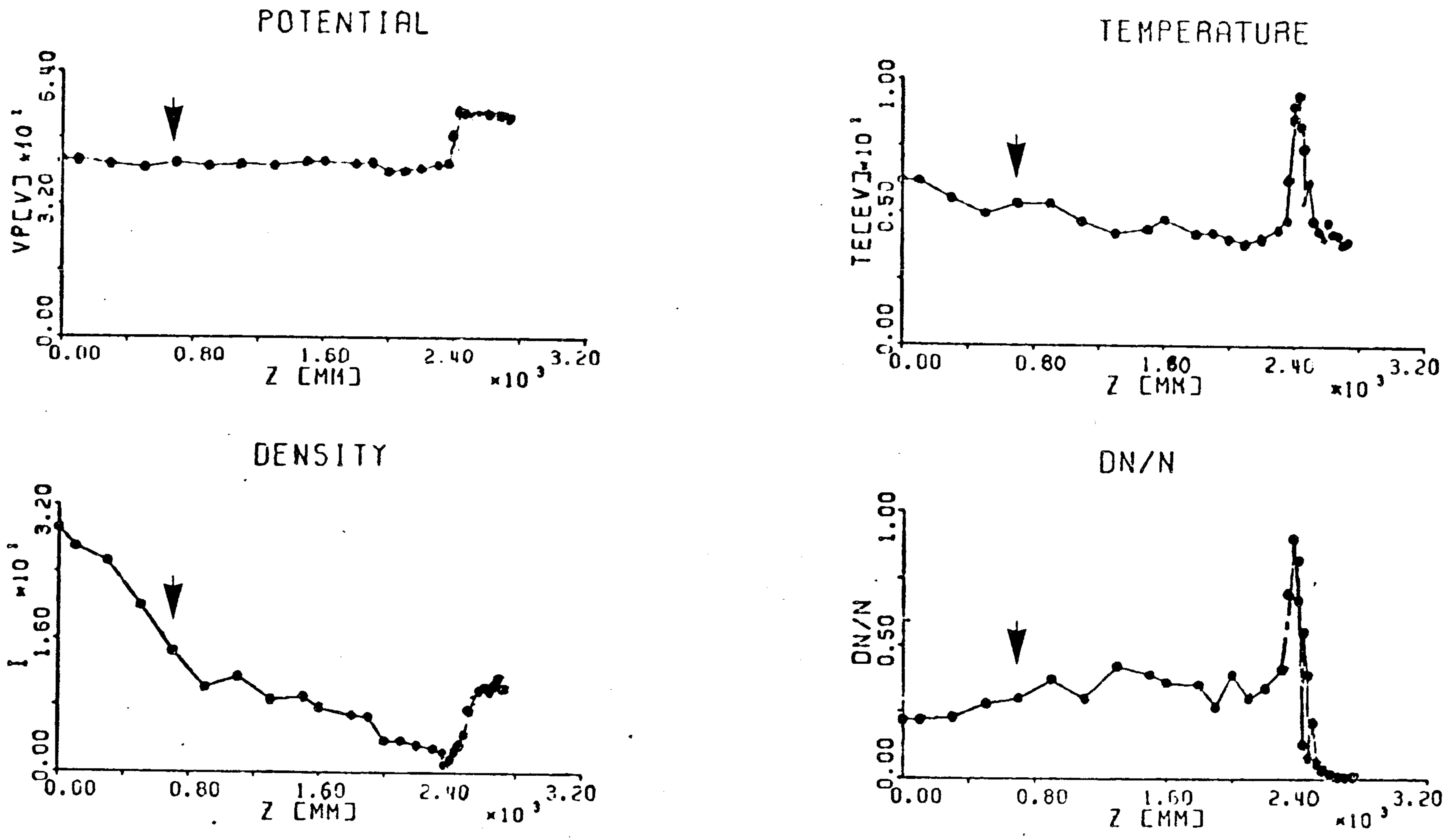


FIG. 2 PLASMA PARAMETERS FOR $V_g = 50$ V

THE ARROWS SHOW THE POSITION OF THE MICROWAVE SCATTERING SYSTEM.

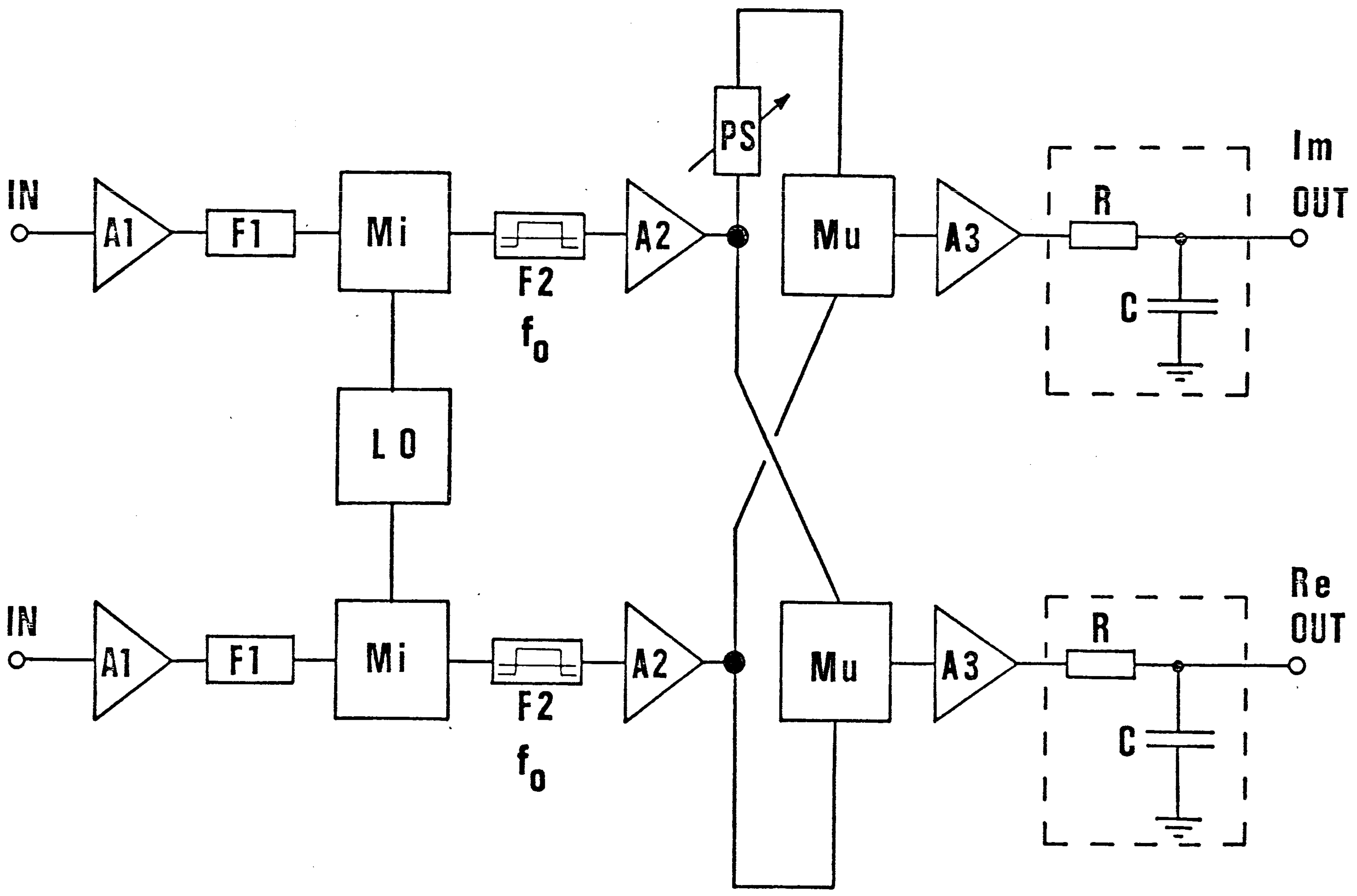


FIG. 3 LAYOUT OF THE USED ANALOG CROSS POWER CORRELATOR

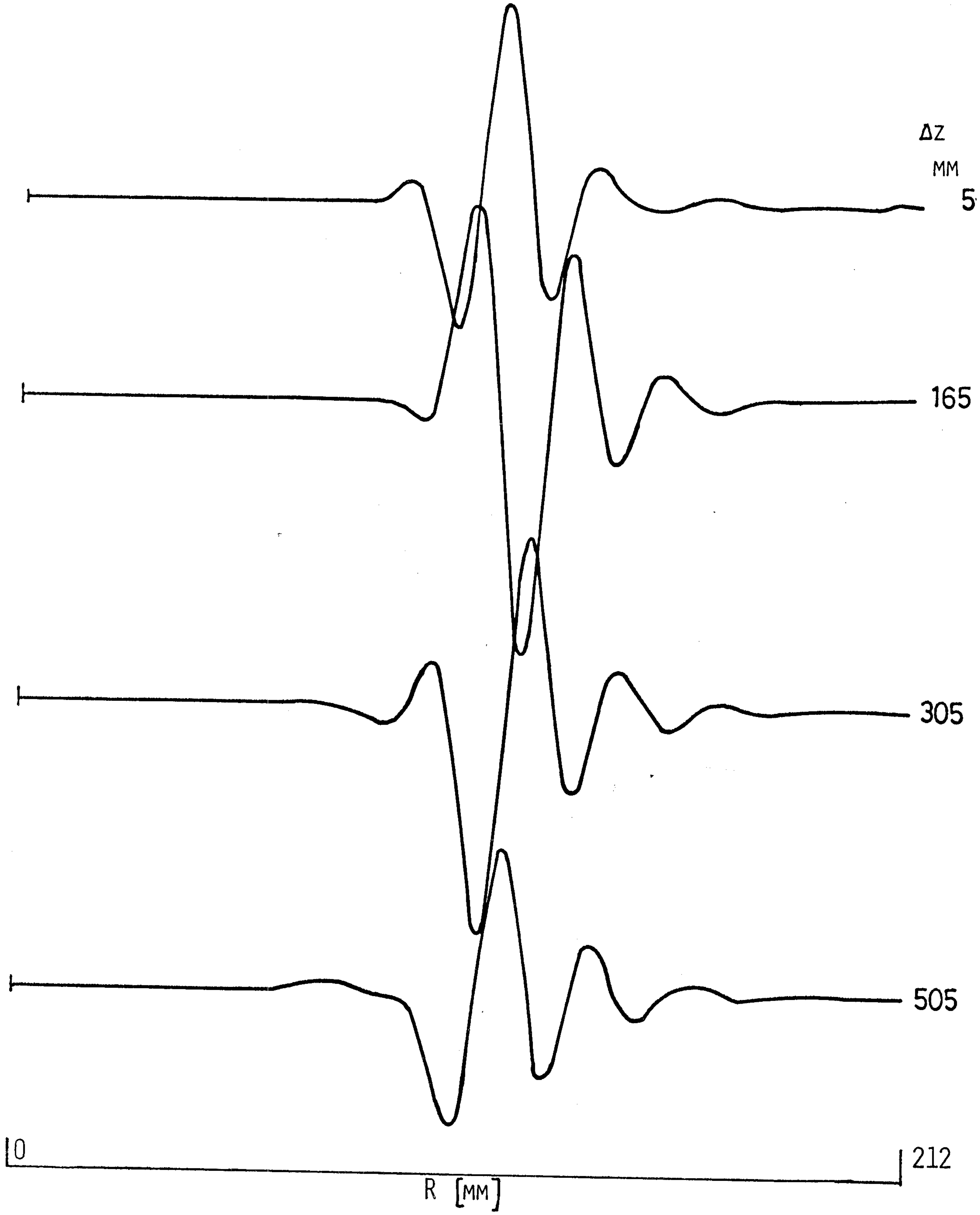


FIG. 4 TYPICAL MEASUREMENTS OF THE CPSD AT 100 kHz

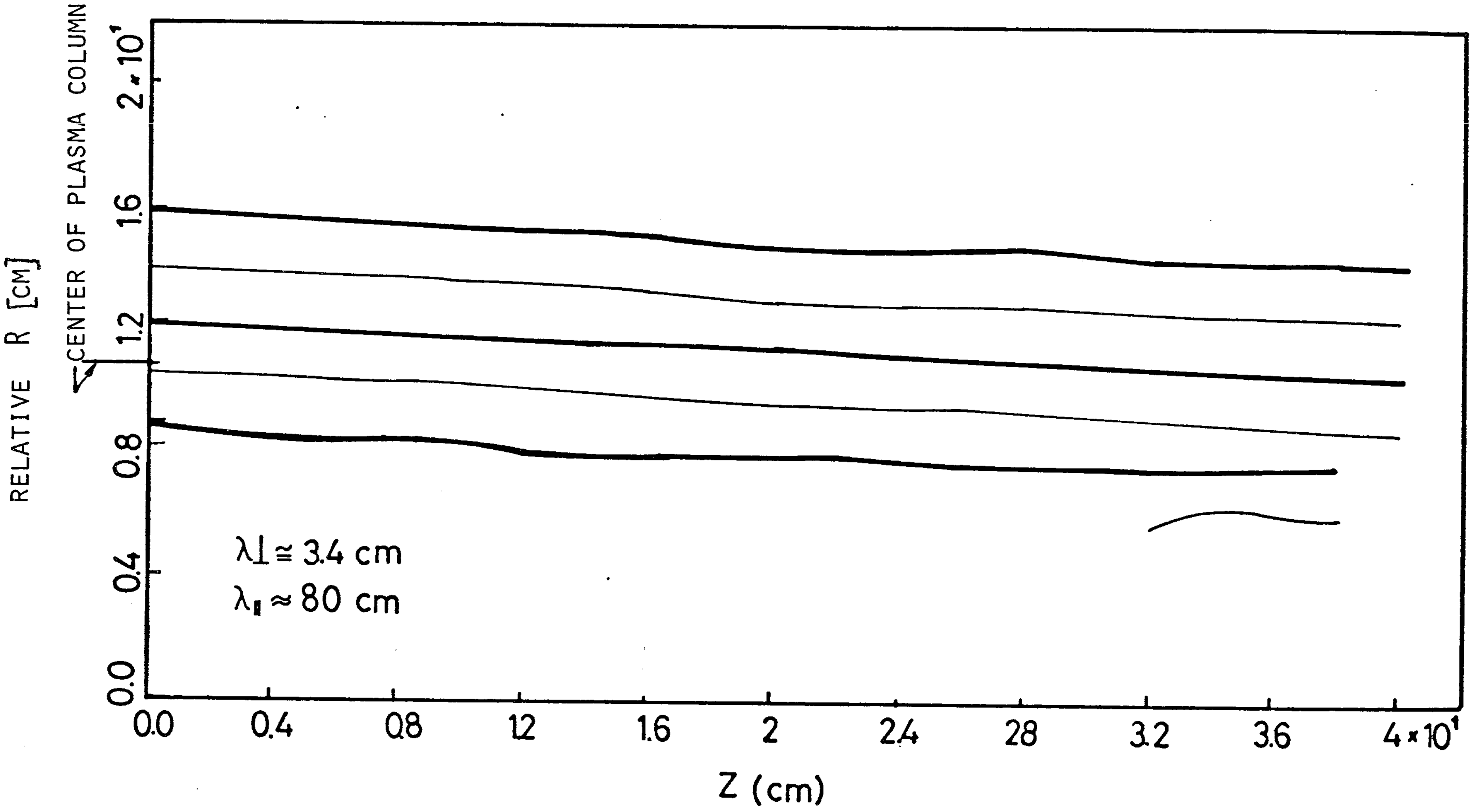


FIG. 5 CONTOURS OF CONSTANT PHASES (━ MAXIMUM, — MINIMUM) OF THE CPSD
AT 50 kHz IN THE R-Z PLANE

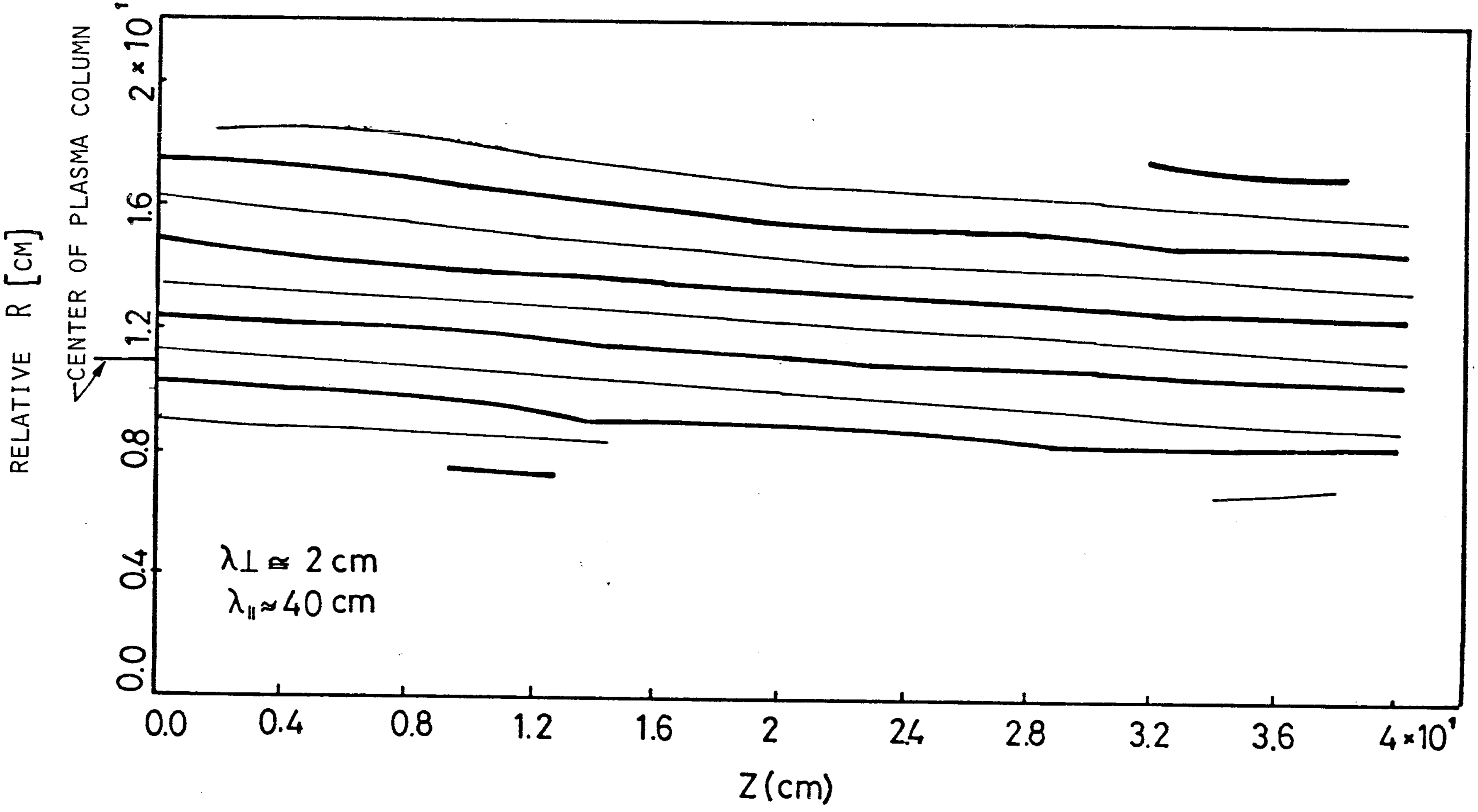


FIG. 6 CONTOURS OF CONSTANT PHASES (▬ MAXIMUM, — MINIMUM) OF THE CPSD AT 100 kHz IN THE R-Z PLANE

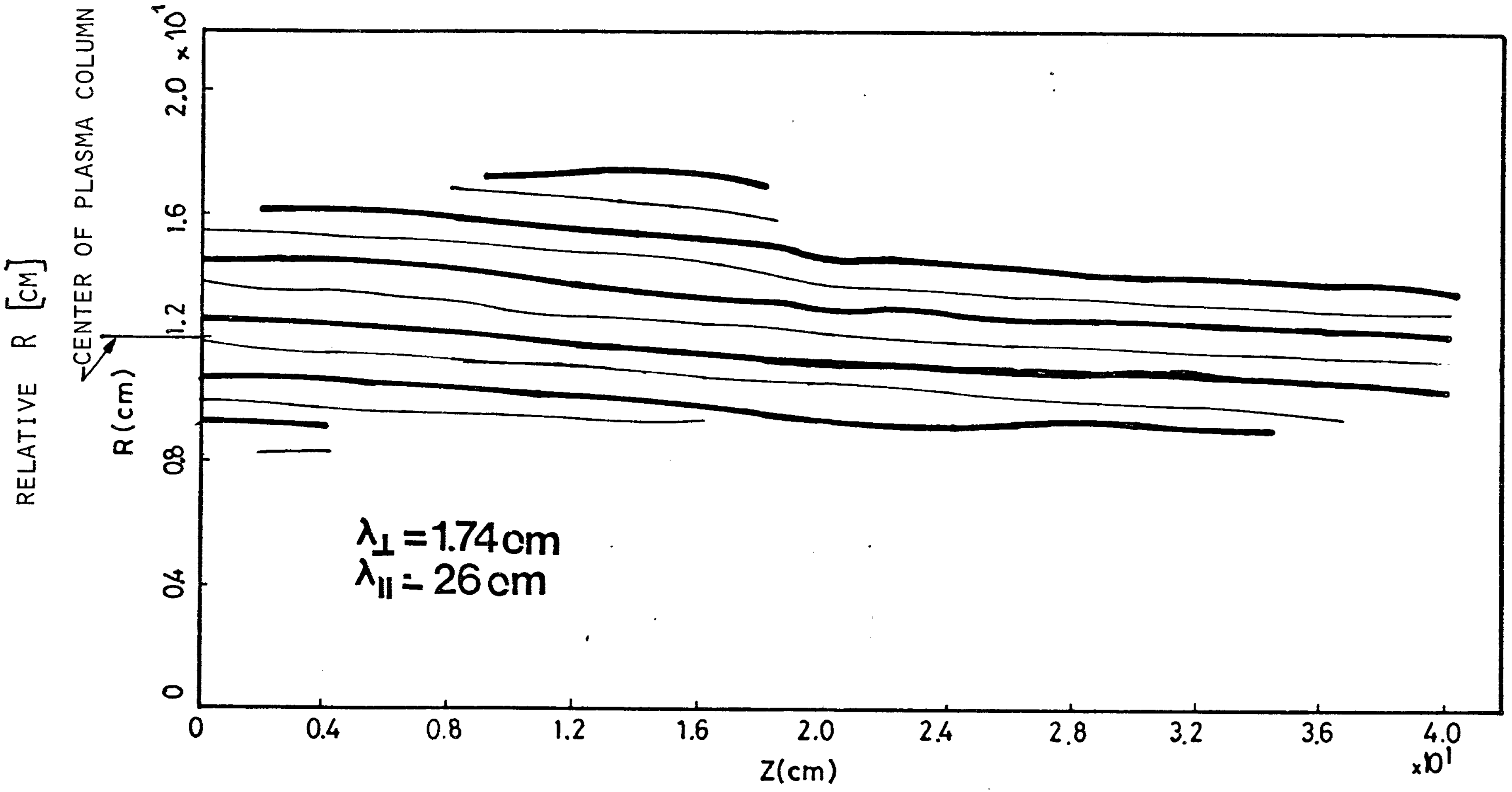


FIG. 7 CONTOURS OF CONSTANT PHASES (━ MAXIMUM, — MINIMUM) OF THE CPSD AT 150 kHz IN THE R-Z PLANE

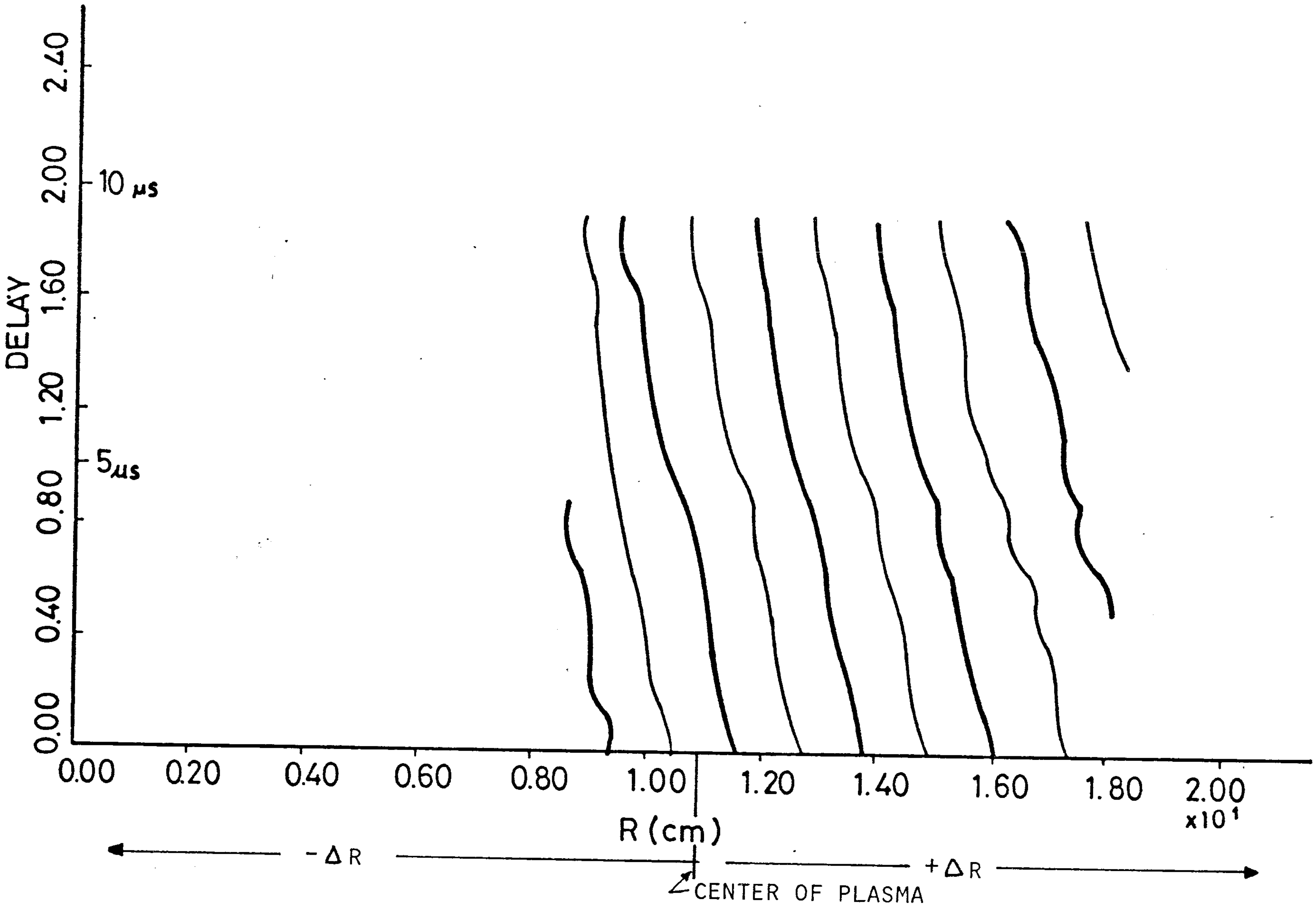


FIG. 8 TIME-POSITION DIAGRAM OF THE CPSD, ΔZ IS FIXED - DIFFERENT DELAY LINE ARE INTEGRATED IN THE CORRELATOR.

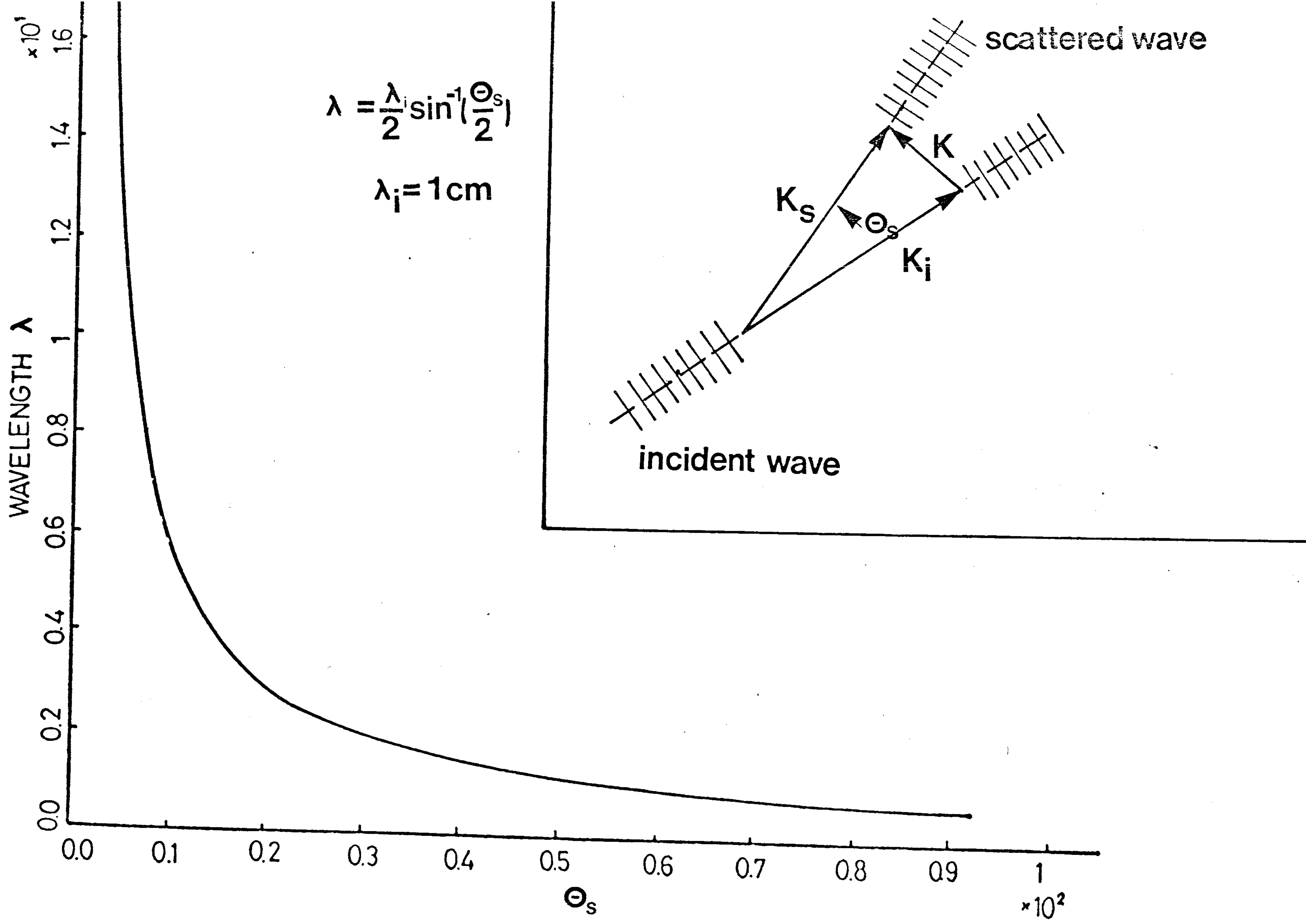


FIG. 9 COHERENT DENSITY FLUCTUATIONS WAVELENGTH VS. SCATTERING ANGLE

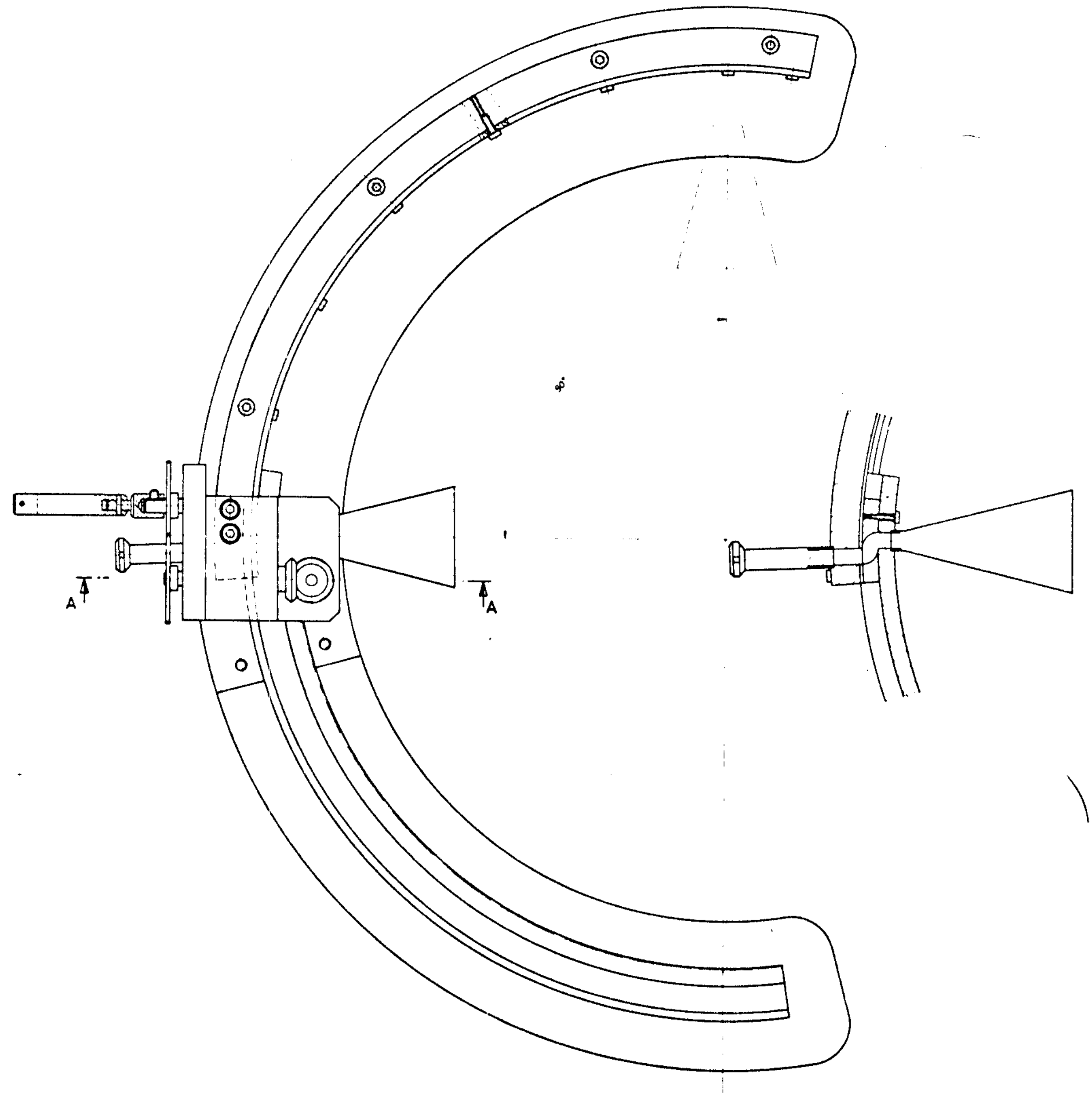


FIG. 10 MECHANICAL DESIGN OF THE AZIMUTHAL SCATTERING STRUCTURE

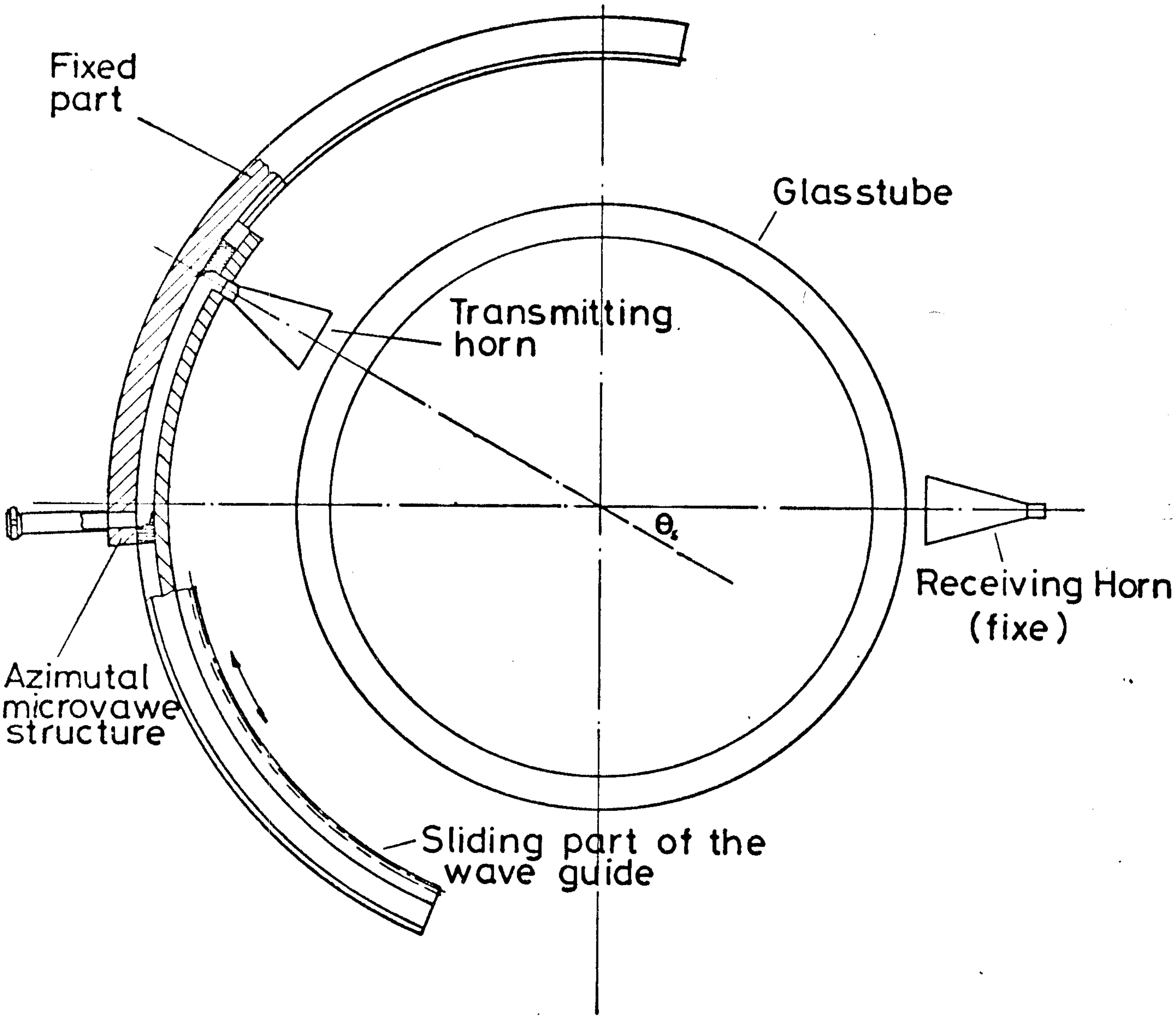


FIG. 11 MICROWAVE SCATTERING ARRANGEMENT WHICH ALLOWS A CONTINUOUS VARIATION OF THE SCATTERING ANGLE

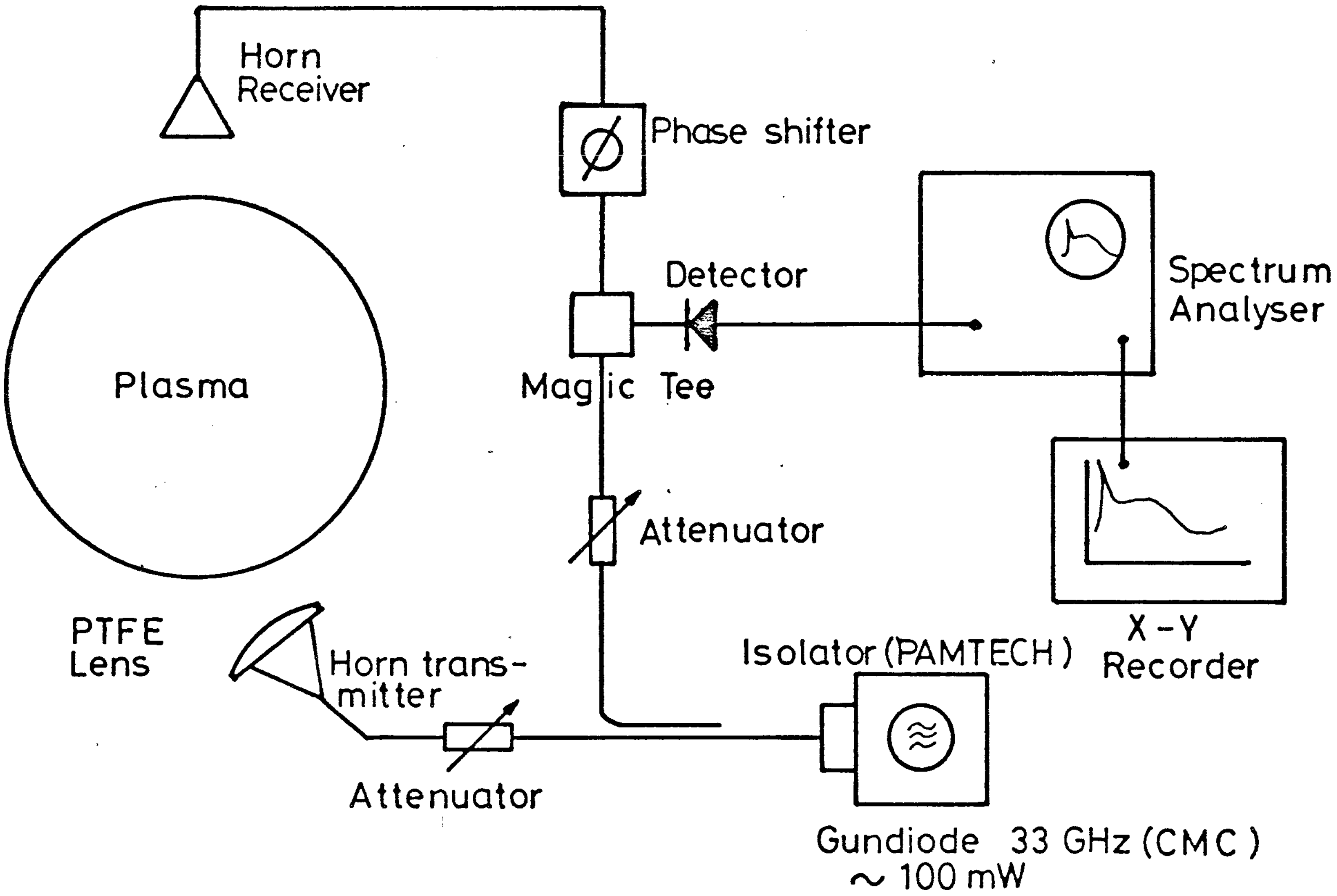


FIG. 12 SCATTERING-EXPERIMENTAL ARRANGEMENT

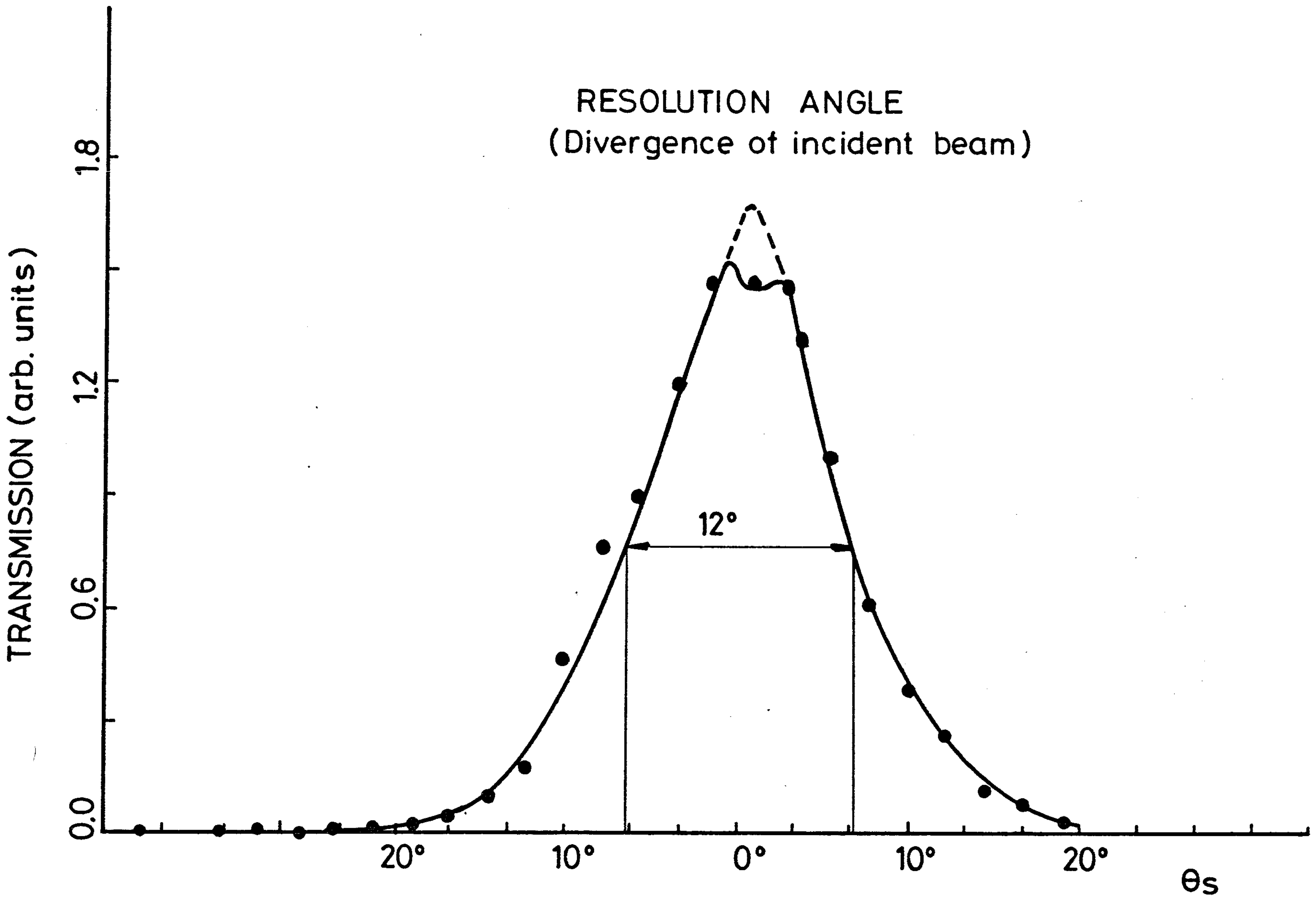

RESOLUTION ANGLE
(Divergence of incident beam)
TRANSMISSION (arb. units)
1.8
1.2
0.6
0.0
12°
20°
10°
0°
10°
20°
θs

FIG. 13

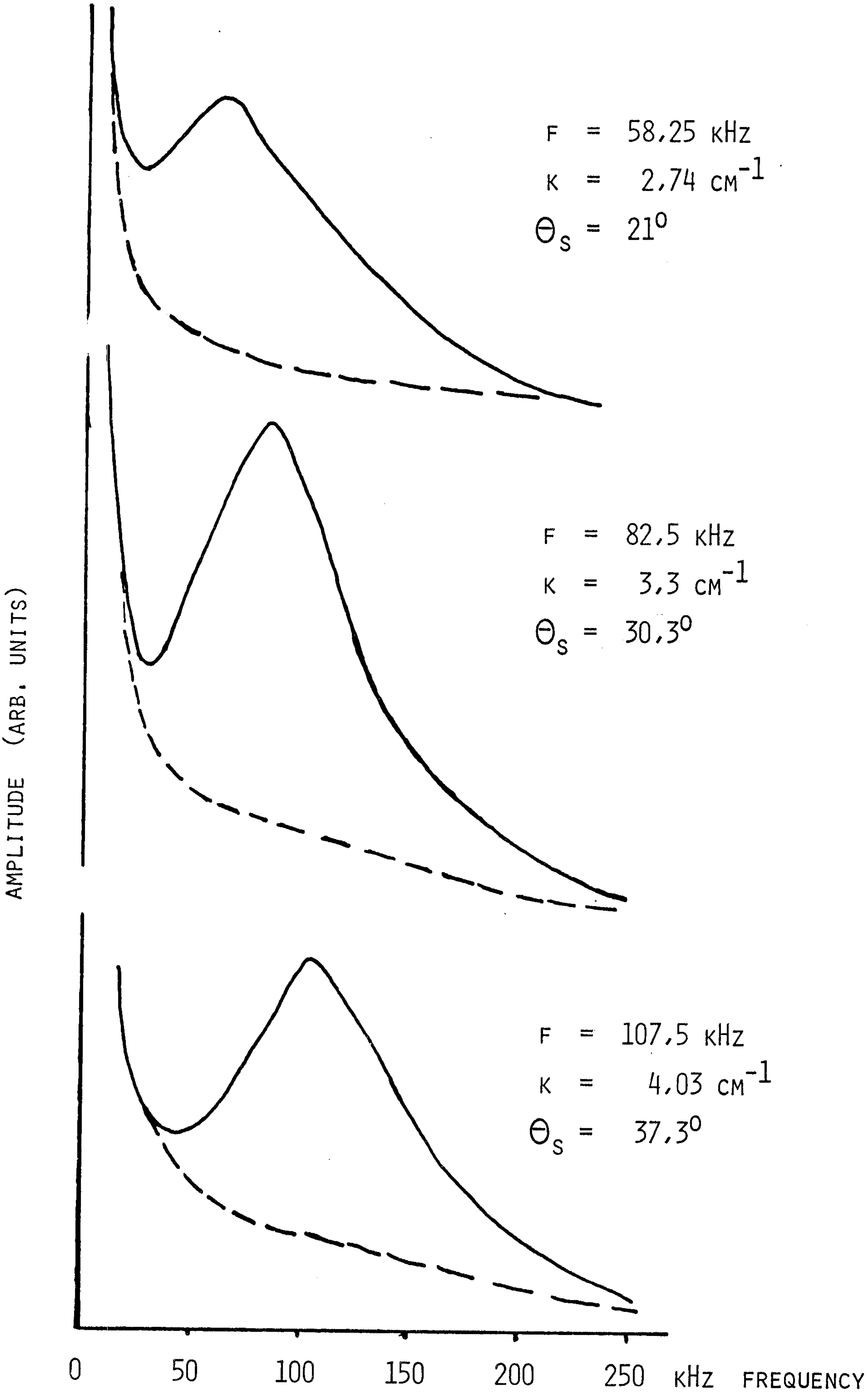


FIG. 14 TYPICAL FREQUENCY SPECTRA OBTAINED FROM THE MICROWAVE SCATTERING SYSTEM (– – – WITHOUT PLASMA)
(—— WITH PLASMA)

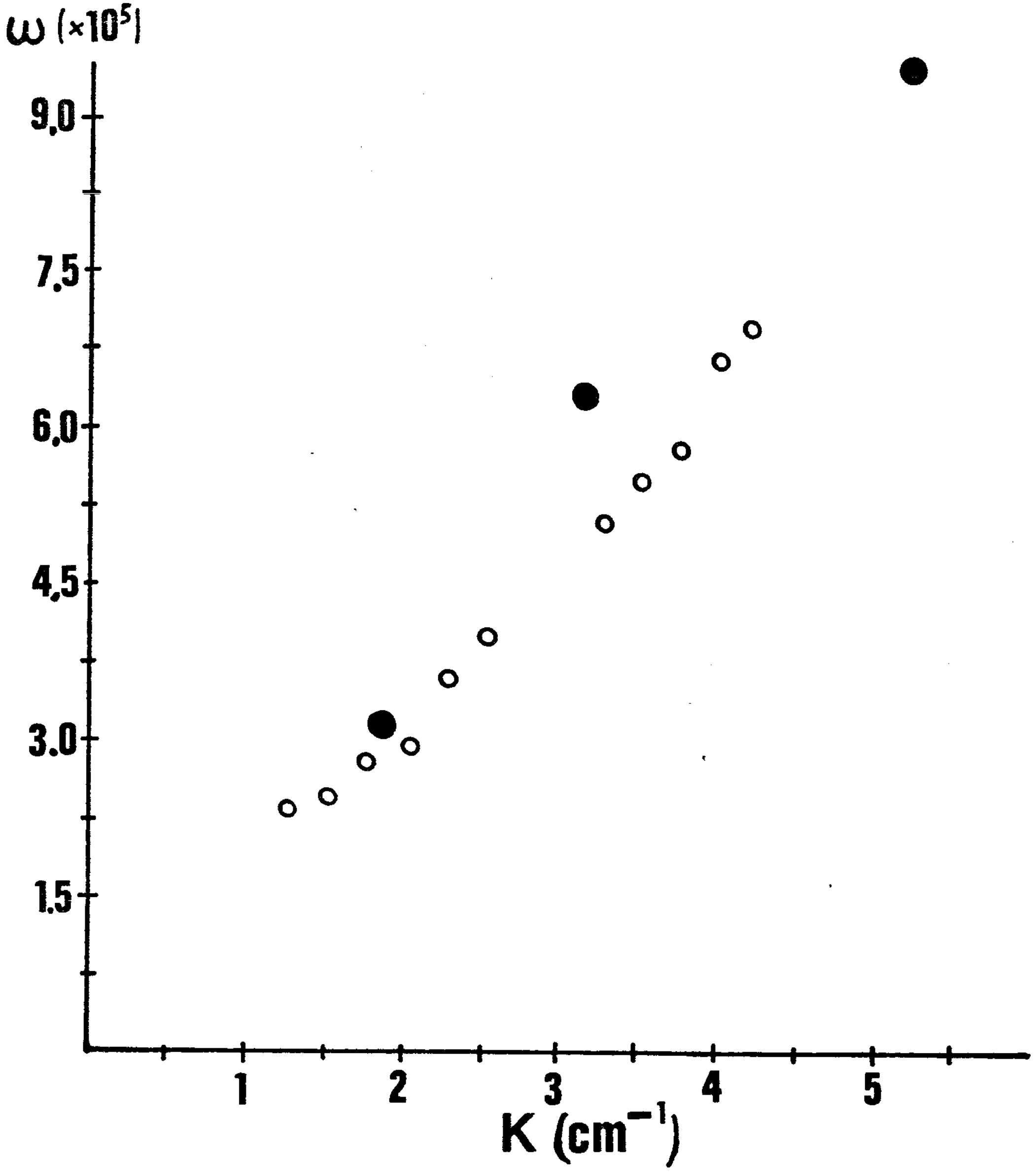


FIG. 15 DISPERSION RELATION AS OBTAINED FROM THE MICRO-WAVE SCATTERING (O) AND FROM THE PHASE CONTOURS OF THE CPSD (●)