

**ELECTROSTATIC ANTENNA SCREENS FOR
ALFVEN WAVE HEATING IN TCA**

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1 INTRODUCTION

In this report I give a brief description of the physical basis and design details of the electrostatic screens constructed for the AWH experiment in TCA.

Electrostatic screens for a poloidal loop antenna, such as that used for AWH in TCA, generally consist of a group of earthed parallel strip blades aligned along the total steady magnetic field and a set of protection or side limiters at either end of the antenna along the toroidal direction. The function of side limiters is to prevent particle and current flow between the plasma and the antenna, the function of the electrostatic screen is to form a capacitive divider to divide the potential of the antenna exposed to the plasma and to short out the component of the near electric field along the total steady field ($E_{||}$). If in addition, both ends of the blades are earthed, an image current circulates in the blades and earth which cancels the component of antenna current parallel to the blades. This results in the elimination of waves with finite $E_{||}$ which may be launched by components of the antenna current parallel to the total steady field. At the same time screens must reduce as little as possible the near magnetic field of the antenna necessary for wave coupling. The capacitive divider function is completely suppressed if the blades are floating so high electric fields appear in the SOL, but the sheath current to the screen is eliminated and the cancellation of $E_{||}$ still occurs.

2. SCREEN TESTS AND DESCRIPTION

A test circuit was constructed to examine the properties of electrostatic screens before a final design and experimental proposal for screens was made. The circuit, shown in Fig. 1a, consisted of a single element linear antenna and an electric probe (Fig. 1b). The plasma SOL would normally be around the position of the probe. Two test screens were examined. The first consisted simply of a flat plate of aluminium which could be either earthed to the back plane or left floating. A second version of the screen was tested in which the ends in the toroidal direction (along the dipole axis of the antenna) were curled back away from the plasma. Curling the blades also gives protection against interaction with particles flowing along field lines. The main electric field component responsible for parasitic plasma coupling is $E_{||}$. The direct field component of $E_{||}$ gives rise to particle acceleration along field lines. Fig. 2 shows the results of measurements made of $E_{||}$ with and without test screens.

Although introduction of screens significantly reduces $E_{||}$ along the screen, the magnitude of $E_{||}$ at the ends of the flat screen increases to about its screenless value if the end is sharp. Curling the ends of the screen away from the plasma reduces $E_{||}$ more uniformly.

The screens used in the AWH experiments are shown schematically in Fig 3. Two types of screen were constructed each consisting of 11 curved blades, 265 mm to 410 mm in total length, approximately 40 mm wide, 0.5 mm thick and separated by 5 mm. In the first, the blades were earthed to the torus at one end by stainless steel supporting poles. In the second the poles were insulated by ceramic stand-offs, and were floating. Due to the complicated three dimensional geometry of the antennas in TCA, the screen blades were aligned along the toroidal field and not along the total steady field in order to make fabrication feasible. As a result, in the case of the earthed screen, nothing is gained by earthing the blades at both ends since the antenna has no toroidally directed current elements; in fact, it gives a measure of protection against radial forces induced in the screens during plasma disruption. This means that waves that may be launched by the small component of antenna current parallel to the poloidal field at finite plasma current are not eliminated by these screens. In actual fact, the necessity to align screen blades along the steady field to eliminate unwanted direct slow wave excitation is not substantiated by experiment. During ICRH in JET [1] where screen elements are normally aligned along the steady total field it has been shown that reversing the toroidal field causes an observable worsening of parasitic effects and lower heating efficiency. In TEXTOR [2] however the same experiment failed to produce a difference in the results for each case. It should be pointed out that Van Nieuwenhove [3] has demonstrated that the shorting of $E_{||}$ and the associated suppression of parasitic coupling and edge plasma dissipation can be performed by the plasma in ICRH.

Strictly, the wave physics of each case is quite different. In ICRH the slow wave is often evanescent and $E_{||}$ does tend to be shorted out. Below the ion cyclotron frequency, however, antenna elements parallel to the total field have been observed to excite guided Alfvén waves [4]. These waves depend on parallel electron dynamics for their existence and by definition are not 'shorted out' by the plasma. When the antenna axis is aligned in the toroidal direction as in AWH, it has been shown [5] that the guided Alfvén wave is more efficiently excited by the parallel component of wave magnetic field at finite frequency than the parallel component of the current elements. This form of coupling to the slow wave cannot be eliminated by

screens. The considerable extra trouble of making curved screen blades for the complicated TCA antenna system is clearly not worth the effort. Examination of such effects is in any case best performed with a rotatable antenna so that the orientation of the antenna current elements can be varied from shot to shot.

In each case, earthed side limiters on each side of the antenna were incorporated to completely obstruct particle flow along field lines. This precaution appeared necessary because the plasma density in the SOL behind the antenna radius is as high as $1-5 \cdot 10^{18} \text{ m}^{-3}$ with electron temperatures around 10 eV [6]. The screens were made of the same material as the antennas, non-magnetic stainless steel, in order to avoid complications in the interpretation of plasma response as a result of impurities when comparing with unshielded antennas. The choice of a low resistivity screen to improve efficiency was not a consideration since the rf generator, AFCO [7], could provide over 100 kW per antenna. In these experiments, this power level is more than enough to recognise the plasma response in the presence of screens. In high power experiments however, or where generator output power is limited, care does have to be exercised in the choice of screen material [8].

An important property of the screens is the amount that they permit the near magnetic field of the antenna to penetrate through to the plasma. The magnetic field transparency of the screens was measured at almost 100%. This is a result of the fact that in designing the screens, care was taken to ensure that the near magnetic field of the antenna was nowhere normal to the screen elements [9]. Further aids are to keep the blades thin and to maximise their number in order to decrease the inductance along paths where eddy currents flow in the screen elements. We conclude that any decrease in coupling to the plasma must be a result of the decrease in near-antenna-density as a result of the screens. In practice, a decrease in the edge plasma density leads to a decrease in the Alfvén wave loading. In these experiments, at the highest powers obtained, the antenna loading decreased by about a factor of two at least.

Typically the RF voltage expected between the antenna terminals and the torus is about 1 kV peak. In TCA the gas particle mean free path is too long for gas breakdown to occur in the low MHz range. Breakdown must therefore occur by secondary electron emission from the antenna and screen material; a phenomenon known as multipacting [10]. Multipacting breakdown occurs when the time taken for an electron to travel the distance between two

electrodes is equal to half the period of the RF voltage. For breakdown along field lines the minimum cutoff frequency for multipacting between two parallel plate electrodes is given by $f_{min} \approx 80/d$ MHz, where d is in cm. As a result, the antenna could be separated from the screen by *at most* 40 cm along field lines. For breakdown between a thin antenna bar and the screen this distance is even larger since the electric field at the antenna is higher for a given potential difference between the antenna and the screen than for the case of parallel plates. Across field lines, breakdown is not expected because the electron Larmor radius is much smaller than the distance between screen and antenna. These conditions make breakdown inside the vessel practically impossible below the ion cyclotron frequency. No sign of breakdown was ever observed during the experiments.

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FIGURE CAPTIONS

- Fig 1. Apparatus used to test the properties of electrostatic screens.
- a) Single bar antenna element fed symmetrically from below an earth plane.
 - b) A movable probe which measures $E_{||}$ by the potential difference between parallel metal strips.
- Fig. 2. $E_{||}$ for the test bar antenna versus distance in the toroidal direction from the antenna.
- Fig. 3 Schematic diagrams of the electrostatic screens.
- a) Top view showing the 11 screen blades. The antenna bars are shown as dotted lines. The side limiters are also shown.
 - b) View along the toroidal direction. The side limiters, not shown, completely block the view down to $a=195$ mm. The plates supporting the blades were made of stainless steel in the case of earthed screens and ceramic in the case of floating screens. The antenna is shown dotted.
 - c) Photographs of TCA antennas with and without screens.

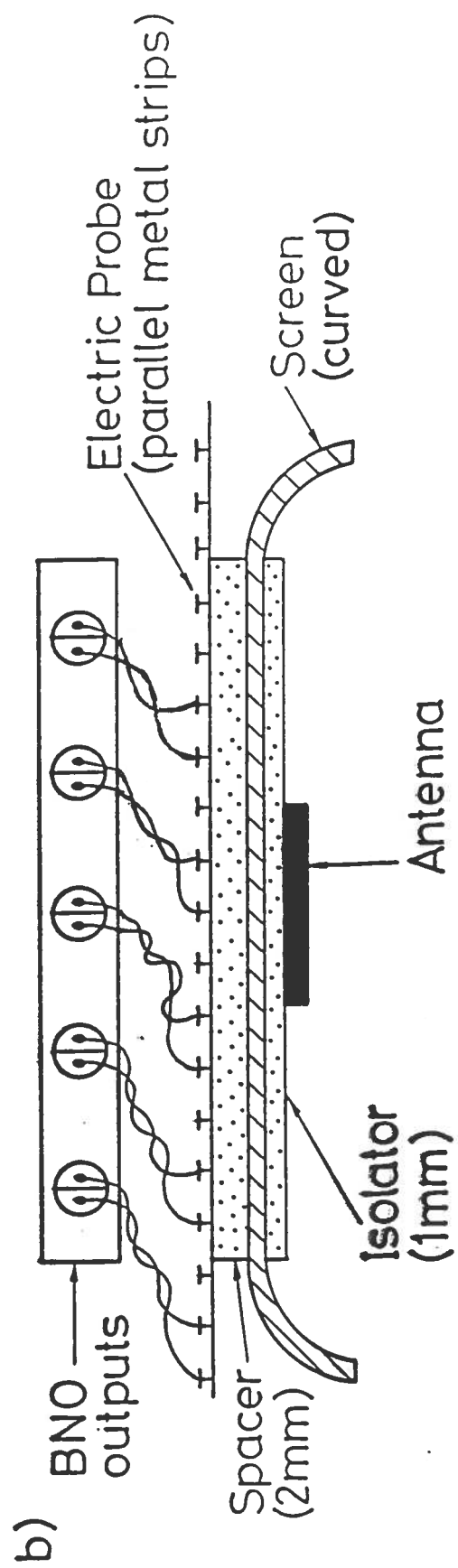
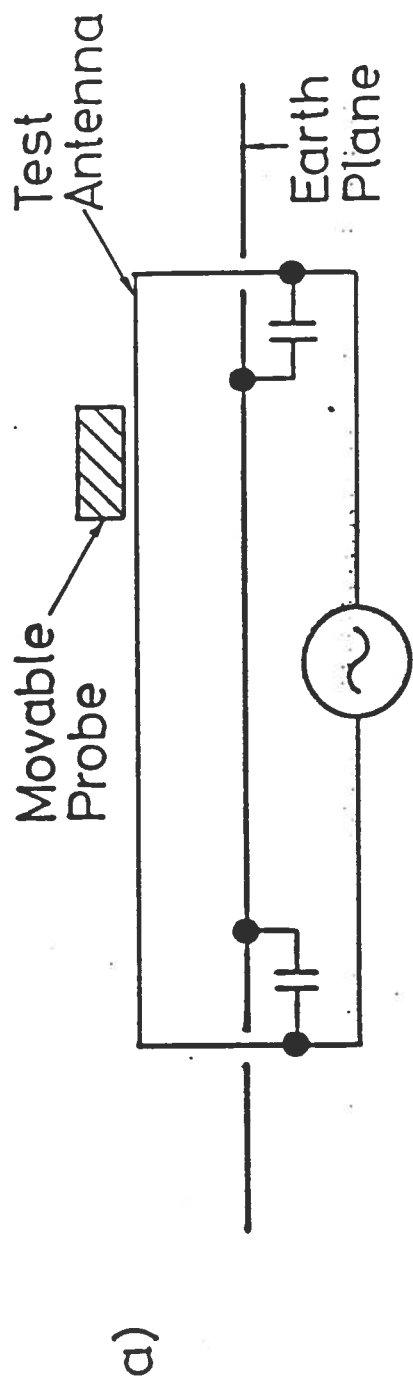


Fig 1.

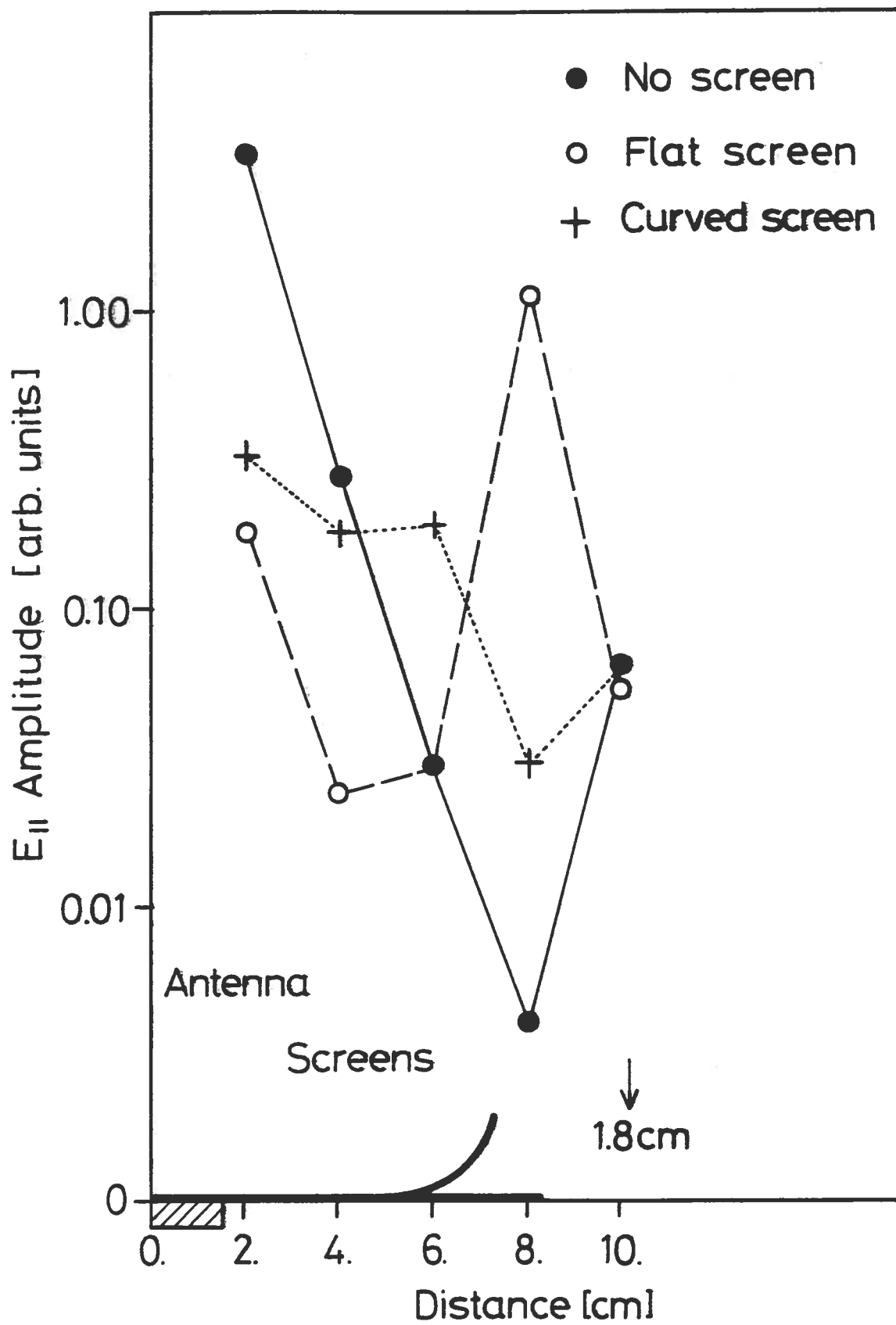


Fig. 2

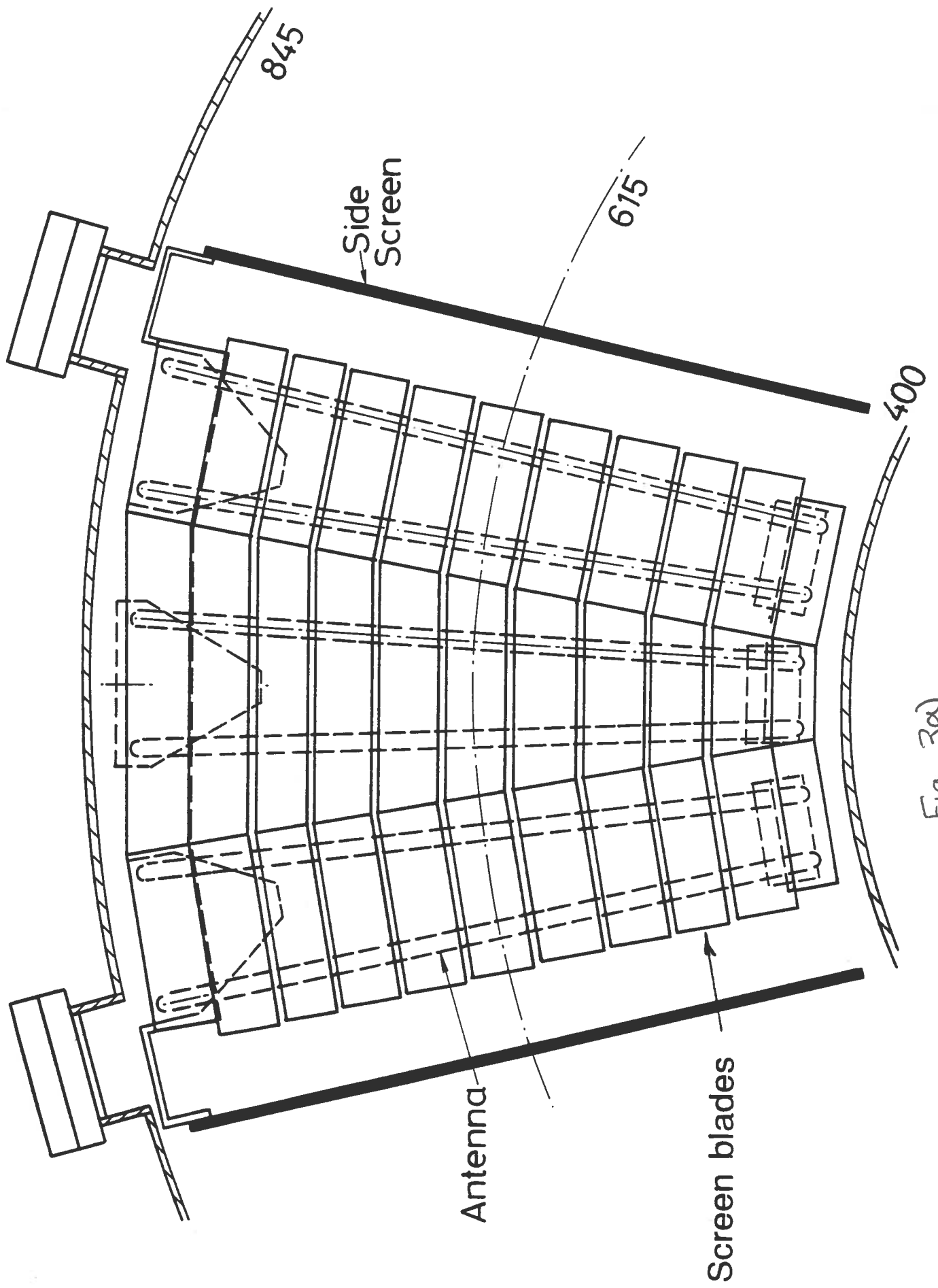


Fig. 3a)

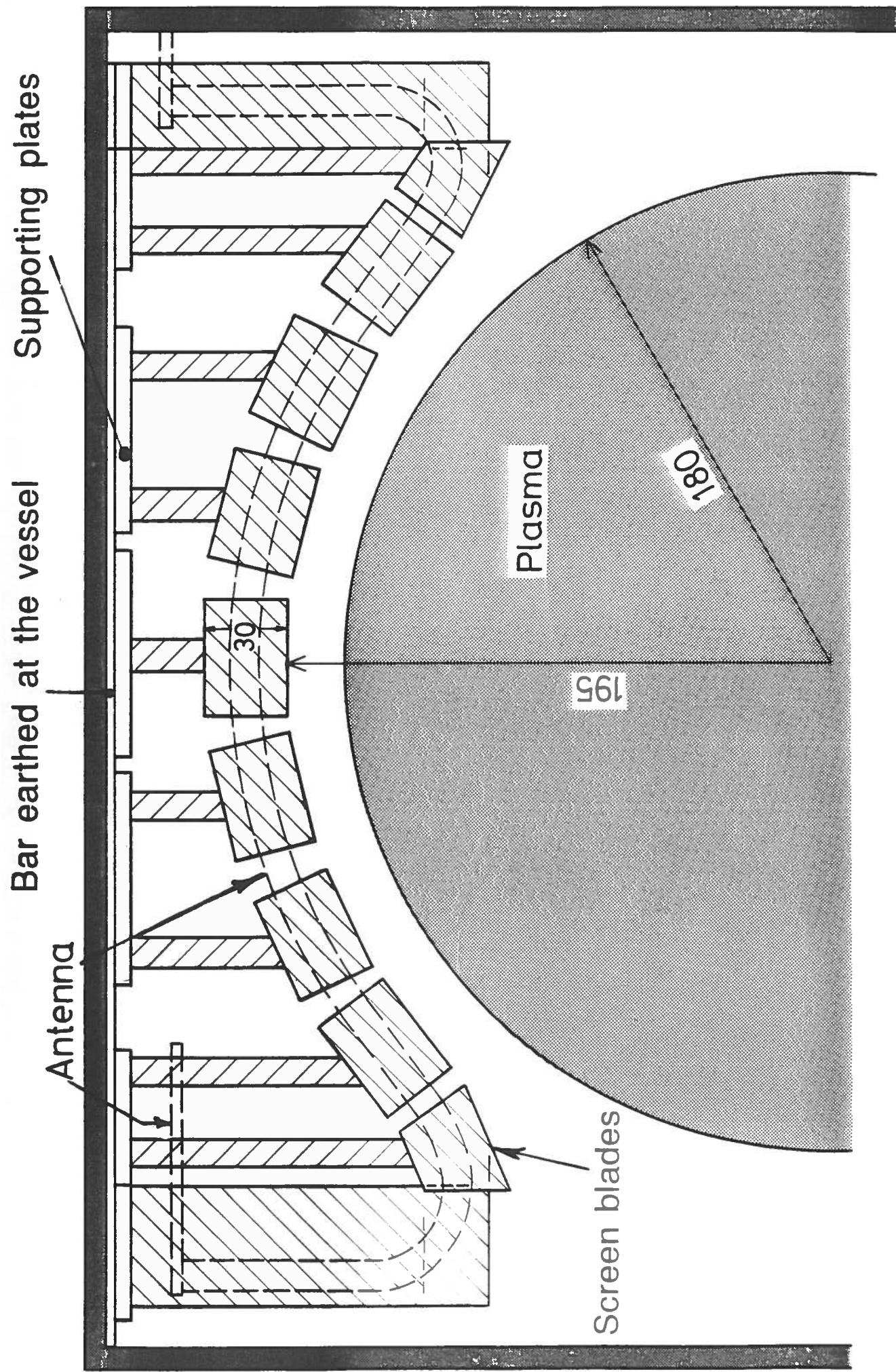


Fig 3b)

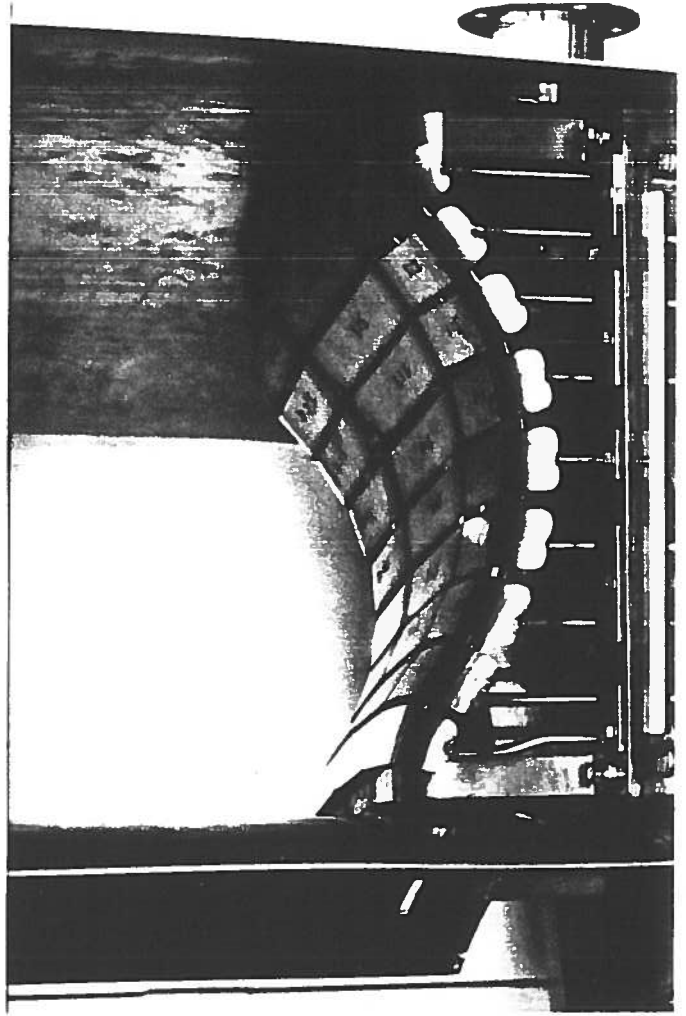
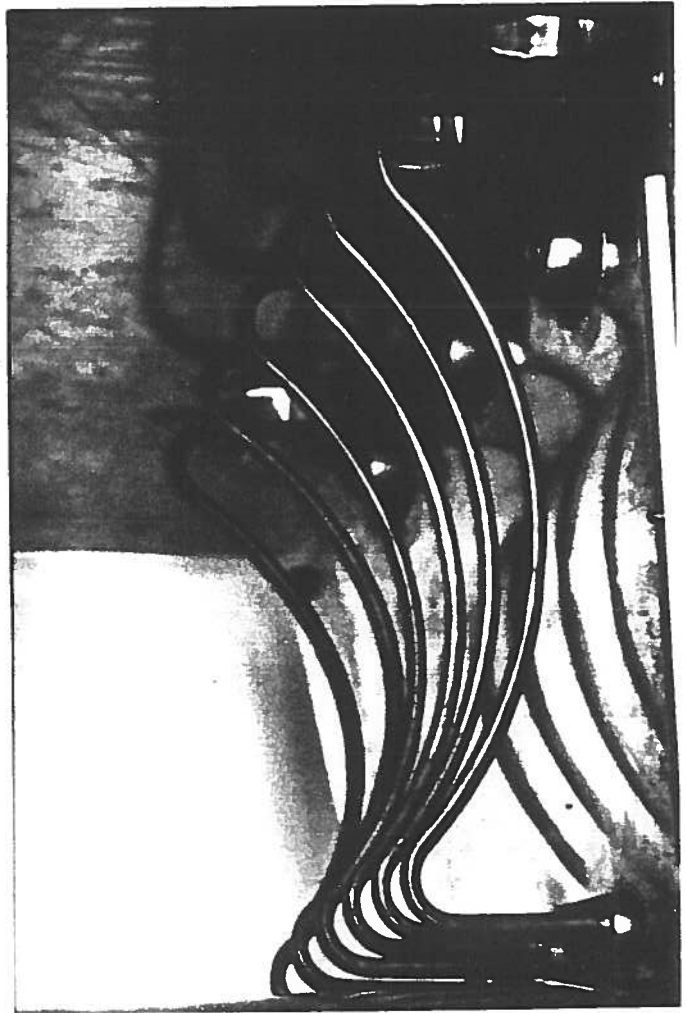


Fig. 3c).