

Magnetic Guarding of Octupole
Conductor Supports

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ABSTRACT

Conductor supports for a toroidal octupole plasma confining field normally intercept field lines and cause particle loss. If these supports are surrounded by a dipole magnetic field caused by currents along these supports, a separatrix excludes the octupole field lines from the region of the supports. Electrostatic probe observations of plasma lifetime in an octupole giving around a 500 microsecond lifetime without this guarding magnetic field showed about a 1.7 fold increase in lifetime with guarding for a gun-injected plasma having an ion temperature of about 40 eV, and about a 1.2 fold increase for a cold ion plasma formed by electron-cyclotron resonance breakdown. Ion extraction and energy analysis¹ was also used to examine the lifetime at different ion energies. The separatrix was about two gyroradii from the supports for 40 eV ions, but many gyroradii for the cold ion plasma. Collectors showed that loss of particles along the null field locus was increased by the guarding field for a hot ion plasma, and that the flux of particles to the supports was reduced by magnetic guarding. The small improvement in lifetime by magnetic guarding suggests that either greatly improved guarding must be provided or there are other plasma losses having a magnitude comparable to support losses.

¹ C.W. Erickson, Rev. Sci. Instr. 37, 1308 (1966)

The major limitation on plasma lifetime in a multipole has long been assumed to be the supports or hangers for the multipole conductors which intercept magnetic field lines.

One can calculate the lifetime expected for a plasma in the octupole with no losses other than plasma hitting the hangers. This lifetime is of the order of the observed lifetime.

Two methods have been proposed to eliminate this loss. One is to magnetically levitate the conductors, the other is to put magnetic guard fields around the hangers. The latter was suggested by Lehnert in 1958 and forms the subject of this paper.

Four current carrying hoops produce the confinement field in the Wisconsin toroidal octupole. Each hoop is supported by three hangers.

A 40 eV Maxwellian plasma is produced by a Z-pinch gun, and travels across a drift tank separating thermal neutrals from the plasma. In about 200 μ sec the plasma becomes uniformly distributed azimuthally around the octupole and is quiescent. The density is then about 10^9 cm^{-3} .

The field produced by the four hoops is zero at the center and increases outwards in all directions. It is about 1 kg at the outside wall and reaches maxima of 4 kg and 6 kg at the outer and inner hoops respectively. This is the field that must be opposed by the hanger guard fields.

The guarded supports are attached to the current carrying hoops (Figure 1). A current flowing to the right in the hoop produces a magnetic induction out of the paper above the hoops. A current is passed through the hanger - down the right leg and up the left - to produce a guard field in the opposite direction within the slot.

Brass clamps outside the vacuum chamber provide both mechanical support and electrical contact to the hangers.

For diagnostic purposes, copper foil, insulated from the hanger, was wrapped around one leg and a punctured disk, surrounding the hanger, was attached to the vacuum chamber wall. These were biased to -45 V to read ion saturation current. A similar disk was located at a side wall, away from the hangers.

The octupole field follows a damped sine wave with time (Figure 2).

Two methods of excitation were used for the hangers. They could be excited in series with the octupole so that the guard field strength had a constant ratio to the octupole field strength (Figure 3) or they could be excited separately with a square current pulse of about 1 msec. The magnitude of the guard field could then be varied relative to the octupole field (Figure 4).

Plasma was injected into the octupole at 1.8 msec in order to utilize the flat top of the sine wave. The guard field was pulsed on at 1.5 msec to provide a constant guard field during the experiment time of about 1 msec.

The flux produced by the guarded hanger and octupole forms two regions with a separatrix between (Figure 5). The amount of flux within the separatrix could be varied between zero and 2.5 gyroradii for 40 eV ions.

It is also possible to produce guarding by running the currents through the hanger in the opposite direction so that the fields add within the slot and oppose outside the hangers (Figure 6).

We call this reverse guarding. The usual method is called forward guarding.

Figure 7 shows the results of forward guarding. Normalized ion saturation current to the hangers and to the lid above the hanger is plotted versus guard field strength. The current is normalized by dividing by the current to a density probe. One sees that any guard field will reduce the ion flux to the hanger and that the reduction is proportional to the guard field.

However, as the guard field is increased beyond a certain point, the ion current to the wall above the hanger begins to increase. This point corresponds to about one gyroradius of guard flux for a 40 eV ion.

It should be noted that the loss to the wall increases with guard field only near the hangers. The wall collector at some distance from the hangers measured an ion saturation current which was independent of the guard field.

If we double the octupole field - to the usual operating strength - we observe similar behavior. The point at which the ion current to the wall along the hanger begins to increase is again at one gyroradius of guarding for a 40 eV ion.

The stronger multipole field reduces the ion current to the wall in the absence of a guard field.

Tests were also made with a B_θ field. This is a toroidal field with a strength of about 350 gauss in the region of zero octupole field.

The results were similar to those for no B_θ .

Since in the process of reducing one loss mechanism, we create another, it might be conjectured that the lifetime of the plasma will not be greatly increased. This is unfortunately correct. The increase in lifetime with guard field is about 10% as measured by ion saturation probes with an uncertainty of about 10%.

Measurements made with an electron cyclotron resonance plasma give similar results. This is despite the fact that the ions involved are cold, < 1 eV, so that a very large number of ion gyroradii are provided by the guard field.

With reverse guarding, the results were somewhat different (Figure 8). At low guard fields, the ion current to the hanger is approximately constant while the ion current to the wall increases. As the guard field is increased to larger values, the ion current to the hanger finally begins to decrease. The difference may be that the separatrix comes closer to or even

cuts through the corner of the hanger with reverse guarding. This would cause ions to hit the hanger until the guard field was increased sufficiently to move the separatrix away from the hanger. The octupole was run at half field strength during reverse guarding studies.

My conclusion is that it is possible to guard an obstacle in a plasma from the plasma.

However, in so doing, other losses are introduced which result in the plasma lifetime remaining constant.

APPENDIX

These results should be considered quite preliminary. Among things to be studied in the future are:

1. Effects of higher guard fields
2. Location of null line for different values of field
3. The mysterious increase in unguarded lifetime from about 350 μ sec to about 600 μ sec in a period of one month.
4. Possibility that octupole field lines take a step outwards or inwards each time they pass hangers. This possibility was suggested by J.E. Hammel in a private communication.

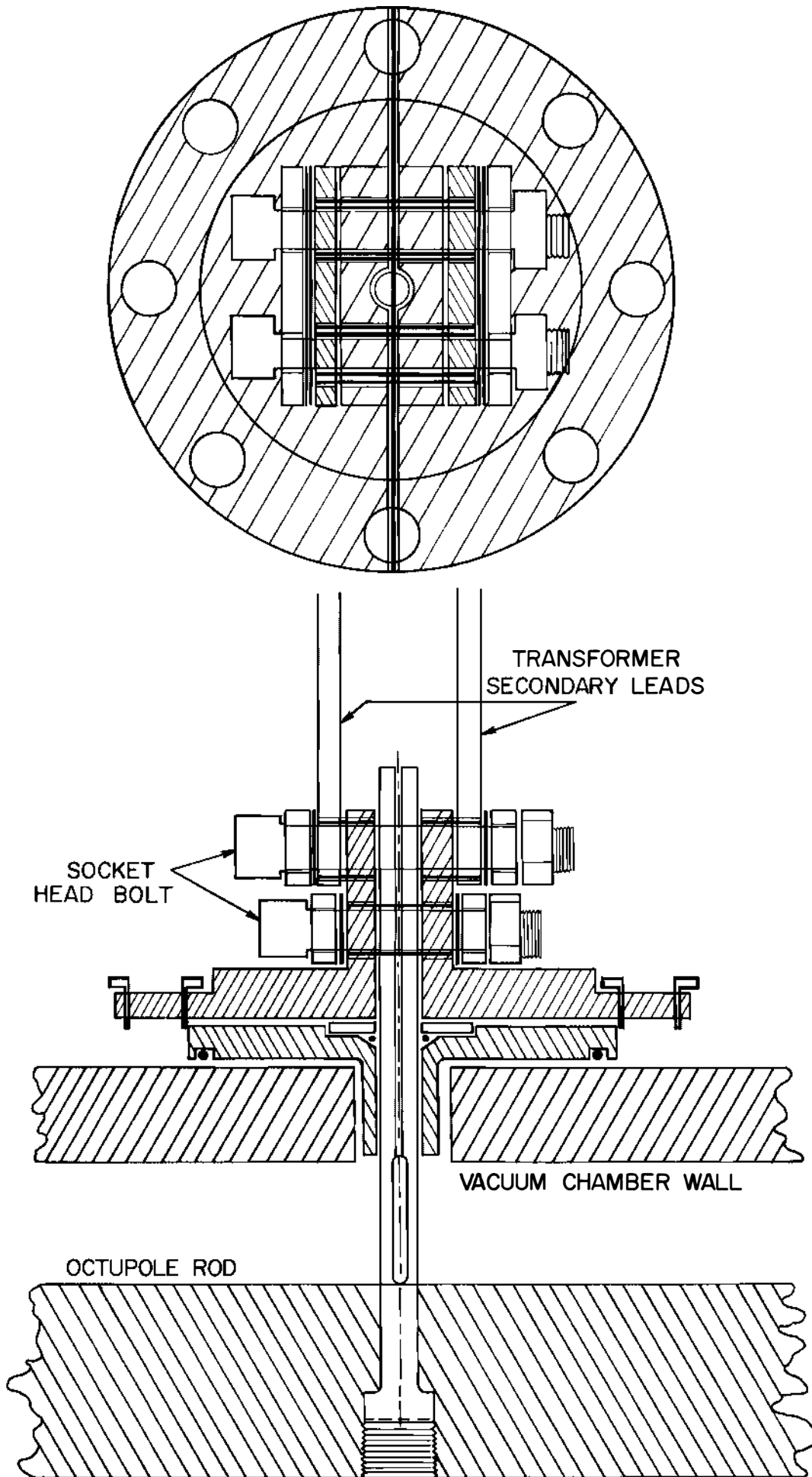
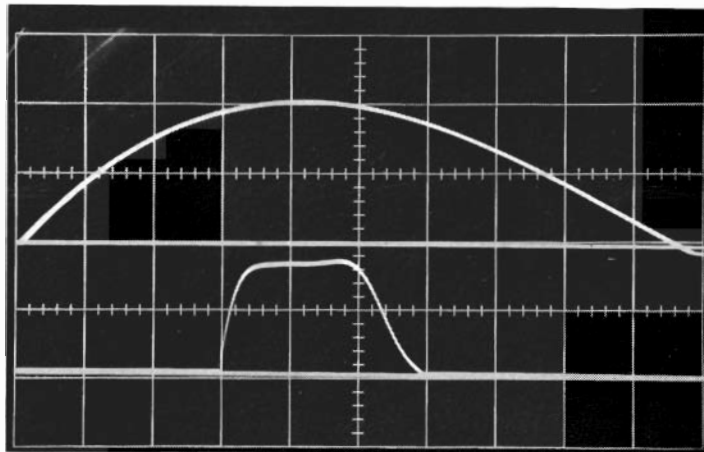


Figure 1

MAGNETIC FIELD VS TIME



OCTUPOLE FIELD

GUARD FIELD FROM
MATCHED IMPEDANCE
LINE

500 μsec /scale division

Figure 2

GUARDED SUPPORT -OCTUPOLE FIRING CIRCUIT

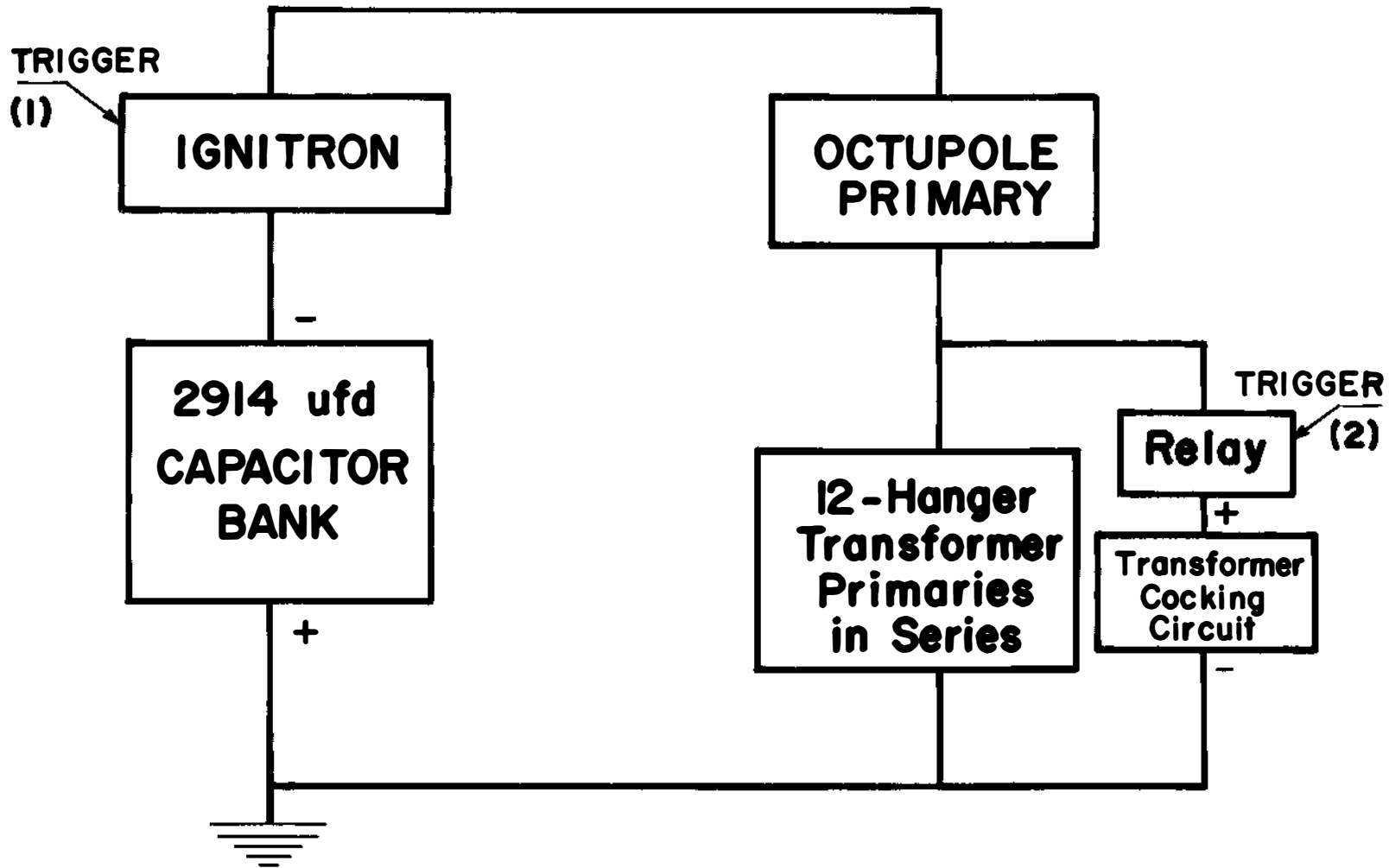


Figure 3

SEPARATED GUARDED SUPPORT --
OCTUPOLE FIRING CIRCUITS

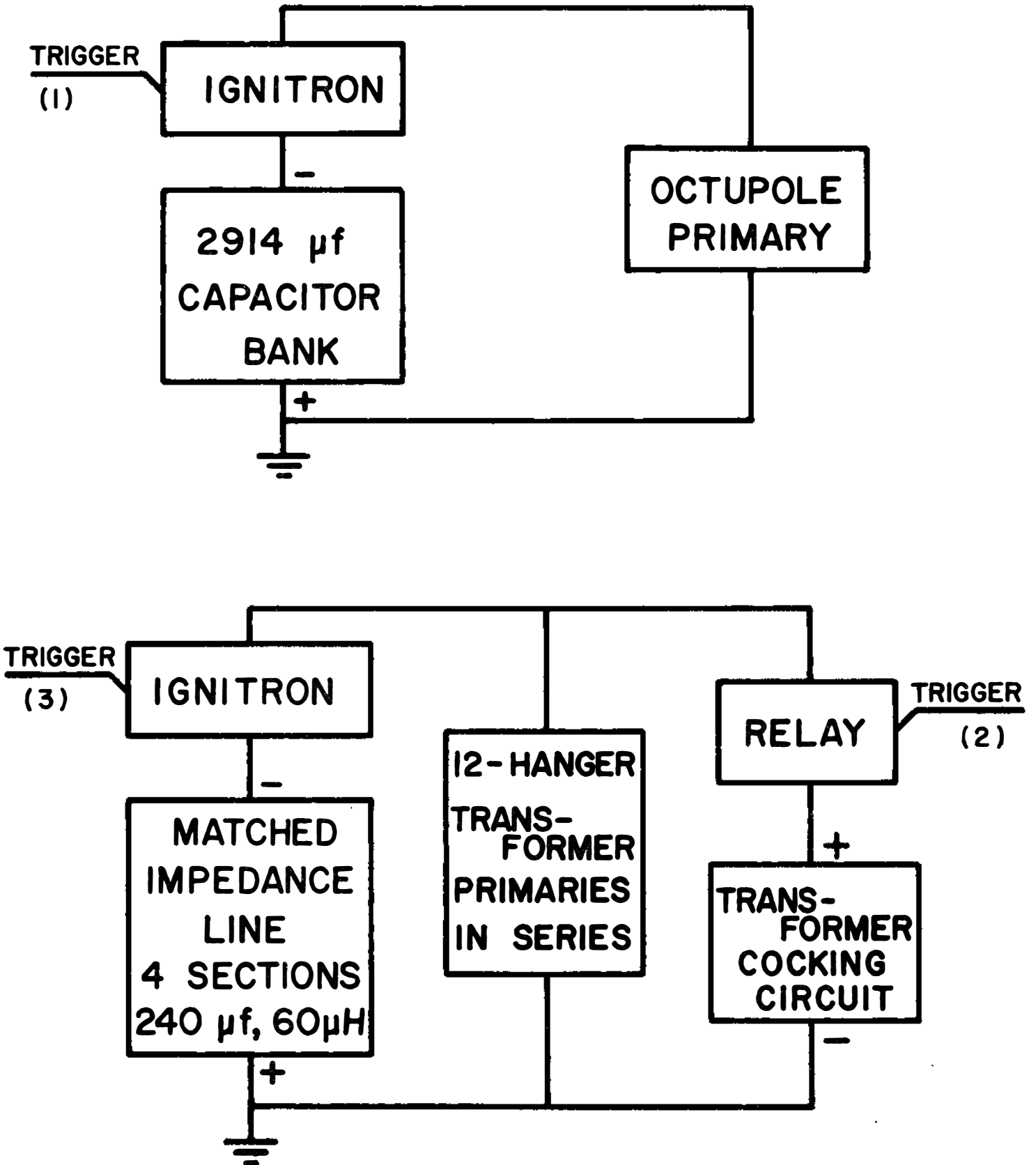


Figure 4

FORWARD GUARDING

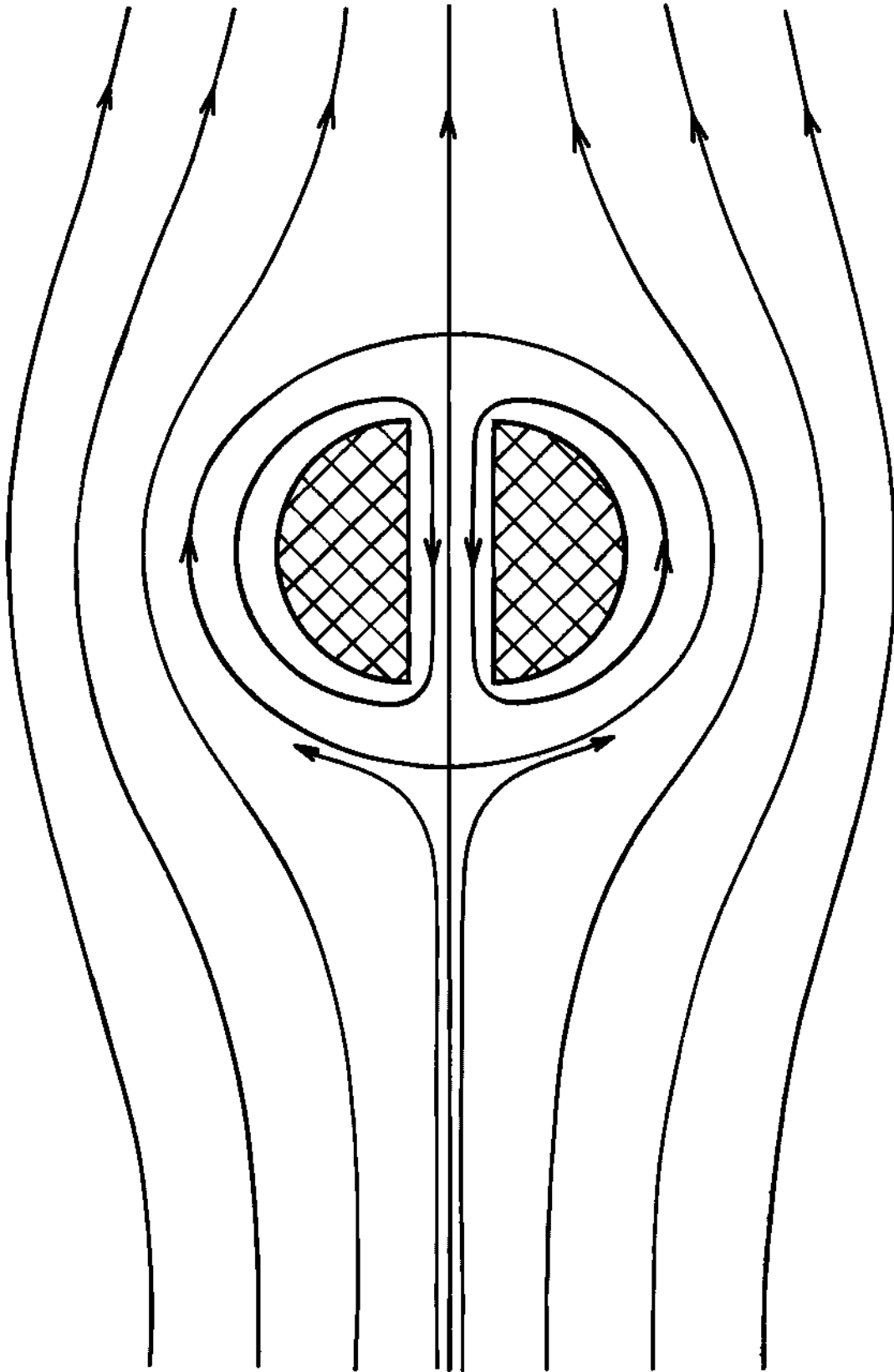


Figure 5

REVERSE GUARDING

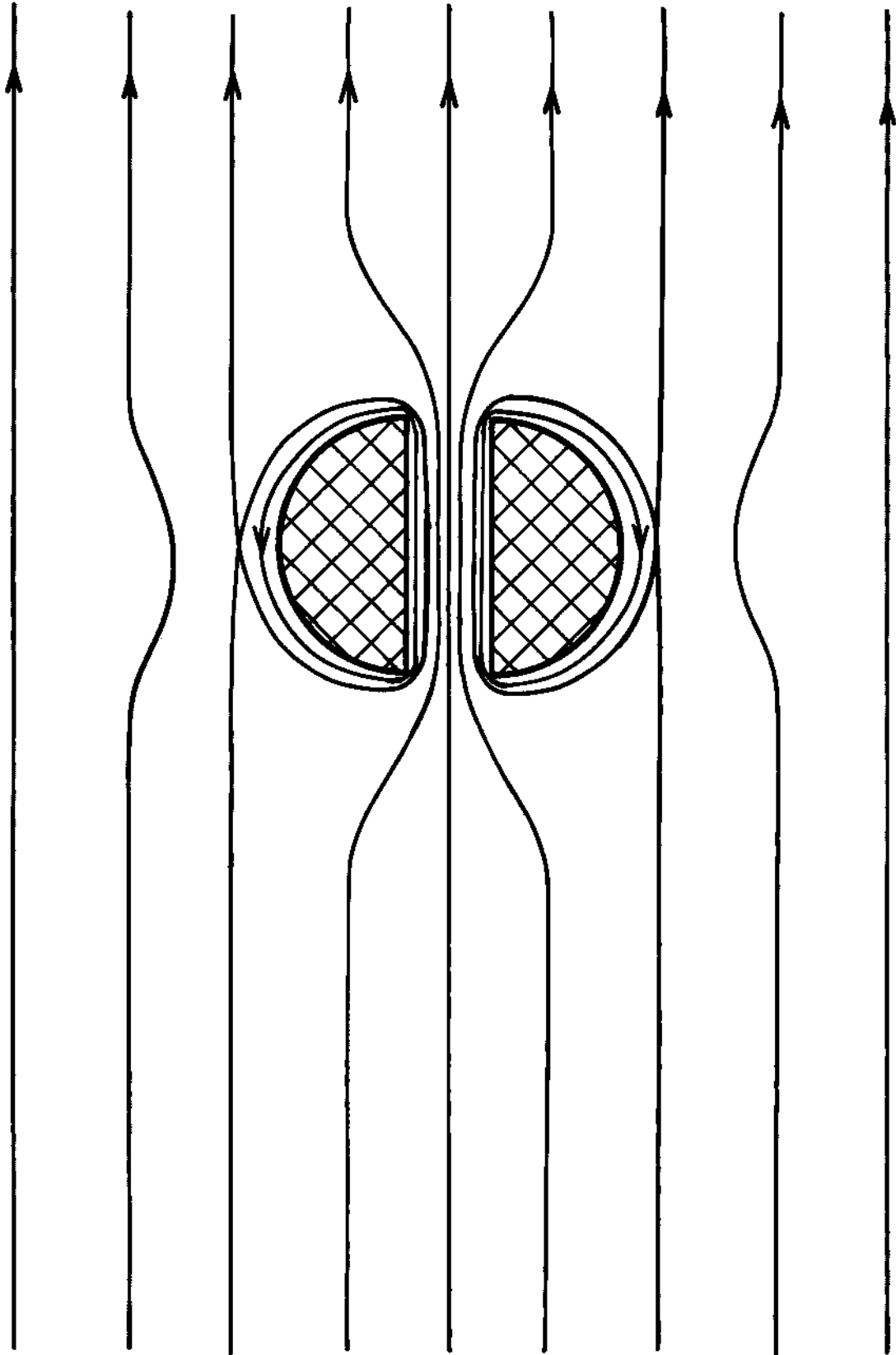
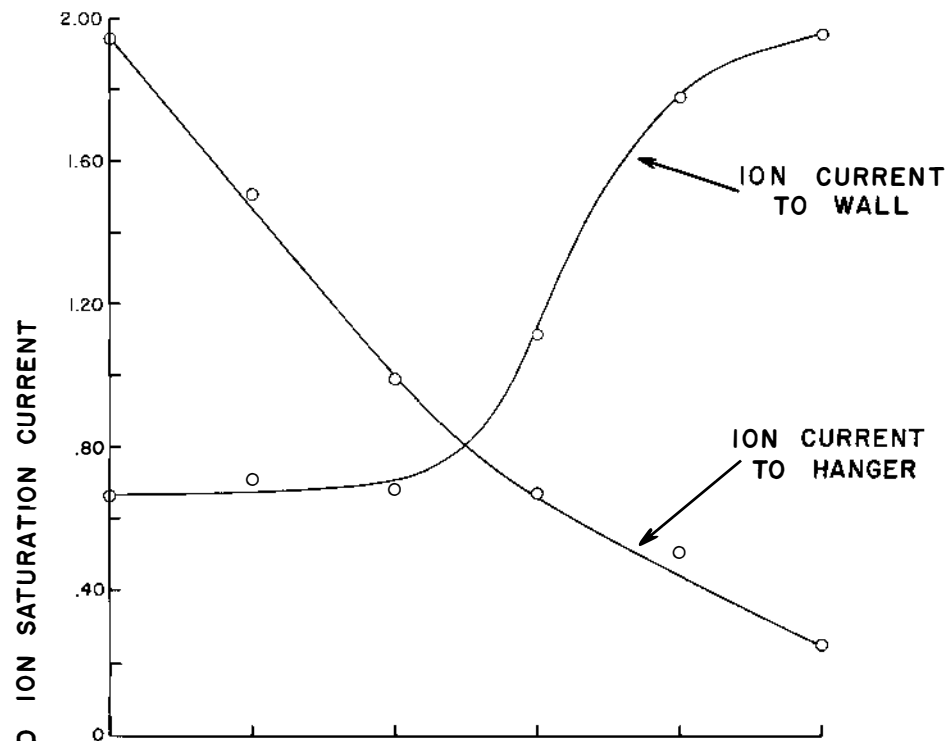
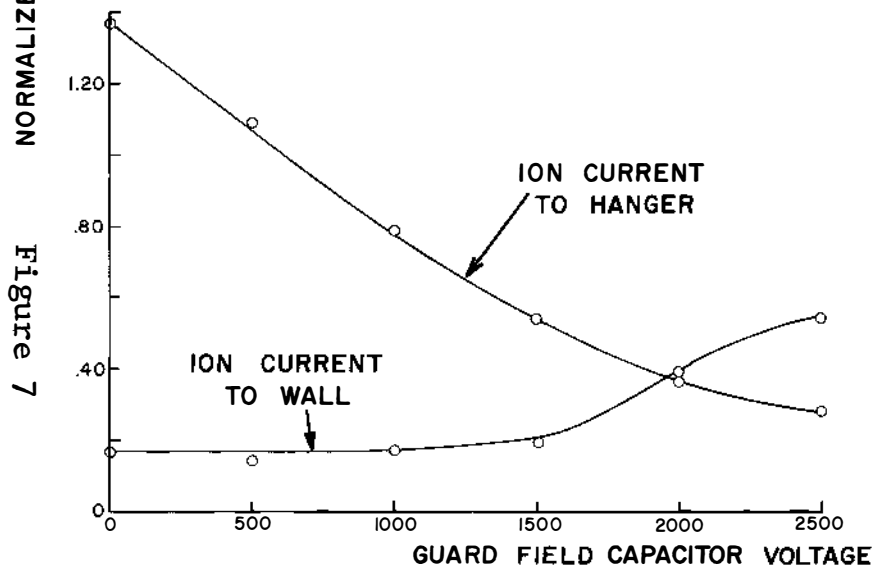


Figure 6



HALF OCTUPOLE
FIELD STRENGTH



FULL OCTUPOLE
FIELD STRENGTH

Figure 7

NORMALIZED ION SATURATION CURRENT

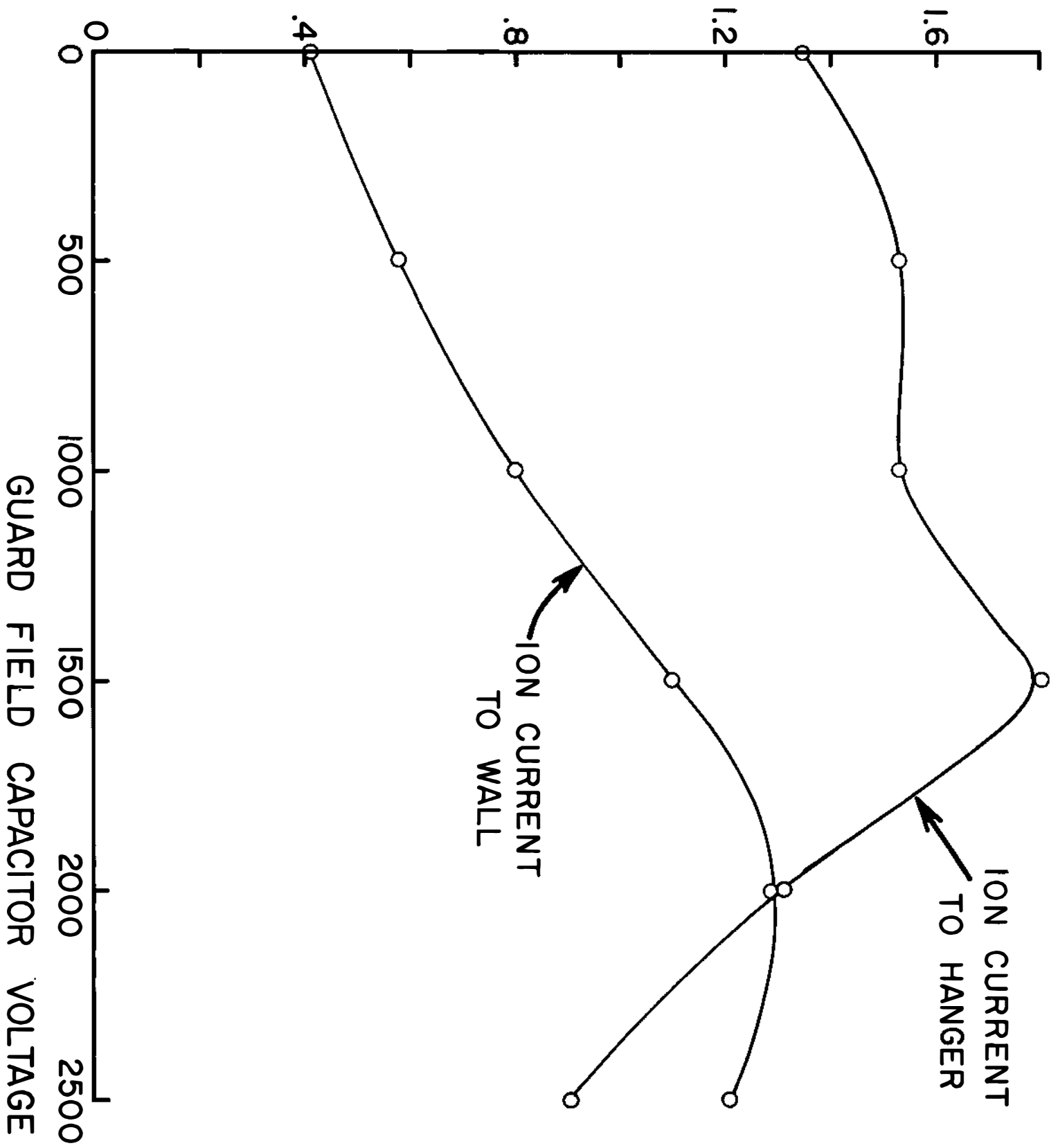


Figure 8