A Further Note on the Probe Paradox

by

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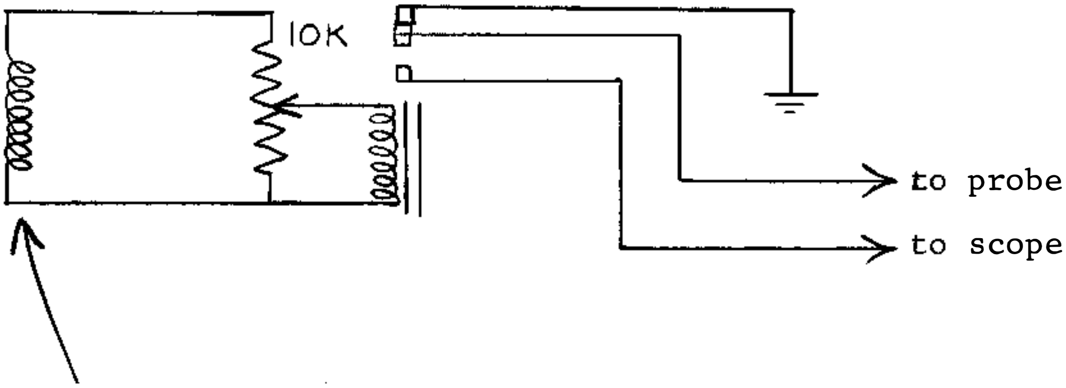
The probe paradox is discussed in detail in PLP 135. Briefly, it involves a discrepancy of ~20 volts between the floating potential measured in the toroidal octupole by high impedance floating probes and by low impedance probes biased to draw zero current. The conclusion of PLP 135 is that the difference is probably caused by the blast of plasma which strikes the probe during the filling process.

This hypothesis has recently been tested by using a mercury wetted relay to switch the probe in or out of the circuit during the first few hundred μsec after the gun fires. The circuit used with the high -z probe is shown below:



12 T around transformer core

Since the relay takes about 2 msec to close, about 200 μsec of dead time is obtained for normal injection at 1800 μsec. The potentiometer allows the closing time to be increased to about 3 msec. The mercury wetted contacts insure that the contacts close abruptly with no bounce.

Figure 1 shows an overlay of two traces, one with the relay circuit, and one without. By grounding the floating probe during the first 450 μsec, the floating potential read by the probe is shifted positive by about 4 volts with respect to the probe that is allowed to float during transport. Direct measurement of the current to the grounded probe shows that the charge collected is

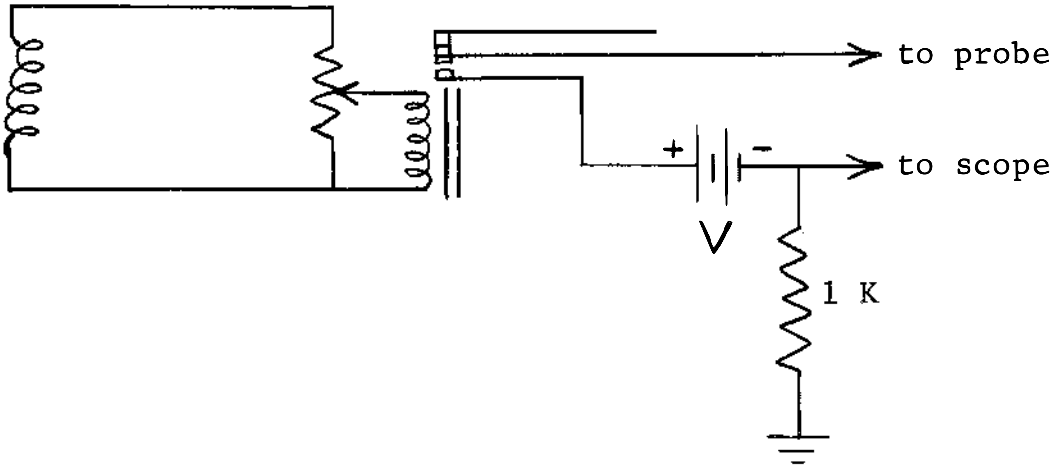
$$Q = \int I dt \cong 10^{-6} \text{ coulombs.}$$

The charge collected by the floating probe, on the other hand, is

$$Q = CV \cong 10^{-8} \text{ coulombs}$$

for $C \approx 200$ pF. A probe with $C \approx 2$ pF collects 10^{-10} coulombs and reads the same potential as the probe which collects 10^{-8} coulombs. The charge above which a floating potential discrepancy exists is therefore $\sim 10^{-7}$ coulombs.

A similar test was conducted on the low -z probe using the circuit below:



The relay was open, allowing the probe to float during the first 250 μsec, and then was connected to a low -z circuit in order to plot out the probe V-I characteristic.

In figures 2 and 3 are plotted the V-I characteristics obtained in this way (protected) and in the usual way (unprotected) for the gun and microwave plasma. Note that the voltage shift is approximately constant and that the low -z probe measures a floating potential the same as that measured by the high -z probe provided that the low -z probe is allowed to float during the first 250 μsec.

There is reason to believe that the shape of the curve in the transition region ($V > V_f$) is inaccurate since it indicates a temperature too high (see PLP 163, 165 and 176) and since $\ln I$ is not proportional to V. Even the protected probe collects > 10^{-7} coulombs during the quiescent decay, however. Hence the problem is apparently not confined to the injection period. The most likely interpretation of the V-I curve is that the more strongly positive the probe is biased, the greater the charge collected and the more positive the potential shift, causing the V-I curve to be flattened out. Such an effect would cause the probe to read a temperature which is too high and a rate of temperature decay which is too slow.

The following conclusions can be drawn from the above observations:

1. The probe paradox is apparently associated with heavy electron bombardment and is noticable when the collected charge exceeds $\sim 10^{-7}$ coulombs or, more accurately, $\sim 10^{-7}$ coulombs/cm^2.

2. It is not possible to say conclusively which probe reads correctly since one may say either that the electron bombardment contaminates the probe or that it cleans it. The weight of evidence is in favor of the high -z probe being correct for the following reasons:

a) The agreement with Erickson's plasma potential measurements (PLP 100) is good if one accepts recent electron temperature measurements (PLP 163, 176), whereas the low -z probe results can be brought into agreement with Erickson's results only by assuming $T_e \sim 10^{-4}\ T_i$.

b) The potential shift continues to increase with increasing charge up to at least 10^{-5} coulombs, and hence, cleaning action, if present, is not complete.

c) Whenever electric fields are derived from measured floating potential gradients, the low -z probe cannot be trusted since the voltage shift depends on the position of the probe during the transport blast.

3. Probes biased to read ion saturation current are probably correct since electron bombardment apparently produces only a voltage shift.

4. Temperature measurements using a probe which collects more than 10^{-7} coulombs/cm^2 are not to be trusted. Rapidly swept probes such as used by Meade (PLP 163) and floating double probes should read properly. A new technique for measuring electron temperature is discussed in PLP 176.

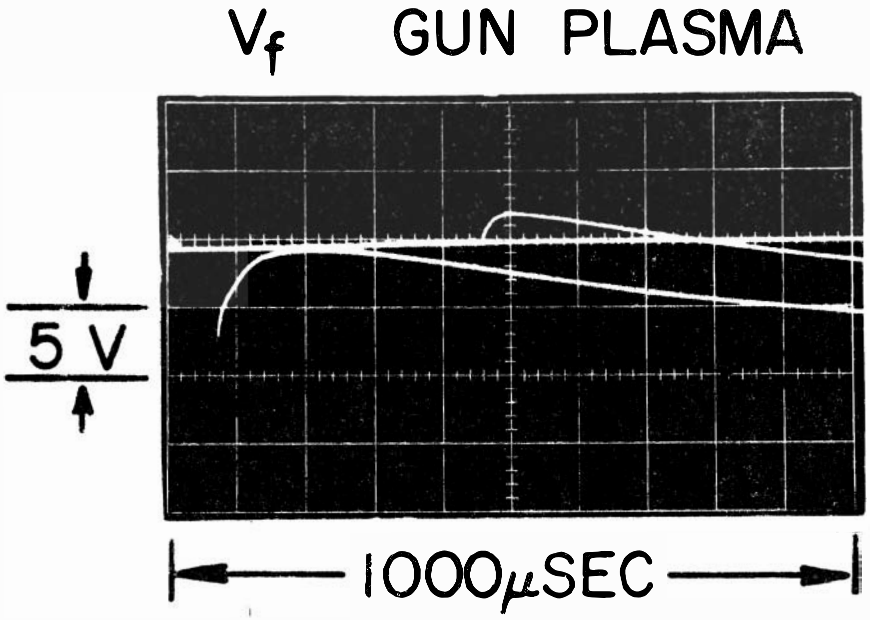


Figure 1

Figure 2

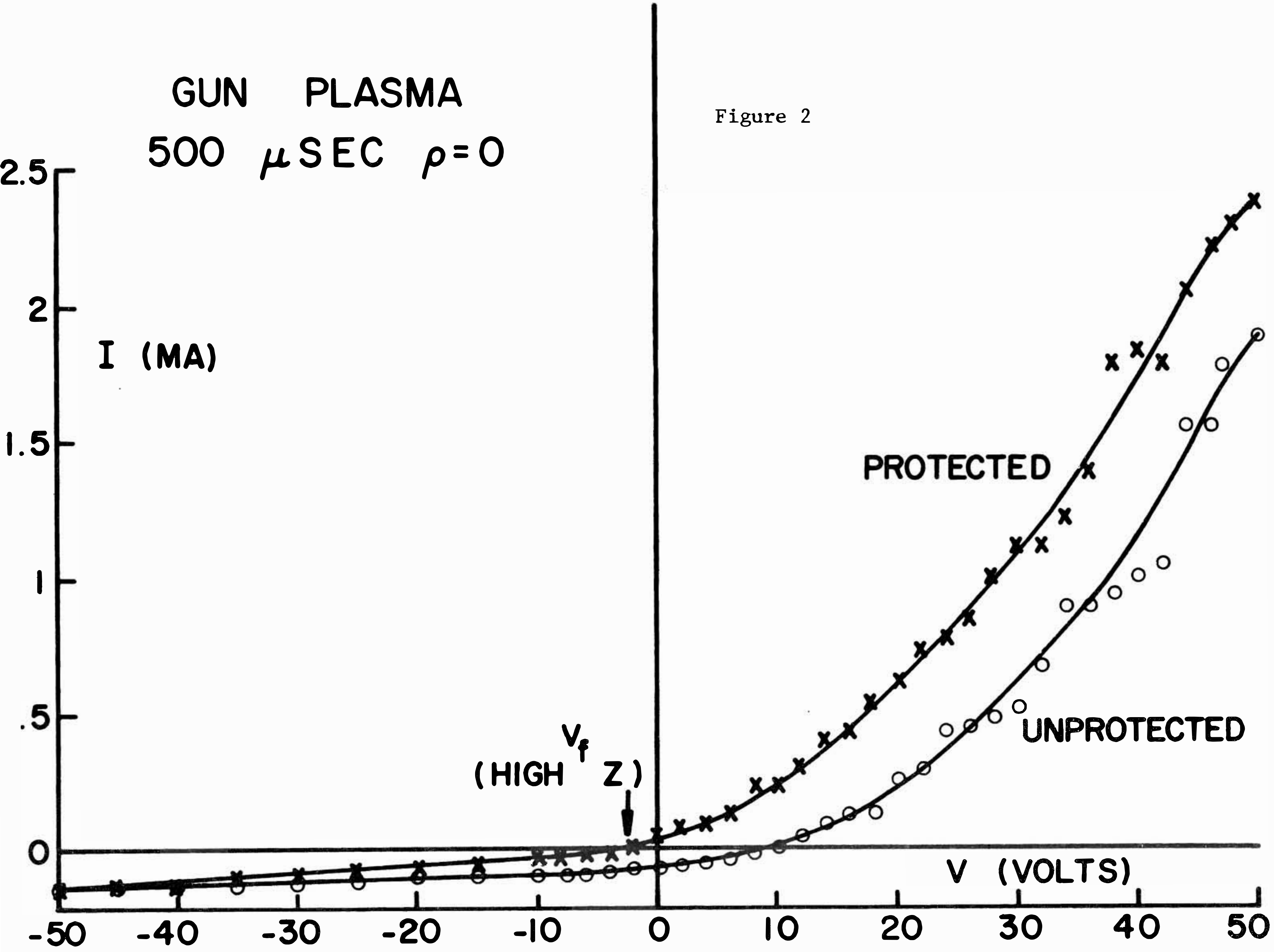
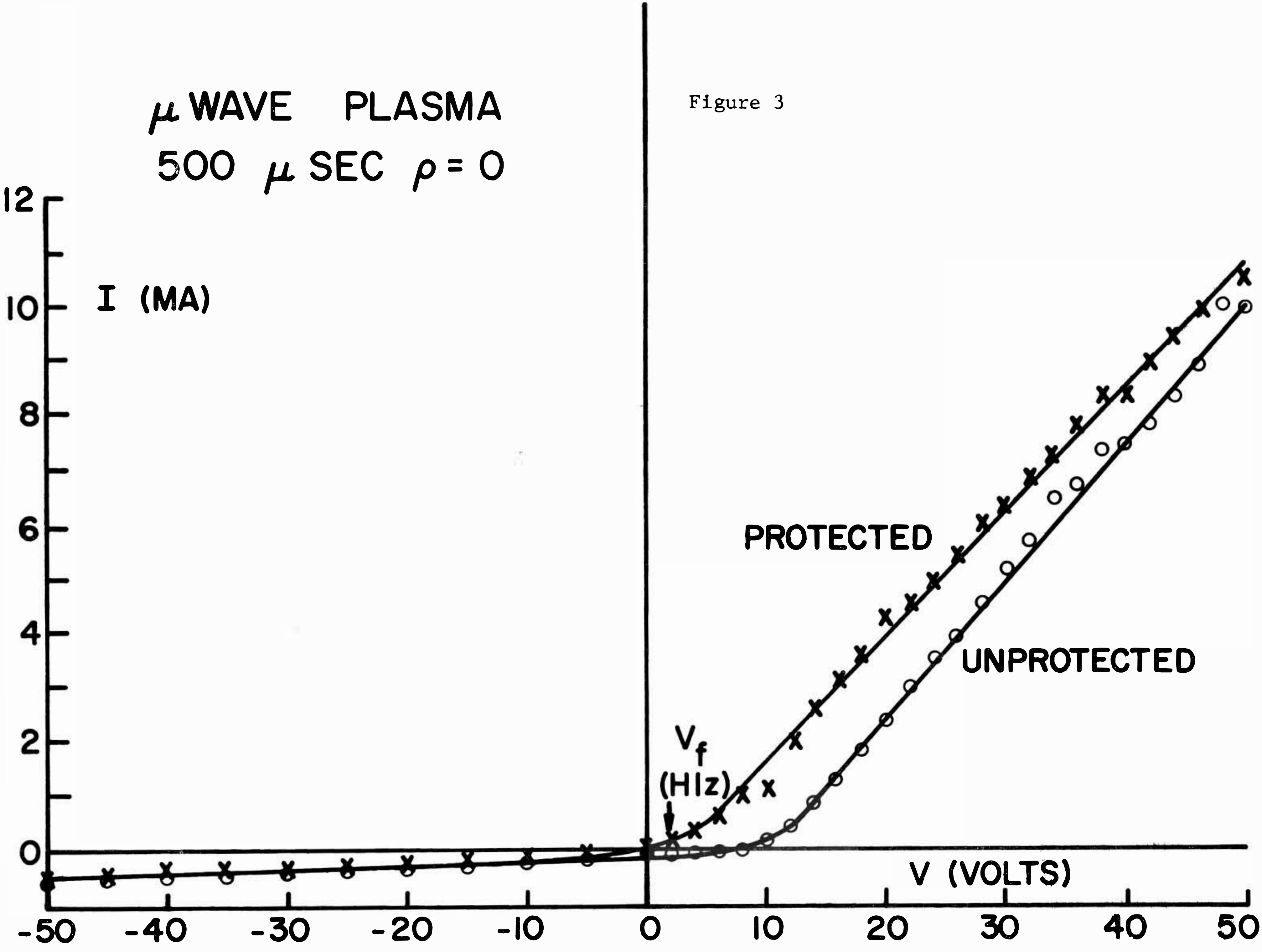

GUN PLASMA
500 μSEC ρ=0
I (MA)
2.5
2
1.5
1
.5
0
PROTECTED
UNPROTECTED
V_f
(HIGH Z)
V (VOLTS)
-50
-40
-30
-20
-10
0
10
20
30
40
50

Figure 3


μ WAVE PLASMA
500 μ SEC ρ = 0
12
10
8
6
4
2
0
I (MA)
PROTECTED
UNPROTECTED
V
f
(HIz)
V (VOLTS)
-50
-40
-30
-20
-10
0
10
20
30
40
50