Measurement of Probe Sheath Resistance In a Mercury Discharge

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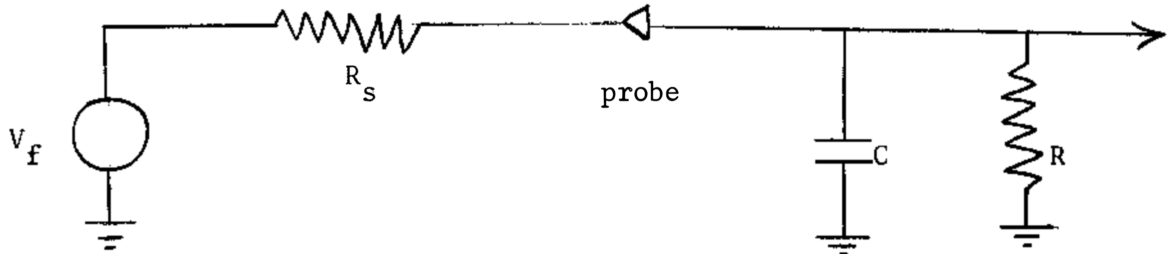
A fundamental limitation to the frequency response of a plasma probe results from the fact that the plasma drives the probe through a finite resistance. An equivalent circuit for a floating probe is shown below:



R and C represent the input resistance and capacitance of the circuit connected to the probe and any capacitance associated with the wiring. If the probe is to faithfully measure the floating potential V_f, the following two conditions must be satisfied:

1) $R \gg R_s$

2) $\frac{1}{\omega C} \gg R_s$.

The driving resistance R_s is associated with the plasma sheath and can be calculated from the slope of the V-I curve at $V = V_f$. For a Maxwellian electron velocity distribution, the result is

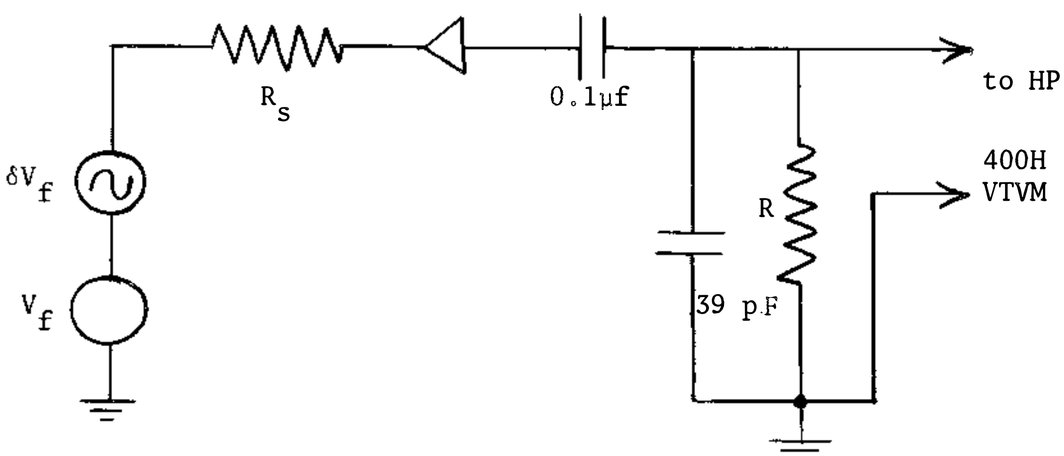
$$R_s = \left.\frac{dV}{dI}\right|_{V_f} = \frac{kT_e}{eI_{oi}} \tag{1}$$

where T_e is the electron temperature and I_{oi} is the ion saturation current to the probe.

A mercury discharge tube (described in PLP 166) has been used to measure the sheath resistance of an 0.076 mm diameter x 4.3 mm long cylindrical tungsten probe. The plasma had $kT_e \approx 1-3$ eV and $T_i \approx 300°K$ and a density which could be varied over an order of magnitude in the 10" cm^{-3} range.

The electron temperature and ion saturation current were measured at four different values of discharge current by plotting out the V-I characteristic of the probe. Since the ion current was not perfectly constant for $V \ll V_f$, I_{oi} was determined by fitting a straight line to the points and extrapolating to $V = V_f$. The electron temperature was determined by plotting $\ell n(I - I_{oi})$ vs V and measuring the slope of the resulting straight lines. Fig. 1 shows the result. The electron temperature varied from 3.3eV at 50 MA discharge current to 0.9 eV at 200 MA discharge current. The electron velocity distribution is nearly Maxwellian over three decades of probe current. From these data, the sheath resistance can be calculated from equation (1).

The sheath resistance can also be measured by using the following circuit



The floating potential was ~40 volts with an 0.5 volt, 150 kHz, sinusoidal oscillation superimposed. The dc component of the floating potential was eliminated by inserting an 0.1 μf capacitor in series with the probe. The ac component of the floating potential was measured by reading the voltage across a variable load resistor R with a Hewlett Packard type 400 H vacuum tube voltmeter. The input capacitance was measured to be 39 pf, representing an additional impedance of 50.5 K.

A plot of output voltage vs load resistor is shown in Fig. 2 for one value of discharge current. The solid line is the theoretical curve with $R_s = 4.4$ K. The sheath resistance calculated from equation (1) is 4.1 K. The accuracy of the experimental points is limited only by the precision of the VTVM and the tolerance of the load resistors. In both cases, the error is ± 5%. Hence, in Fig. 2, the diameter of the data points represents the experimental accuracy.

This procedure was repeated for the other three values of discharge current, and in Fig. 3 the measured sheath resistance is plotted vs the sheath resistance calculated from T_e and I_{oi}. There is a slight systematic error of about 5%, but the agreement of the measured and calculated values is well within the experimental accuracy as indicated by the error bars. The error is estimated to be about ± 10%, mostly resulting from the difficulty of obtaining a unique value for I_{oi}. The slope of the V-I curve at $V = V_f$ was also measured and gave agreement to within the accuracy of the measurement (about 30%).

In summary, these data show quite strikingly that in this density and temperature range, that the sheath resistance of a floating probe is accurately given by the simple relation

$$R_s = \frac{kT_e}{eI_{oi}} .$$

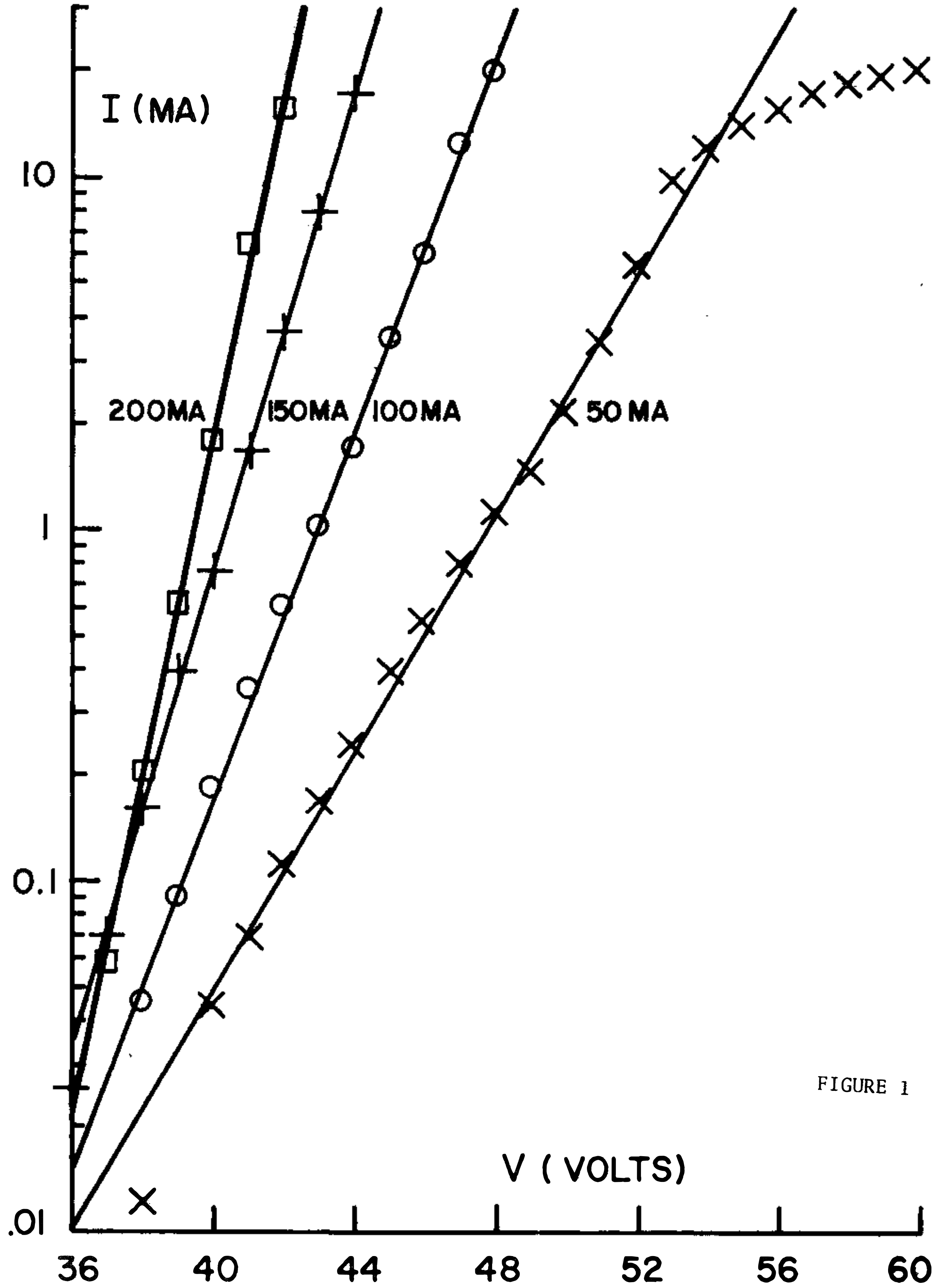


FIGURE 1

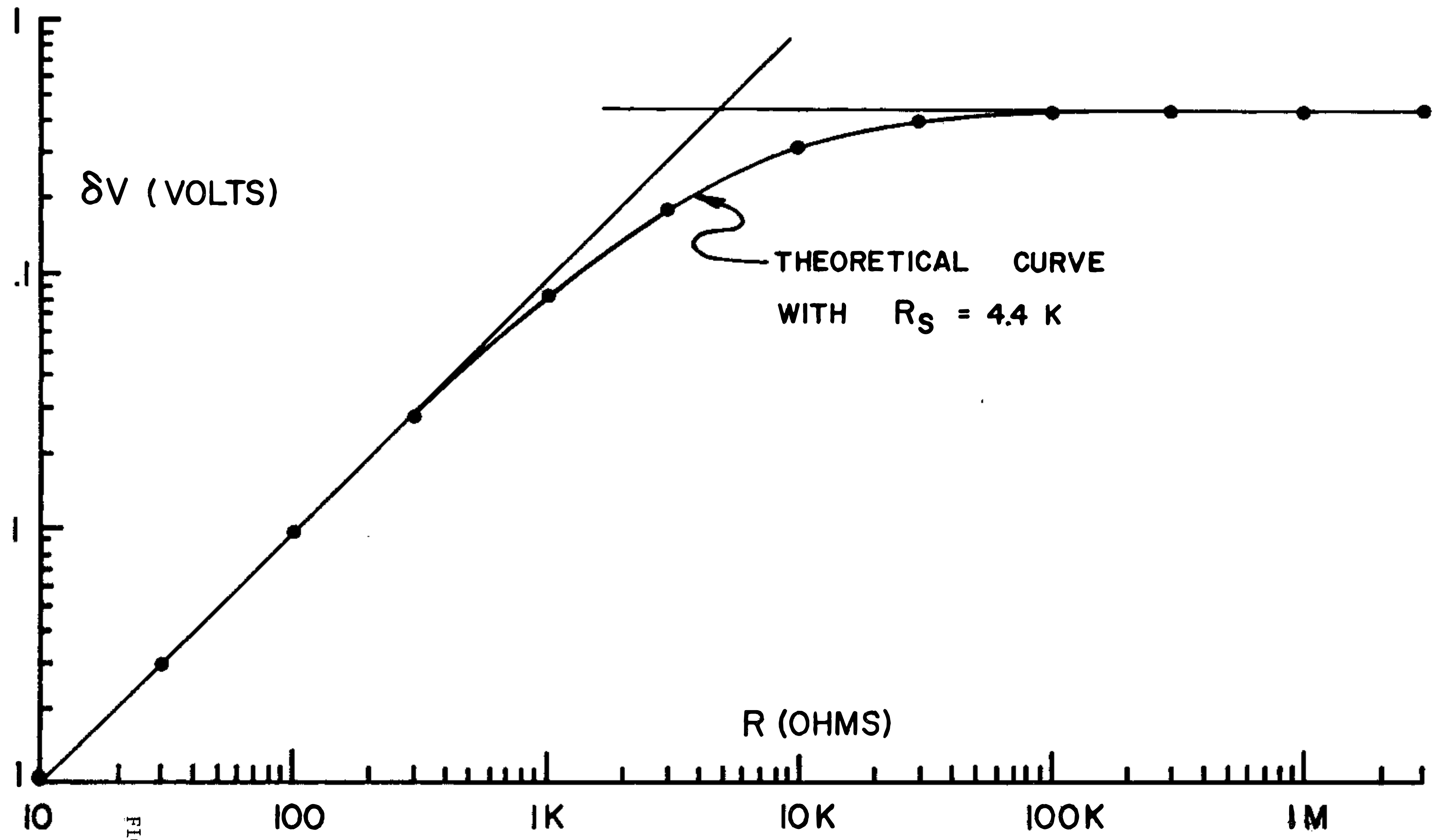

δV (VOLTS)
1
.1
R (OHMS)
10
100
1K
10K
100K
1M
THEORETICAL CURVE
WITH R_S = 4.4 K

FIGURE 2

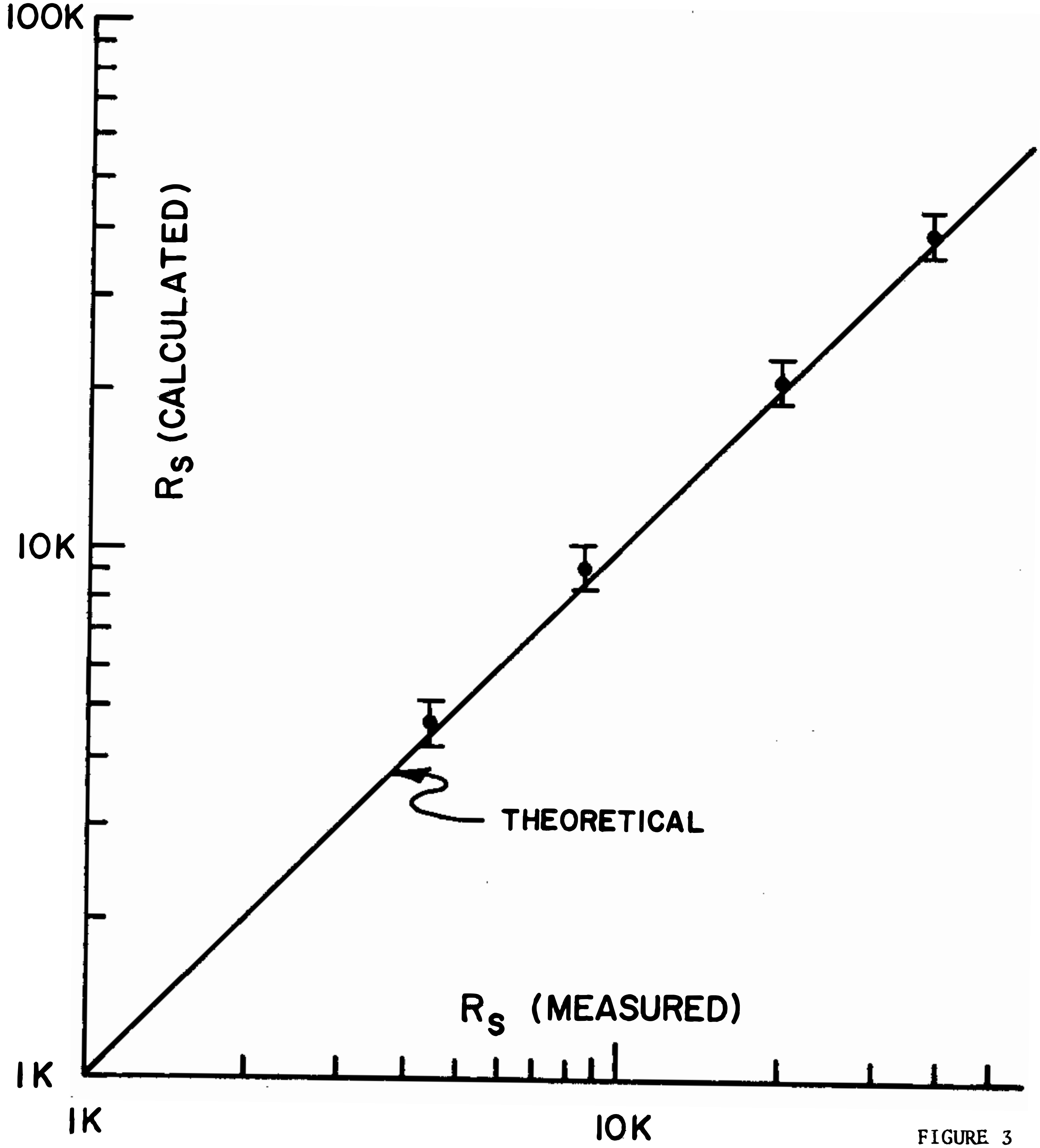


FIGURE 3