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An Investigation of Cables for Ionization Chambers *+

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ABSTRACT

Nine coaxial cables which have been proposed or are presently being used for carrying the currents generated in ionization chambers have been critically studied with reference to their suitability to this application. Included in this study are four low-noise triaxial cables, three low-noise two-conductor cables, and two of other types of cables. For each cable the following characteristics were determined: inherent noise currents, currents produced by cable movements, polarization currents, the degree of electrostatic shielding of the central signal-carrying conductor, and radiation induced cable currents. This study indicates that two low-noise triaxial cables, both employing Teflon dielectric surrounding the central conductor, offer the best overall performance for use with ionization chambers.

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DISCLAIMER

DISCLAIMER

INTRODUCTION

In the use of ionization chambers to quantify radiation fields one may encounter difficulties due to spurious currents. Such currents have a variety of origins and may represent a source of inaccuracy in the measurement of the ionization current generated in the chamber. Whether extraneous currents will limit the accuracy of a particular measurement will depend upon many factors such as, field intensity, the inherent precision capability of the current measuring instrument, and the magnitude of extraneous currents.

A complete ionization chamber system can be divided into four parts; 1. an ionization chamber, 2. a source of potential for polarizing the chamber, 3. an electrometer including readout device for reading the current generated in the chamber, and 4. an interconnecting cable which carries the currents generated in the chamber to the electrometer. Spurious effects may originate in any of these four parts. In this study, attention was focused exclusively on the perturbing effects which are founded in the interconnecting cable.

Seven cables which are in current use with ionization chambers were compared relative to several distinct effects. The particular cables considered are listed in Table 1. The source of the cable, whether the cable is a coaxial or triaxial type, and the dielectric which immediately surrounds the central conductor are noted. The table shows that three different dielectrics, polyethylene, Teflon, and Teflon tape, are represented. Each of the cables has a low-noise treatement of one form or another on the outer surface of the inner dielectric. The cables are listed in chronological order based upon their first use or consideration in our laboratory. The Amphenol cable has been out of production for a number of years but is still in relatively wide use.

Two other cables were considered briefly but found to be manifestly unsuitable for use with ion chambers. The one is Amphenol No. 21-199, an RG-58 type, The other, Belden No. 8232, is a triaxial version of RG-59. Neither has a low-noise treatment and both have quite imperfect shielding. Both cables showed excessive noise with the Belden cable being particularly live.

It should be stressed that in the experiments to be described, the central conductor was always regarded as the signal carrier. This is also true for the Capintec cable. Capintec employs a unique configuration in their dosimeter system wherein the signal is carried by the inner shield of the triaxial cable. Therefore, the results reported here for the Capintec cable do not really apply to the particular manner in which Capintec employs the cable.

The various effects which were considered in the present investigation are listed in Table II. All of the cables considered possessed suitably low steady state leakage or conduction currents for use with three terminal ionization chambers. However, significant polarization currents were found which varied appreciably among the cables tested. Important differences were also uncovered regarding microphonic effects, shielding, and radiation induced cable currents. A strange soakage current was discovered in three cables which is related to imperfect shielding.

EXPERIMENTAL METHOD

The different cable phenomena were studied with the common experimental arrangement depicted in Fig. 1. The attachment of a specimen cable to an electrometer is indicated in schematic fashion. The current, I, picked up on the central conductor is fed directly into the electrometer. As the electrometer has infinite input impedance, the current I must necessarily flow entirely thru the feedback element R_F whenever the grounding key is open. The feedback voltage V_F is automatically adjusted in order to hold the electrometer input near ground potential. Thus the current in the cable is manifested by the feedback voltage and is merely given by the quotient V_F by R_F. The outer shield is held at a variable potential, V_S. For certain measurements a capacitor was substituted for the feedback resistor so that charge displacements could be measured directly. The electrometer was a vibrating reed type, either a Model M3 dating from the Manhattan Project at the University of Chicago or a Cary Model 411.

The cable-electrometer configuration is precisely that employed for measuring ionization currents. In normal use a chamber would be attached to the other end of the cable. The collector of the chamber would be tied to the central conductor, the guard to the inner shield, and the shell or outer electrode to the outer shield. Thus the outer shield would carry the polarization potential to the chamber.

Bare specimen cables were employed in this study. For ready comparison of the results all cables were cut to a standard length of 3 m. A BNC connector was mounted on one end for ready attachment to the electrometer. The other end of the cable was blanked off by a special termination. The termination maintained the insulation of the center conductor yet completely shielded it without introducing any gas volume.

EXPERIMENTAL RESULTS

Noise currents were observed at the output of the electrometer amplifier which was operating with a band width of approximately 0.2 Hertz. On these terms some differences were noted among the cables but these differences were minor. The rms noise current was less than 0.3 fA/ m for each of the cables. Thus the special conducting coatings over the inner dielectric of each cable effectively reduce noise currents to a level where noise currents are not likely to limit the accuracy of measurements of chamber currents.

Dielectric leakage, or conduction, currents were evaluated at biases up to 6 V. All of the cables displayed more than an adequate degree of insulation resistance in steady state. Again minor differences were noted among the cables but in no instance would the steady state leakage be a likely influence in the measurement of chamber currents. Even at a bias of 6 V, the steady state leakage currents were less than 2 fA/ m for every cable.

When the bias across a cable is changed large transient currents ensue. These transient currents are not conduction currents but rather represent electric polarization phenomena in the dielectric of the cable. With reference to such transient currents, wide differences do indeed appear among the seven different cables studied. Fig. 2 illustrates the characteristic behaviour of the different cables in terms of charging curves. In the figure the logarithm of the current is plotted against time. The cables were well neutralized preparatory to beginning the measurements. At time t = 0, the bias across the cable was suddenly changed from 0 to 6 V.

The cables roughly divide into three groups with reference to the charging curves. The Amphenol, Capintec, and Exradin cables are very similar and show significantly less charging currents than the others. The two Microdot cable types and the Victoreen cable are also somewhat similar and show the greatest magnitude of charging currents. The Keithley cable shows a similar behaviour as the others but with a magnitude somewhat between the two other groups.

When a cable is held at constant bias for a prolonged period and the bias is abruptly reduced to zero, a transient negative discharge current ensues. Characteristic discharge curves are shown in Fig. 3 corresponding to the charging curves of Fig. 2. The close similarities of the curves in the two figures is immediately apparent. For each cable, the discharge curve very closely parallels the charging curve thus demonstrating that these transient currents do indeed represent a polarization, as distinct from conduction, process. However, the extent that the polarization represents a dipolar or space charge phenomena is not revealed by these measurements.

The behaviour just described is a well-known characteristic of polymer dielectrics and has been the subject of considerable study. For a better comparison of the cables regarding polarization, the discharge curves were integrated over time to obtain the total charge displacement. These results are given in Table III. The total charge released by each cable, which are 3 m in length, is given in the second column. The cables had been polarized to saturation at 6 V. The two Microdot types and the Victoreen cable are seen to exhibit an order of magnitude greater polarization than the Amphenol, Capintec, and Exradin cables.

Normally cable polarization is not a problem in working with ionization chambers. For one thing, cables usually operate at biases which rarely exceed 1 V. However, should a cable be accidently electrically stressed, then the discharge curves shown in Fig. 3 would indicate the relative recovery rate or neutralization time.

It has not been possible to establish suitable standard conditions for comparing microphonic sensitivity. The polarization response of the cable doubtlessly indirectly enters microphonic sensitivity. Some differences do exist among the cables tested. One particular quantitative comparison was made. In this test the cables were held under a tensile stress of approximately 2.5 Newtons. The cables were supported over their entire length to prevent sagging. A change in tensile stress was found to be accompanied by a reproducible and reversible charge displacement. The charge displacements observed for an increase in tension of 5 Newtons are given in column 3 of Table III. Generally the charge displacement is positive for an increase in tension. The only exception was the Microdot coaxial cable which exhibited a negative charge displacement as well as the biggest effect in magnitude.

The Amphenol, Capintec, and Keithley cables showed no effect at zero bias. The entries in the table for these cables represent the charge displacements for the same increase in tension as the others but observed with the cables biased at 6 V. These latter displacements were always of the same polarity as the bias and are seen to be quite similar in magnitude for the three cables.

Perhaps the most startling discovery in this investigation relates to the effectiveness of the cable shielding. The degree of shielding is easily determined in terms of the capacitive coupling between the central conductor and outer shield of the cable while the inner shield is fixed at ground potential. For the coaxial cables one must improvise an outer conductor external to the cable. The method used here was to immerse the cable in a conducting liquid which then constituted the outer electrode.

The results are shown in column 2 of Table IV. No capacitive coupling could be detected in four of the cables. The other three exhibited effects several orders of magnitude greater than the minimum detectable value. This capacitive coupling would not be objectionable if it were just a pure capacitive coupling. Unfortunately, the phenomenon is somewhat more complex.

When the potential of the outer shield is changed, persistent charging currents ensue which decay in some characteristic way. These currents may linger for several minutes. The really surprising fact is that the persistent currents are opposite in sign to the change in potential. The same behaviour in varying degrees is exhibited by each of the cables which showed a measurable capacitive coupling.

The persistent current observed in each of the three cables is illustrated in Fig. 4. The logarithm of the current is plotted against time. The change of potential of the outer shield for these curves was 300 V. The magnitude of the effect displayed by the

Keithley cable is sufficiently small as only to cause a possible problem under the most extreme measurement conditions.

An explanation of this effect is offered. Firstly, it must be assumed that the inner shield has some degree of openess. Secondly, the low-noise coating of the dielectric must be either patchy or not sufficiently electrically conducting. When the potential of the outer shield is increased, the surface of the dielectric under an opening in the shield will initially be raised in potential to an extent. As time goes on, however, the raised potential of this area will dissipate thru the conducting coating as well as thru volume polarization of the dielectric. The decreasing potential in such areas will be accompanied by a corresponding movement of charge in the dielectric immediately beneath the area.

Radiation induced cable currents are well known. There are two separate effects. The one is the negative current proportional to the radiation intensity which is induced on the central conductor. This is usually referred to as the "Compton" current and will be referred to here as the "direct" effect. Doubtlessly photoelectrons play a greater role in this effect than Compton electrons relative in the majority of situations. The second effect is a radiation induced conductivity in the dielectric. The current which the latter effect represents is positive or negative depending on the bias and has a magnitude which, at least approximately, is proportional to the bias.

As a consequence of the different behaviour of the two effects, it would be possible to find a value of positive cable bias for which two separate currents cancel. However, this is probably not a very practical method for minimizing radiation induced cable currents.

The presence of the two effects does cause some difficulty in determining the magnitudes of the separate effects. The method employed here was to determine the cable current at equal positive and negative biases. The direct effect was taken as the arithmetic mean of the two currents. The induced conduction current was taken as half of the current observed at positive bias minus the current observed at negative bias. This procedure seems to give a consistent interpetation to the measurements.

Only the results pertaining to the direct effect are reported here. Column 3 of Table IV shows the direct current induced in each of the cables when exposed to a uniform Cobalt-60 field at an exposure rate of 7.1 R/ min. The Amphenol cable which showed excellent behaviour in every other respect but which is only a two-conductor cable exhibits the greatest radiation induced cable current. The Exradin cable has the smallest effect, slightly smaller than that observed in the Capintec and triaxial Microdot cables. The Victoreen cable also shows a relatively small effect. Actually, there is really little difference in the magnitude of the effect between the triaxial Microdot, Capintec, Exradin, and Victoreen cables.

The second radiation effect, the induced conductivity, shows generally a complex time dependence. When the irradiation is terminated, the induced conductivity displays a persistent component with a complex temporal behaviour. In some instances there may be permanent radiation damage and a consequent lasting increase in the conductivity. Further studies of radiation induced conductivity are in progress.

CONCLUSIONS

Several low-noise cables have been compared in terms of their suitability for use with ionization chambers. On an overall basis the Capintec and Exradin cables, which are triaxial and involve Teflon as the dielectric, gave distinctly superior performance.

The Keithley cable, also triaxial but with polyethylene as the dielectric, has a minor defect associated with imperfect shielding. More importantly perhaps, the Keithley cable shows a radiation induced current approximately twice as great as the best cables.

The Victoreen cable has excellent characteristics except for substantial dielectric polarization. However, perhaps its most serious limitation is that it is only a two-conductor cable and therefore does not provide fully for the needs of guarded ionization chambers.

The Amphenol cable gave excellent performance except for a large radiation induced current. This latter effect would only cause difficulty when long lengths of cable must be exposed to radiation. Unfortunately this cable also only provides two conductors.

The coaxial and triaxial Microdot cables prove to be poor choices for use with ionization chambers. This is not a general fault with Microdot cables. A number of other Microdot cables are expected to be eminently suitable for use with ionization chambers. Actually both the Capintec and Exradin cables are probably manufactured by Microdot.

Quite sizeable capacitive coupling which penetrated the shielding was found in three cables. These same cables displayed a strange transient current which is opposite in sign to the soakage currents that are characteristic of inadequately guarded ionization chambers.

ACKNOWLEDGEMENTS

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AMPHENOL (21-537)	COAXIAL	POLYETHYLENE
MICRODOT (275-3801)	COAXIAL	POLYETHYLENE
MICRODOT (250-3822)	TRIAXIAL	POLYETHYLENE
CAPINTEC	TRIAXIAL	TEFLON
EXRADIN	TRIAXIAL	TEFLON
KEITHLEY	TRIAXIAL	POLYETHYLENE
VICTOREEN	COAXIAL	TEFLON TAPE

Table I   Cables included in the present study.

SO ME PERTURBING EFFECTS IN CABLES

NOISE CURRENTS

DIELECTRIC LEAKAGE

DIELECTRIC POLARIZATION

MICROPHONIC SENSITIVITY

SHIELDING EFFECTIVENESS

RADIATION INDUCED CURRENTS

Table II Various cable effects which were studied.

SAMPLE	Q_p / 10^{-15} COULOMBS	Q_t / 10^{-15} COULOMBS
AMPHENOL	250	120*
MICRODOT-CO	10,000	-3,800
MICRODOT-TR	5,000	1,400
CAPINTEC	1,200	200*
EXRADIN	700	470
KEITHLEY	1,700	200*
VIDTOREEN	13,000	500

*6 VOLTS BIAS

Table III Polarization and microphonic charge displacements.

SAMPLE	C_L / 10^{-15} FARADS	I_C / 10^{-15} AMPERES
AMPHENOL	< 0.05	320
MICRODOT-CO	69	280
MICRODOT-TR	18	55
CAPINTEC	< 0.05	55
EXRADIN	< 0.05	50
KEITHLEY	1.33	110
VICTOREEN	< 0.05	65

Table IV Capacitive coupling thru shield and radiation induced currents.

FIGURE CAPTIONS

Fig. 1 Schematic of circuit arranagement for detecting cable currents.

Fig. 2 Charging currents observed in neutralized cables when the bias is abruptly increased to 6 Volts.

Fig. 3 Discharge observed in cables polarized at 6 Volts.

Fig. 4 Negative soakage currents observed when the surrounding potential is abruptly raised from ground to 300 Volts.

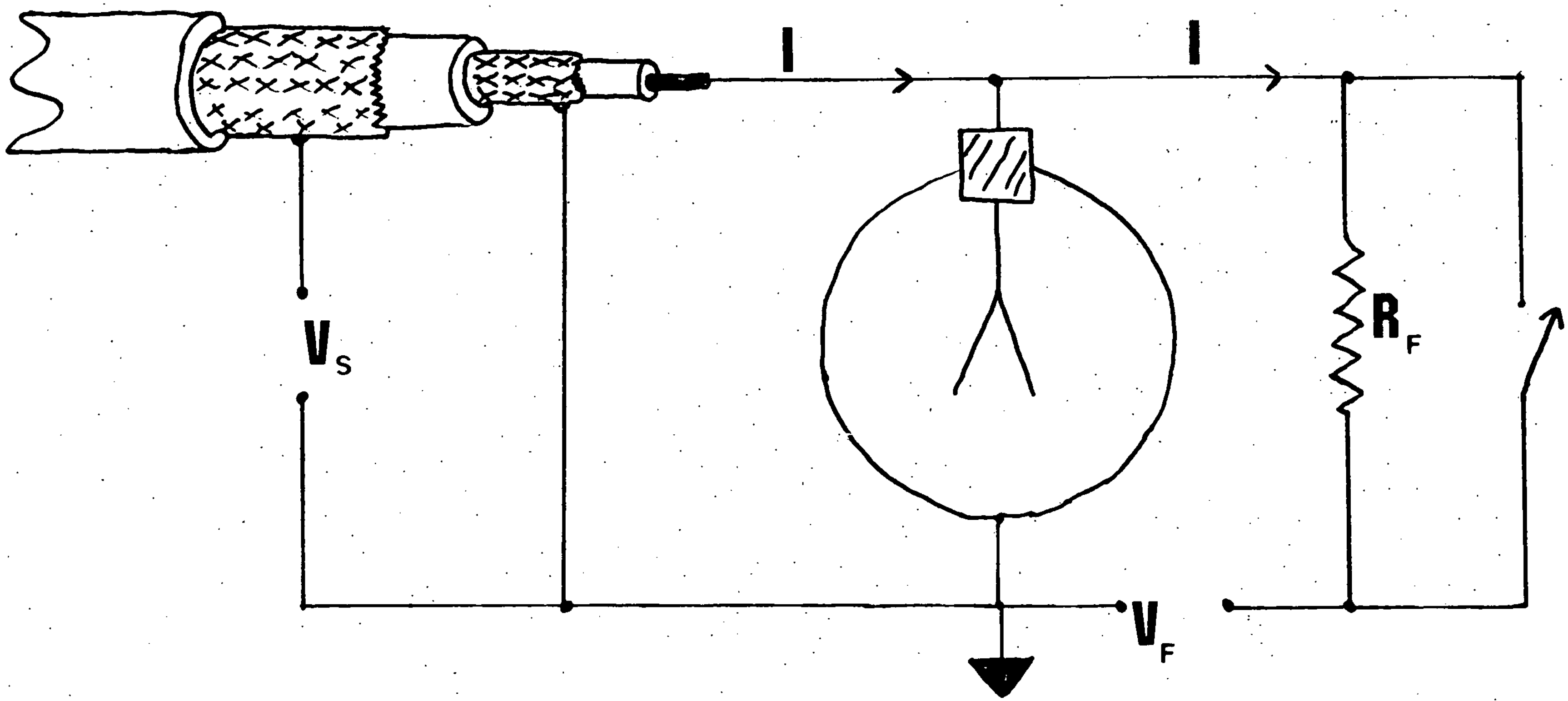

Fig. 1

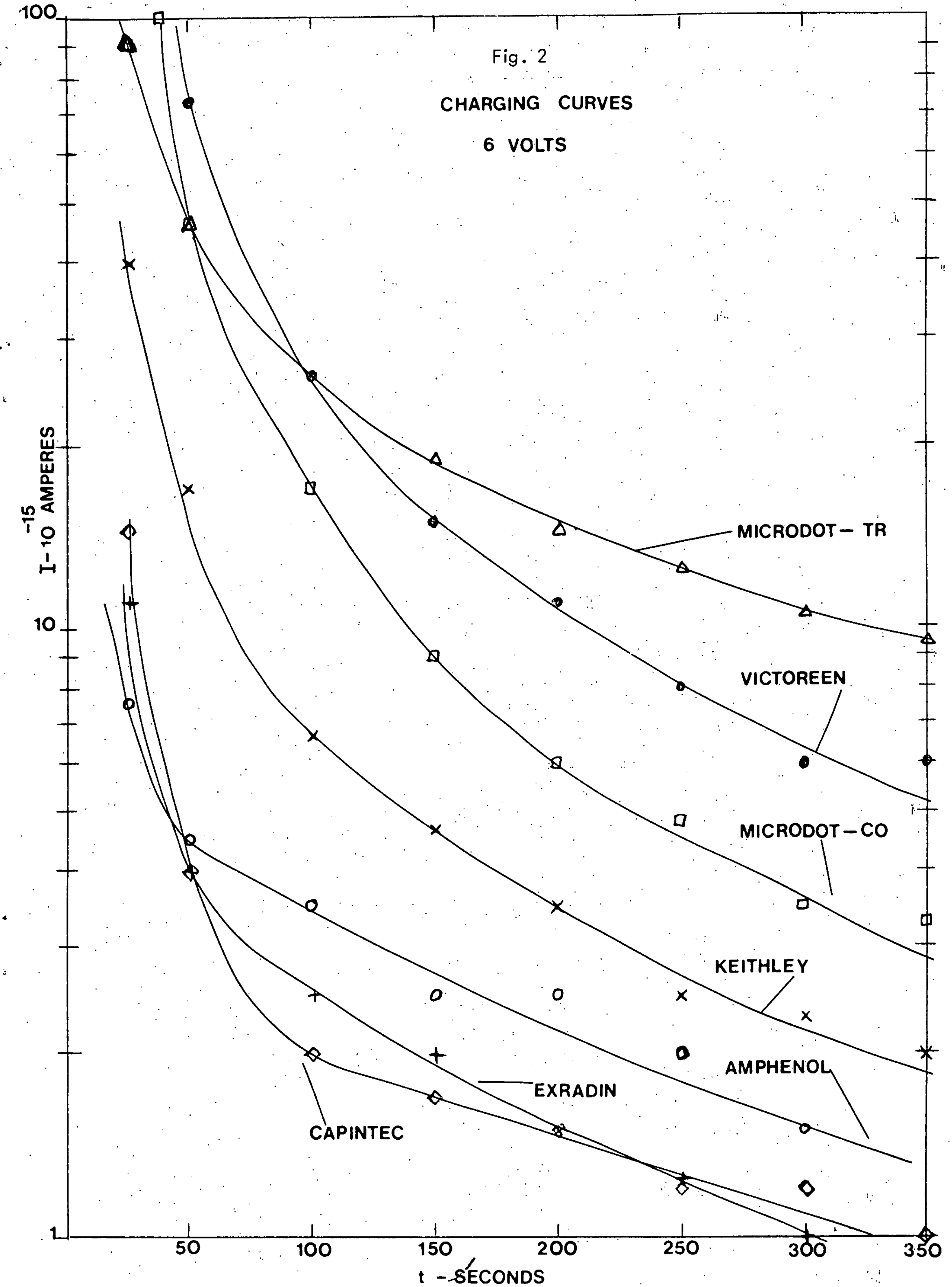
Fig. 2
CHARGING CURVES
6 VOLTS
MICRODOT – TR
VICTOREEN
MICRODOT – CO
KEITHLEY
AMPHENOL
EXRADIN
CAPINTEC
I – 10^-15 AMPERES
t – SECONDS
100
10
1
50
100
150
200
250
300
350

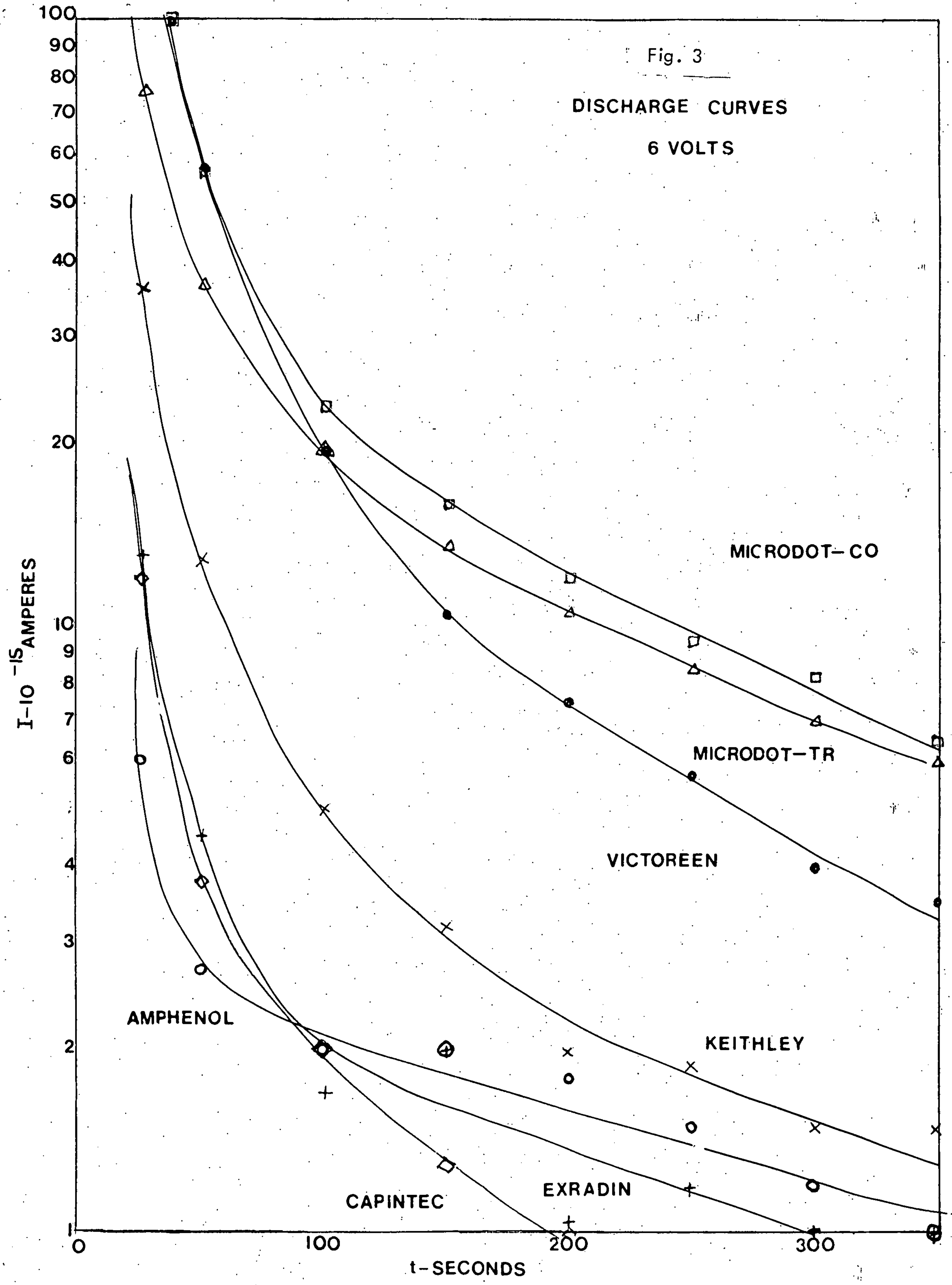
Fig. 3
DISCHARGE CURVES
6 VOLTS
MICRODOT-CO
MICRODOT-TR
VICTOREEN
KEITHLEY
AMPHENOL
CAPINTEC
EXRADIN
I-10 -15 AMPERES
t-SECONDS
100
90
80
70
60
50
40
30
20
10
9
8
7
6
4
3
2
1
0
100
200
300

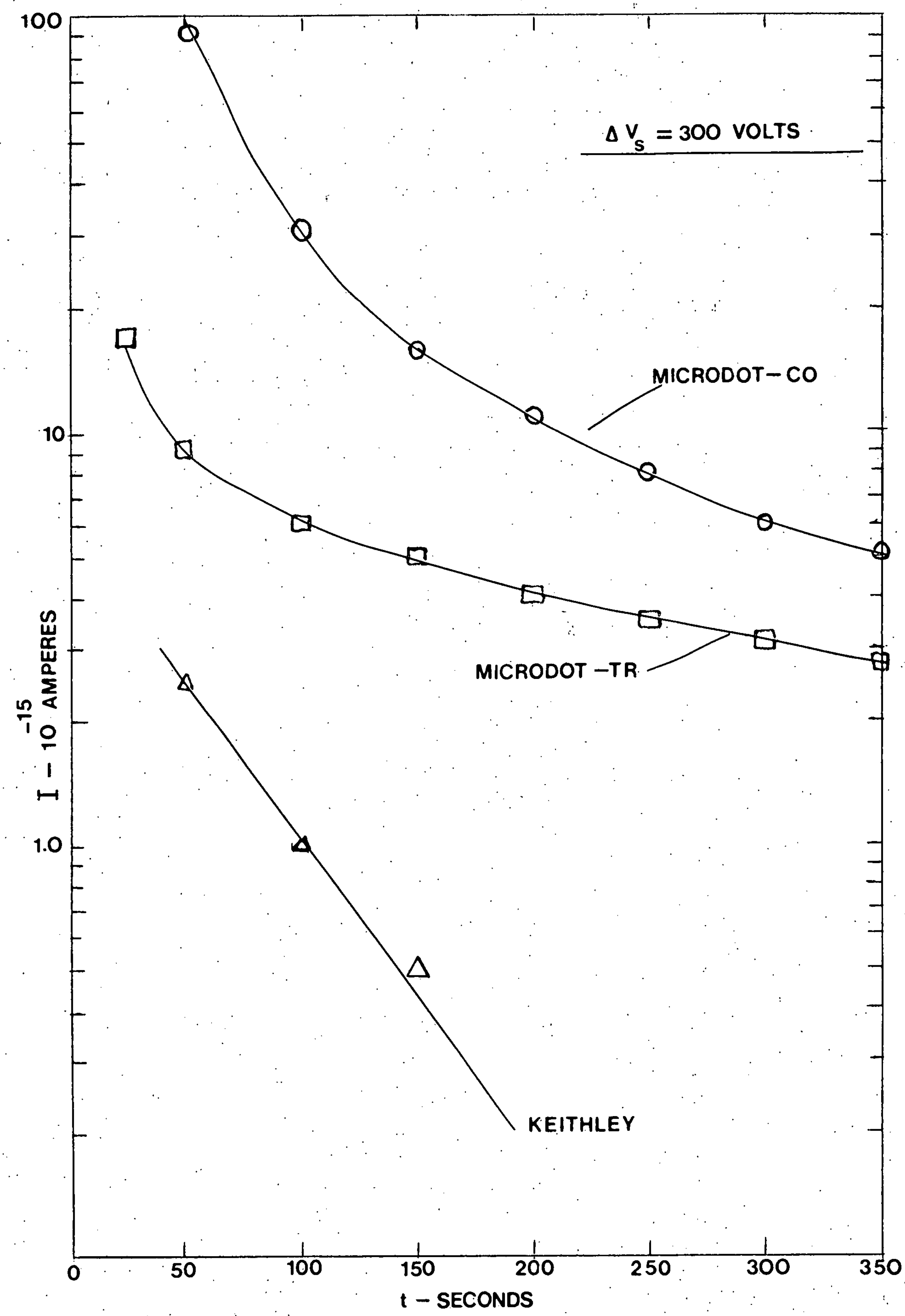
100
10
1.0
$I - 10^{-15}$ AMPERES
$\Delta V_S = 300$ VOLTS
MICRODOT—CO
MICRODOT —TR
KEITHLEY
0
50
100
150
200
250
300
350
t — SECONDS

Fig. 4