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THIRD QUARTERLY REPORT

RESEARCH IN THE DEVELOPMENT EFFORT OF AN IMPROVED MULTIPLIER PHOTOTUBE

CONTRACT NO, NASW 1038

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FIRST DYNODE GAIN MAPPING

The importance of well designed electron optics preceding dynode one, in a multiplier phototube, to its ability to efficiently count single events at the photocathode has been reported earlier. A second critical parameter is the gain uniformity of dynode one. To investigate this characteristic some special tubes were built which would allow as large an area of dynode one, as possible, to be "contour mapped". These special tubes had image sections with reduced magnification, nominally 0.35 instead of the usual 0.7, a larger first dynode, and larger defining aperture preceding dynode one (275 x 300 mils). The net result of this design is an effective cathode area of 750 x 800 mils. The image sections of these tubes were also made focusable by separating the photocathode from its cylindrical electrode and operating it a few volts negative with respect to the cylindrical electrode so that the image of a point source of electrons from the cathode could be focused on dynode one. Figure 1 is a schematic representation of this system.

In the performance of the experiment to be described, the tubes were operated under normal conditions of voltage, light intensity, and counting rate and in the usual test fixture. The light source, however, was modified by the addition of a microscope objective lens so that the small aperture which normally floods the cathode was, instead, focused onto the cathode in a spot a few mils in diameter. This light source was mounted on a microscope stage compound, removed from a Bausch & Lomb metalographic camera. This complete assembly was then supported, above the photocathode of the tube under test, by the mu-metal shield that enclosed the entire tube. The calibrated two directional motion provided by this compound allowed the small spot of light to be accurately positioned at any desired point on the cathode.

The method used, in obtaining the data to be discussed, was to mechanically center the compound with its light source over the center of the multiplier phototube cathode. From this position two mutually orthogonal diameters were scanned across the cathodes with points located 80 mils apart. To the right and left and above and below these diameters at 80 mil intervals other lines were scanned with the same point spacings. This method produced an array of approximately 100 equidistant points from which to plot the contour lines.

Figure 2 is a plot of the first dynode response of tube No. 016513 to the input radiation. The numbers indicate the relative anode current as read with an electrometer. The back side of dynode one is to the right of the drawing with its open side and dynode two at the right. The vertical line to the right of center represents the location of a wire across the top of the dynode (see Figure 1) whose function is to extend the field of dynode one into a region where primary electrons might tend to bypass into dynode two. This wire would normally be covered by the aperture plate in smaller aperture tubes. Figures 3a and b are photographs of a raster scan of dynode one in this tube. These pictures were produced by projecting a small spot of light onto the cathode and applying deflection to the tube with a special yoke designed for these tubes when used as star trackers. The output of the tube was fed into the vertical input of a Tektronix 545 scope and the amplified vertical signal from the 545 was applied to the Z-axis input of a DuMont 304A scope, with X and Y inputs driven in sync with the multiplier tube scan, to produce intensity modulation of the beam. Unfortunately, this scope operates with the cathode of the CRT at high negative voltage so that d-c coupling to the Z input is difficult if not impossible, hence the video signal is differentiated which makes the pictures somewhat difficult to interpret. However with careful attention to the direction of the scanning signals applied to the multiplier tube and taking into account the image inversion produced by the electron optics of the image section of the multiplier these photographs provide useful information for determining the orientation of dynodes one and two when making the contour plots. Another interesting feature of these two photographs is that the effect of clipping by the conical aperture is shown. The spot of light projected on the cathode was moved off center in opposite directions so that in Figure 3a the back edge of dynode is rounded off while the wire across the forward edge and the area in front of dynode two is plainly defined, in Figure 3b the forward edge of dynode one is severely rounded while the square corners at the back of dynode one are easily identified. This effect is a clear demonstration of one of the advantages of this tube design which was described in the first quarterly report, namely that electrons, thermal or photo, which originate outside the effective cathode area are excluded from regions of the tube immediately adjacent to dynode one. A comparison of Figure 2 and Figures 3a and b shows good correlation between high and low secondary emission ratio areas. While it is difficult to determine from the photographs which is high and which is low it does show nonuniformities which the plot in Figure 2 quantiatively identifies. While the peak dynode SE ratio areas are mainly restricted to the ends of the dynode significant portions of these peaks do extend well toward the front edge of dynode one where collection efficiency is good.

Figure 4 is a plot of the total signal count, in thousands of counts, for pulse amplitude distributions taken over the sur face of dynode one. Note that the high total count areas are located at the edge of dynode one toward dynode two with the low total count area at the back of the dynode where the field penetration of dynode two is small. The low total count area just in front of dynode 2 is probably due to electrons that bypassed dynode one and perhaps even dynode two so that the output pulse amplitude due to these electrons were below the threshold of the analyzer and therefore not counted. It was necessary to raise the threshold of the instrument to cut off channels 1, 2, and 3 so that the unusually large number of low amplitude noise pulses did not seriously reduce the live time of the analyzer and increase the time required to collect the data.

A plot of the channel number in which the peak of the single electron spectrum fell for each point on the cathode is shown in Figure 5. Two areas are shown, one in which the peak occurred in channel 10 or lower the other in which the peaks fell in channel 20 or higher. The overlap in these two areas resulted from the fact that the pulse height distributions in these areas had two peaks, which seemed to be too real to be ignored. It was suspected that under the special conditions of these experiments, it was possible to resolve the peak in the early channels (low gain) due to dynode two as well as the higher gain peak in the later channels due to dynode one. Linear plots of these spectra were required, however, to show this detail which would not be apparent in the more usual log plots. It is interesting to note that, in general, the distributions which peak in the later channels are located in the same place on dynode one as the high gain areas shown in Figure 1. Figure 6 shows several representative spectra (on a linear scale) taken with this tube and the points where the primary electrons struck dynode one are shown on Figure 4.

Figure 7 is a plot of the relative cathode sensitivity. This plot indicates 3 to 1 variation in sensitivity which is significant but not sufficient to explain the large variation seen in Figures 2 and 3.

Similar experiments, to those just described, were performed with tube, No. 016507, which was identical to No. 016513. A plot of the relative SE ratio of dynode one is shown in Figure 8. A band of high SE ratio occurs down the center of the dynode with lobes extending toward the back. This characteristic is in general similar to the corresponding plot of dynode one for tube No. 016513 in Figure 2 except for the low area at the center of the dynode. While careful control is exercised over the oxidation procedures in forming the dynode surface there are presently no means by which the SE ratio can be controlled point by point over the dynode surface. For this reason one might expect to see rather wide variations in this characteristic, perhaps even wider than is seen between these two tubes. The total pulse count plot of Figure 9, however, bears a marked resemblence to that of Figure 4 indicating again the higher collection efficiencies for secondaries generated near dynode two. Since this depends greatly on the mechanical and electrical characteristics of the multiplier one might expect this parameter to be largely invariant from tube to tube. In Figure 10 is shown the contour representing the channel number in which the peak of the single electron spectrum occurred. The resemblance between this plot and that of Figure 8 is unmistakable. An additional experiment was performed with this tube to determine what effect masking the cathode had on the ability of the tube to produce a single electron spectrum. First of all the cathode was flooded and the spectrum, so labeled, in Figure 11 was obtained. Then a mask, with a hole of the shape shown by the dotted area in Figure 10, was placed on the cathode. This mask restricted the photoelectrons to the higher and more uniform gain area of dynode one. As a result the other spectrum of Figure 11 was obtained.

The implication is, of course, that the gross nonuniformities of dynode one have the effect of "smearing" the single electron spectrum and that high gain combined with SE ratio uniformity are critical parameters in the production of a well defined single electron spectrum by a multiplier phototube. A cathode sensitivity plot of this tube is shown in Figure 12. This variation in cathode sensitivity, of less than 1. 5:1, is again insufficient to explain the larger variation indicated in Figures 8 and 10.

MAGNESIUM OXIDE DYNODE ONE EXPERIMENTS

This tube, although constructed before the end of the last report period, appeared to be unstable and not testable. After a subsequent period of about a month on the shelf the instability seemed to have disappeared so that testing could again be considered.

It has been shown[1, 2, 3] that the SE ratio of an insulating material can be enhanced by producing an electric field internal to the material so that secondary electrons generated by primaries penetrating the surface see an accelerating field out of the material. Because of these principles and the fact that a high gain dynode one is of critical importance to a good single electron counting characteristic a tube, with a one micron layer of MgO on dynode one was made. To perform this experiment the tube was connected as shown in Figure 13. The high voltage was applied between aperture and ground with dynode one at aperture potential. The photocathodes were made 360 volts negative with respect to aperture-dynode one. Under these normal operating conditions a spectrum was taken and is shown in Figure 14 (a). Next, with the high voltage applied as before, the photocathode was made 90 volts negative and dynode two was connected to aperture and dynode one made -45 volts with respect to aperture. The light intensity was increased so that dynode one was bombarded strongly to charge it to aperture-dynode two potential, thus producing an accelerating field, for secondaries, out of the MgO. Following this charging procedure dynode two was returned to its proper potential on the divider and the light intensity reduced to its previous level, the photocathode was returned to -360 volts but dynode one remained at -45 volts. A spectrum was taken which is shown in Figure 14 (b).

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1 "Study of Electrical and Physical Characteristics of Secondary Emitting Surfaces", WADL Tech. Report 59-473 p-6 (1959).

2 "Study of Electrical and Physical Characteristics of Secondary Emitting Surfaces", WADC Technical Documentary Report No. ASD-TDR-62-707 p-34 (1962).

3 "An Investigation of Secondary Emission of Pulse Techniques", L. G. Wolfgang, Doctoral Thesis, Purdue University, 1963.

The charging procedure described above was repeated except that dynode one was operated at +45 volts with respect to aperture, thus producing a retarding field. A spectrum thus obtained is shown in Figure 14 (c). The net result of these tests indicate that the accelerating field does improve the distribution but unfortunately the time actually spent in counting (0.1 min.) was short enough so that statistical variations make it difficult to detect any shift in the peak location of the distribution.

CASCADE APERTURE TUBES

To further confirm the results reported in the second quarter of this contract two additional tubes of this design were constructed except for the fact that the second aperture was made mechanically and electrically, an integral part of dynode one. This has the slight disadvantage of making the tube somewhat more difficult to assemble due to alignment requirements between the image section and the multiplier section of the tube. This requirement, however, is far outweighed by the fact that no additional contact need be brought out through the glass envelope of the tube and the control voltage may be applied to the aperture electrode which has a base pin connection. In Figure 15 are shown six spectra, three for each tube, with -10, 0, and +10 volts respectively, applied to the aperture electrode. In both cases there is a marked improvement in the peak-to-valley ratio of the distribution and in the case of No. 036528 a very significant reduction in the dark count. The reasons for this improved operation were fully discussed in the second quarterly report.

VOLTAGE DIVIDER NOISE CONTRIBUTION

Not much attention has been given to the problem of noise contributions of circuit elements external to the tube, with the exception of the selection of a good preamplifier. For this reason it was decided to check a tube in different divider networks. The standard divider uses 100,000 ohm 0.5 watt resistors except for the image section where it is 5.5 times this value and for the last two dynodes it is 1.5 and 3.0 times respectively. The other divider was made using 20 megohm resistors which happened to be available. These resistors are a pyrolytically deposited carbon film on a ceramic rod with kovar end caps so that glass tubing can be sealed around the resistor element enclosing it in an inert gas atmosphere. The tube used for this experiment was constructed some time ago on another contract. It has good statistics and is an exceptionally low noise tube. Figure 16 shows the two signal spectra with their respective dark spectra. While the signal spectra are, for all practical purposes identical there is a 6:1 difference in the total dark count. An additional fact which lends credence to belief that the low noise divider resistors may be responsible for this lower total noise in that the same 10,000 ohm 0.5 watt carbon load resistor was used in both cases, a low noise 10,000 ohm resistor not being available. Further investigation of this effect is required, however, before definite conclusions can be drawn.

FUTURE PLANS

In view of the results of the dynode mapping requirements it seems desirable to further investigate means by which as large an area, as possible, on the cathode be imaged on as small an area, as possible on dynode one. Some tentative design changes have been considered and appropriate steps will be taken to see if these changes are possible in the standard tube types made by this laboratory.

Additional investigation of the effect of the voltage divider and load resistors is also planned. Some low noise components are now available to start this work.

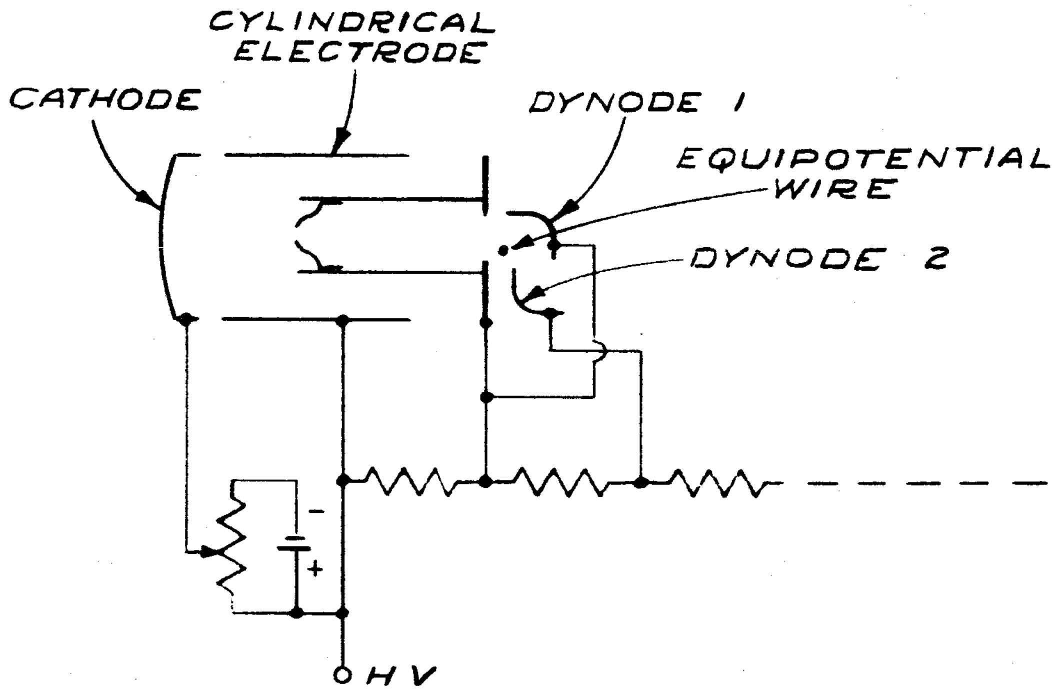

CYLINDRICAL ELECTRODE
CATHODE
DYNODE 1
EQUIPOTENTIAL WIRE
DYNODE 2
HV

FIGURE 1

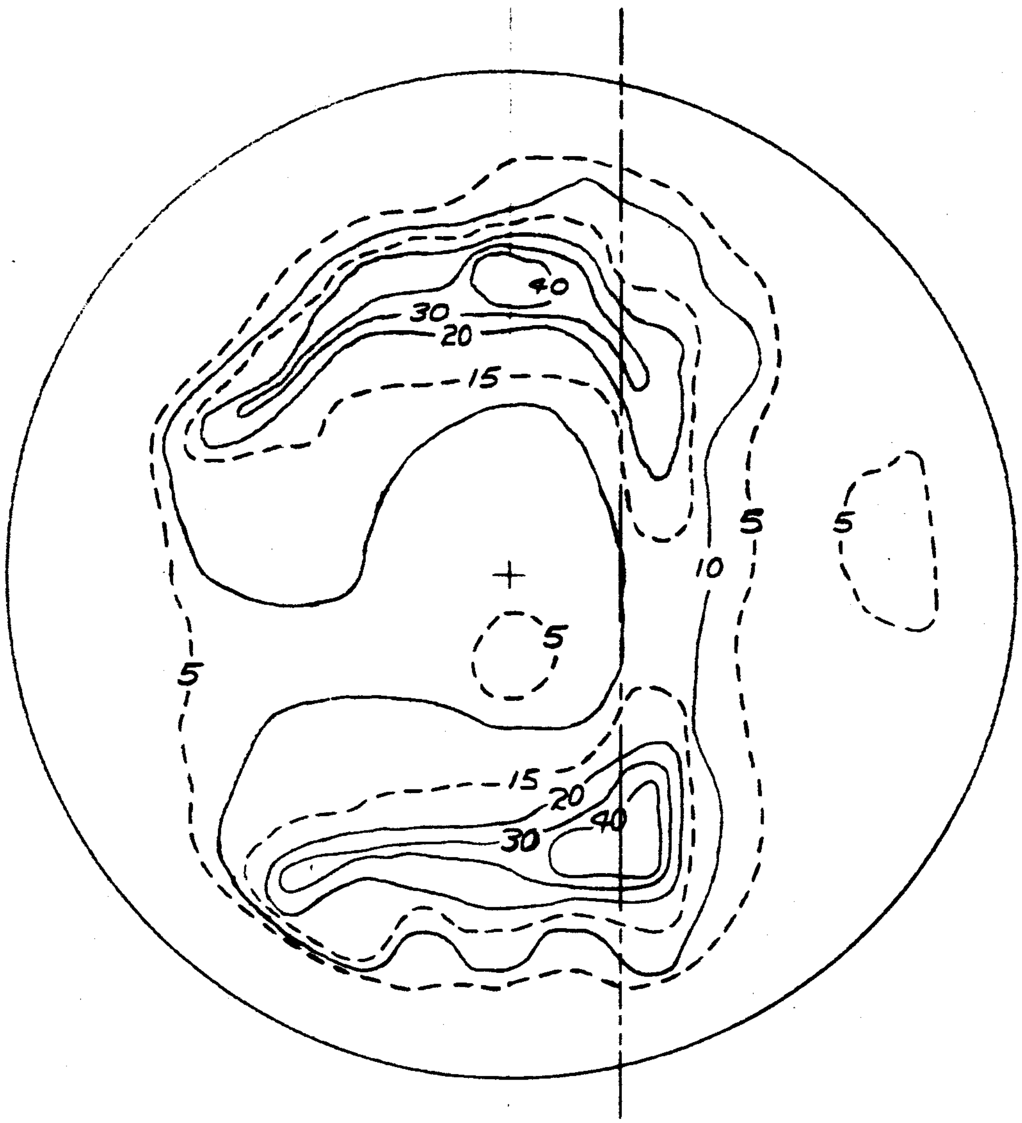
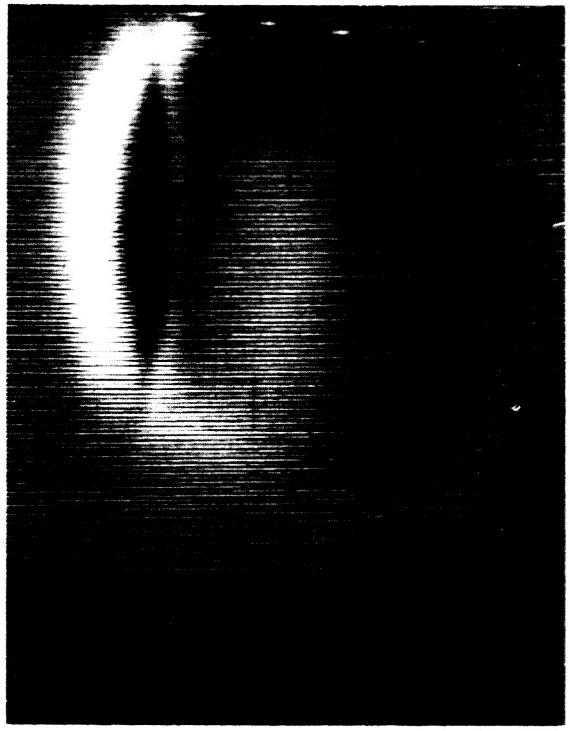


Figure 2

(a)



(b)

Figure 3

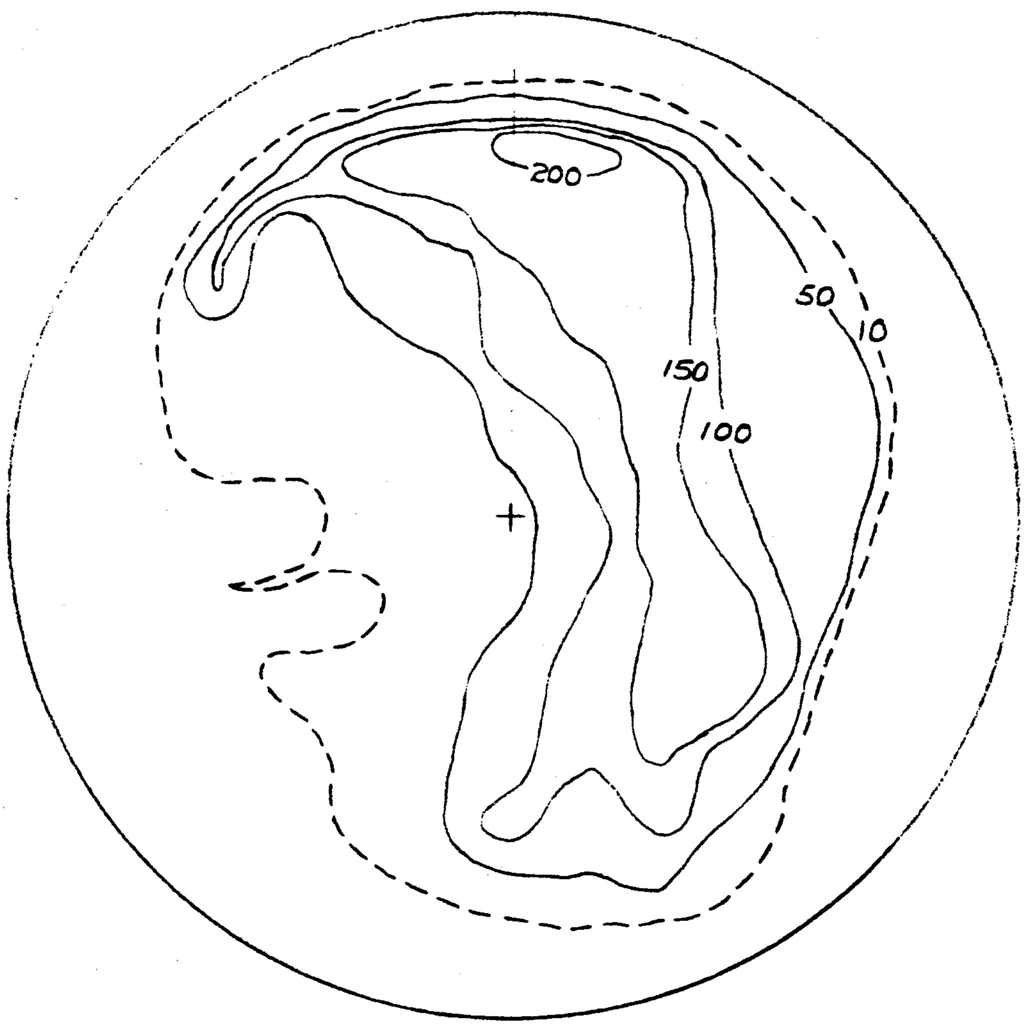


Figure 4

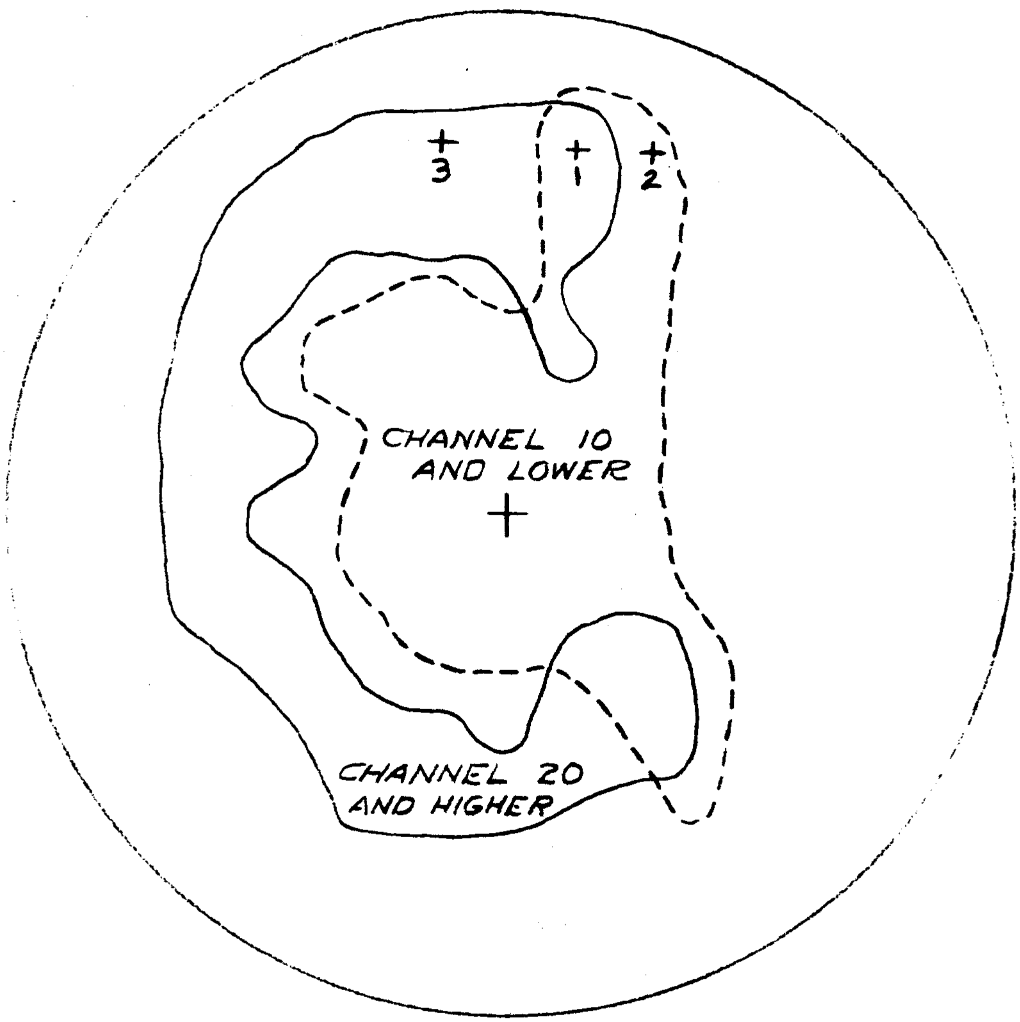


Figure 5

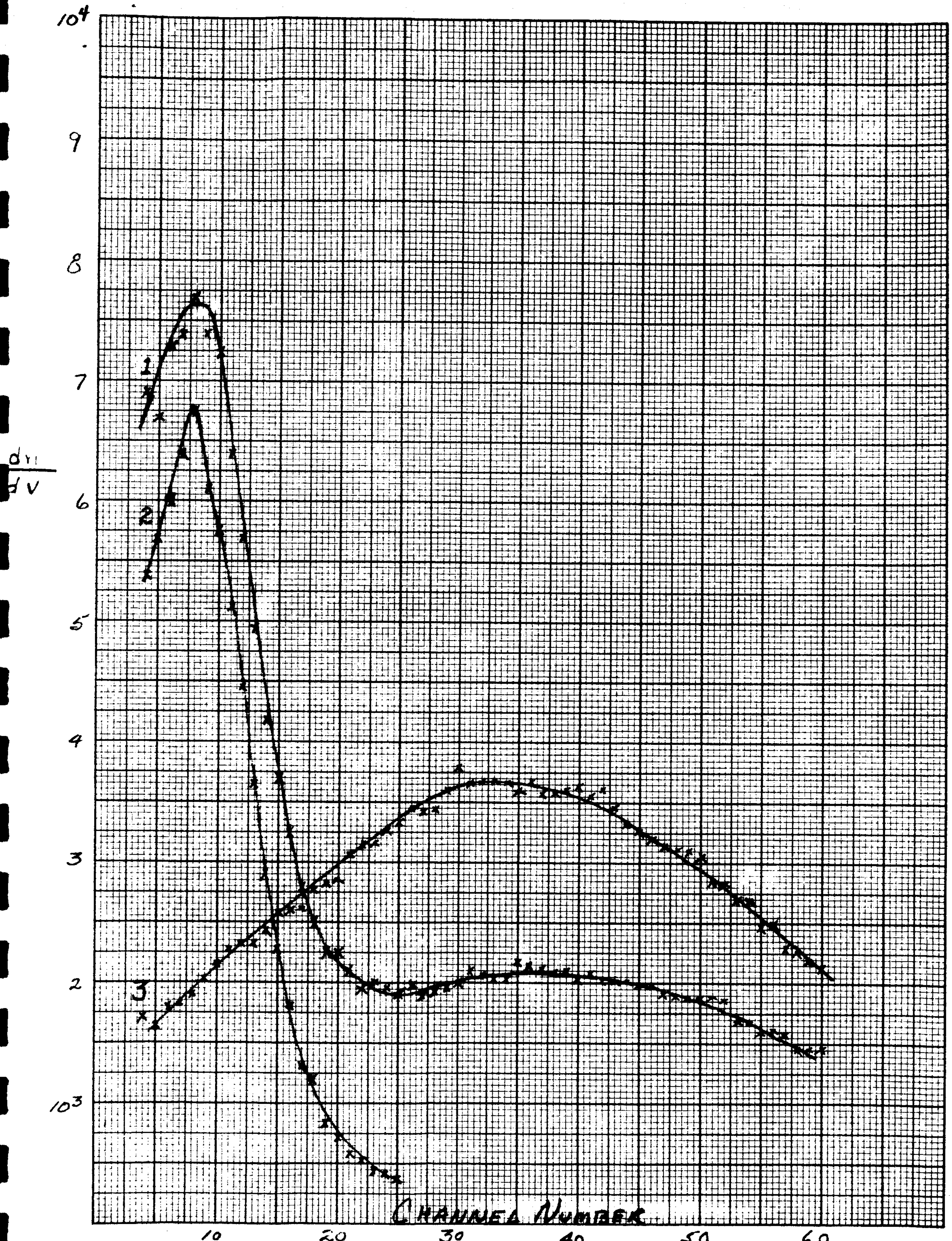


FIGURE 6

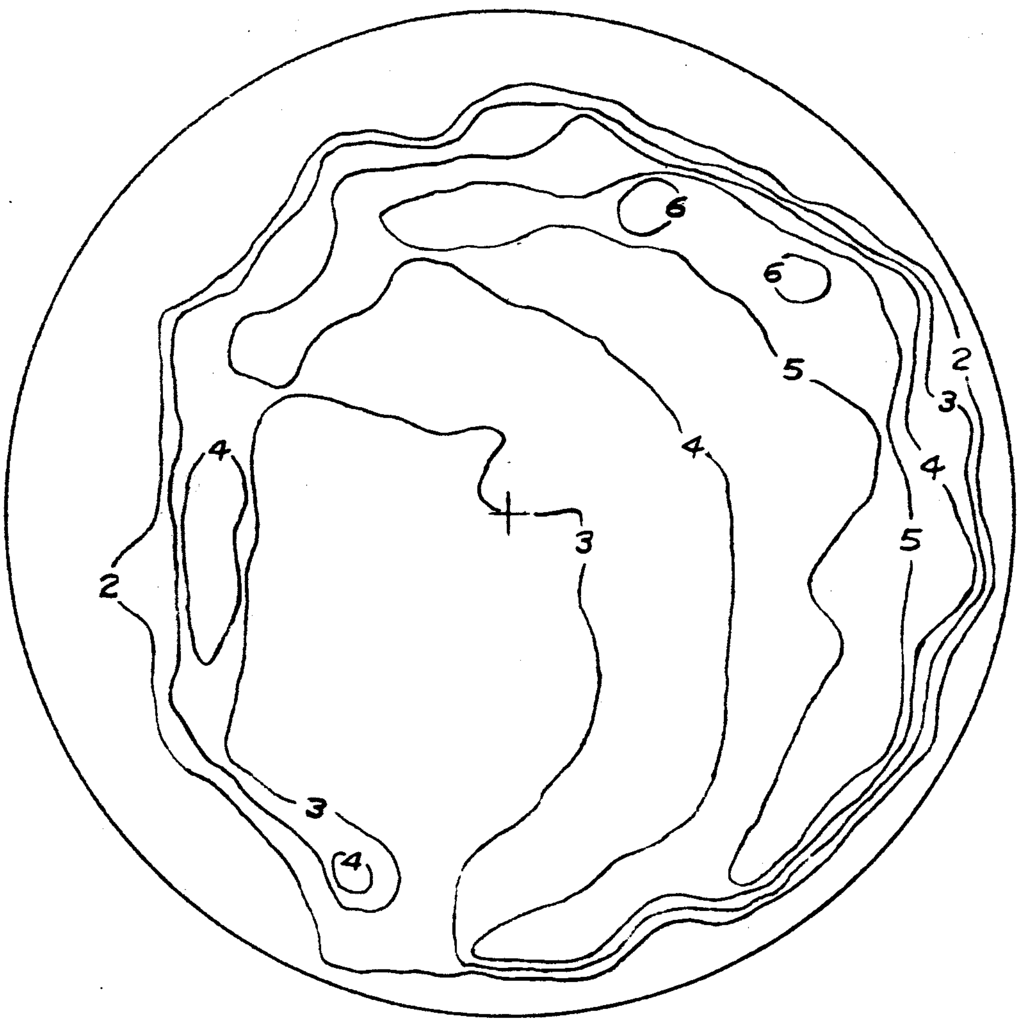


Figure 7

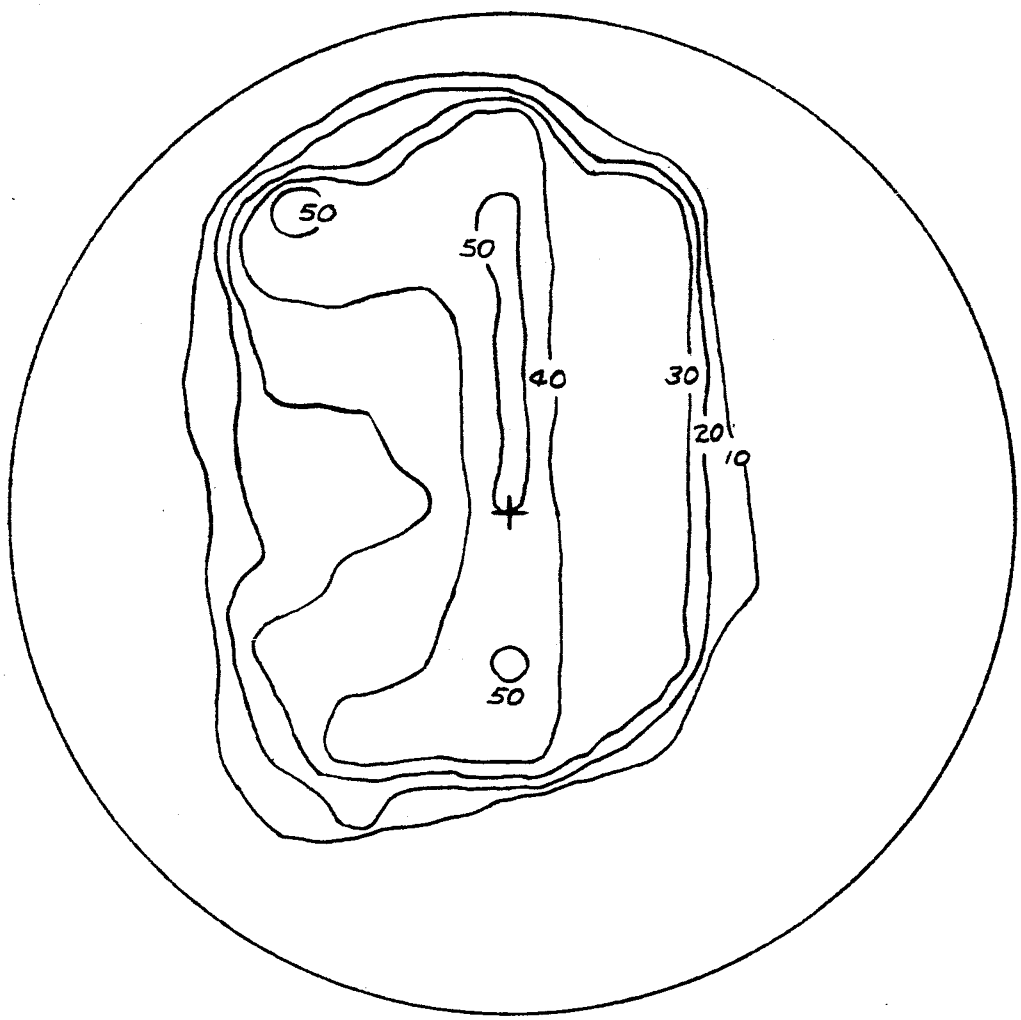


Figure 8

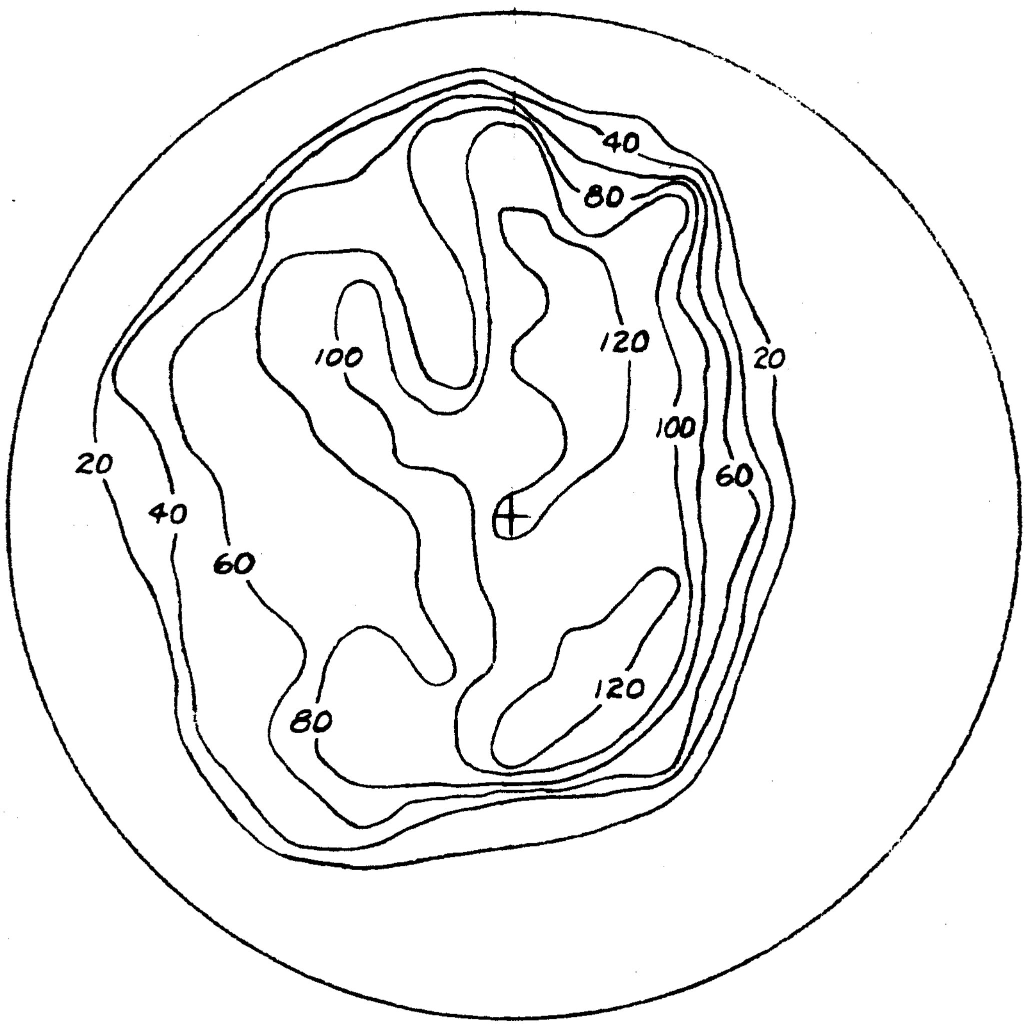


Figure 9

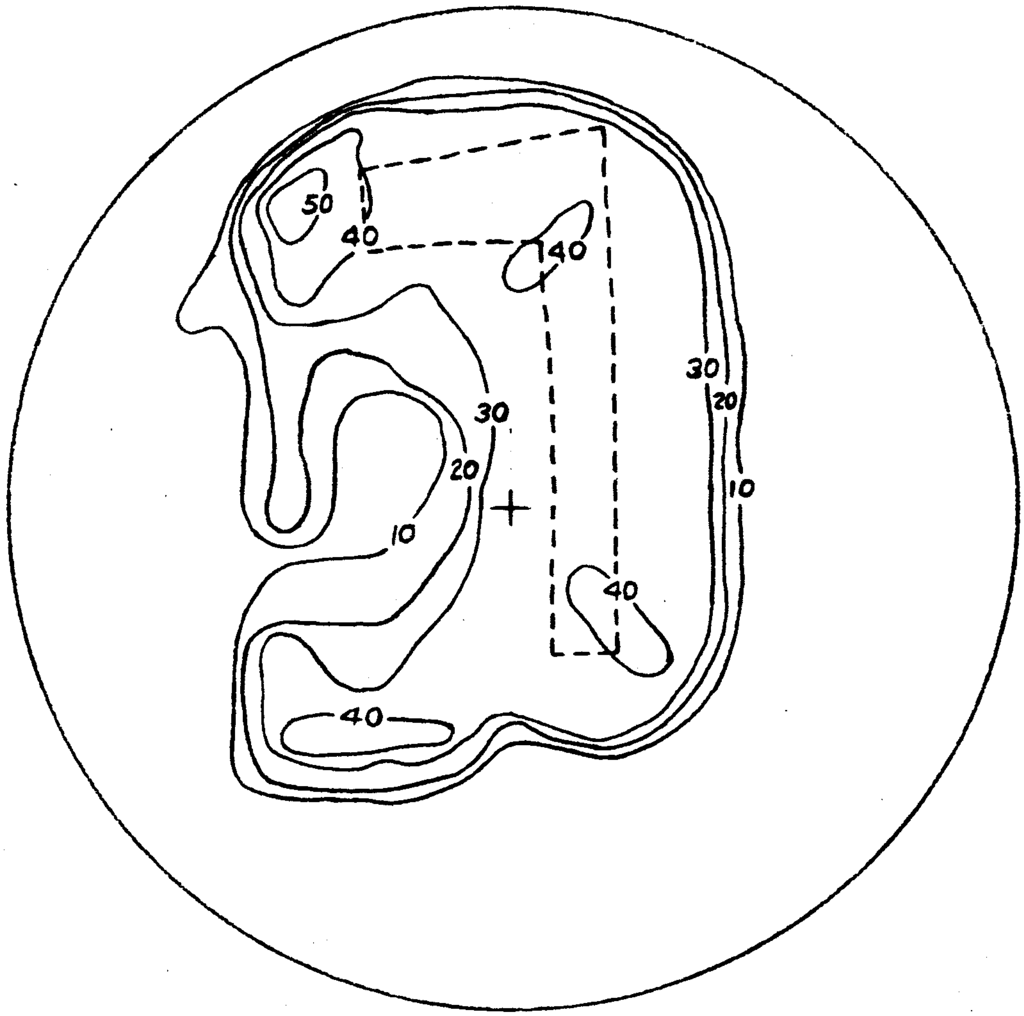


Figure 10

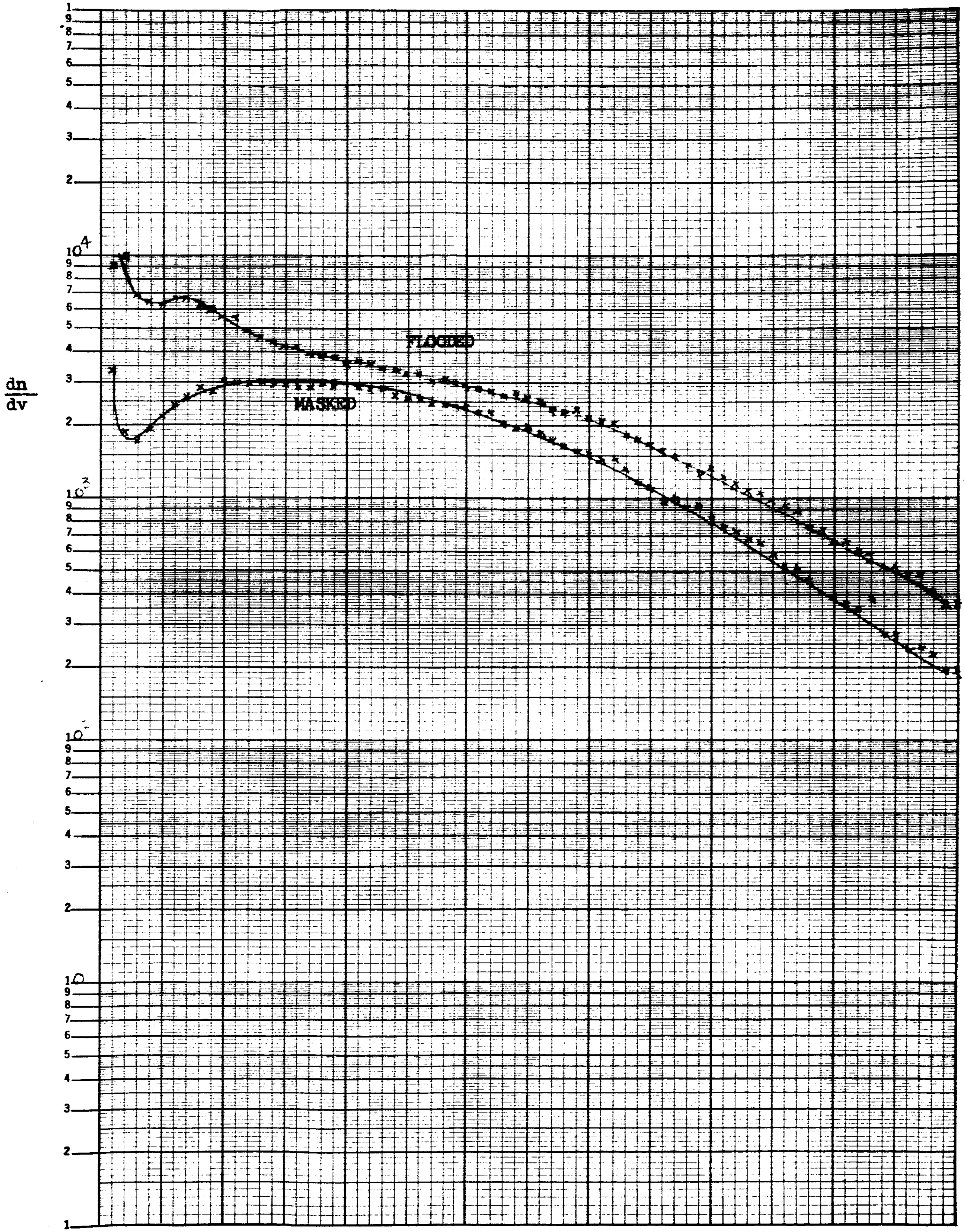


FIGURE 11

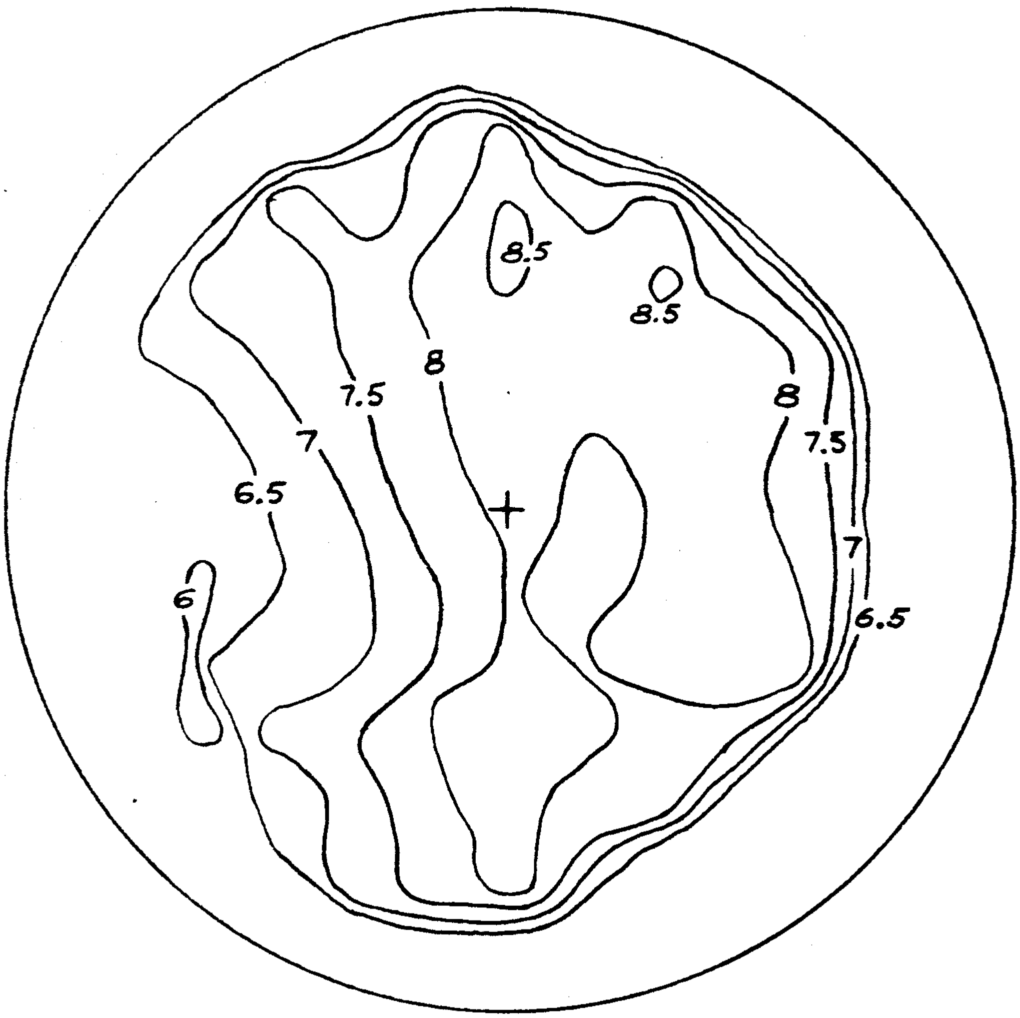


Figure 12

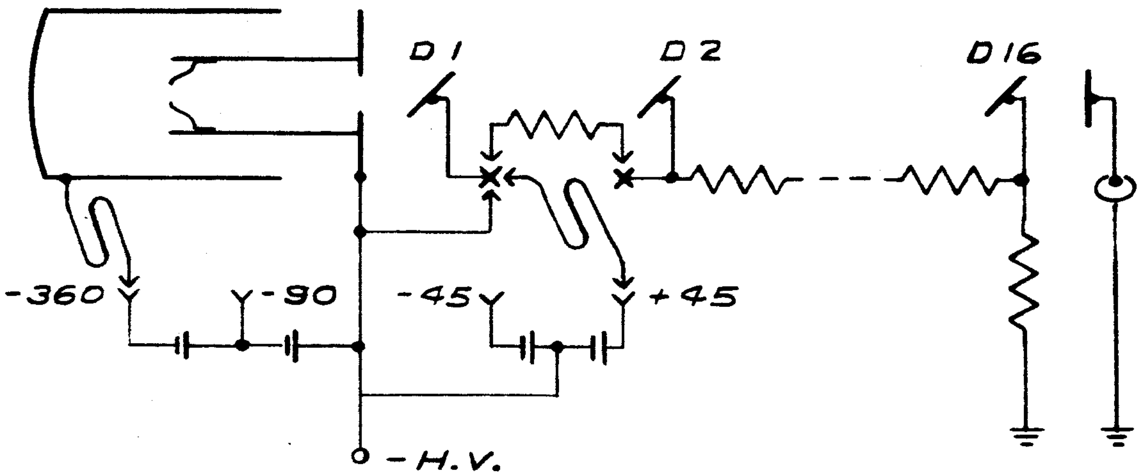


FIGURE 13

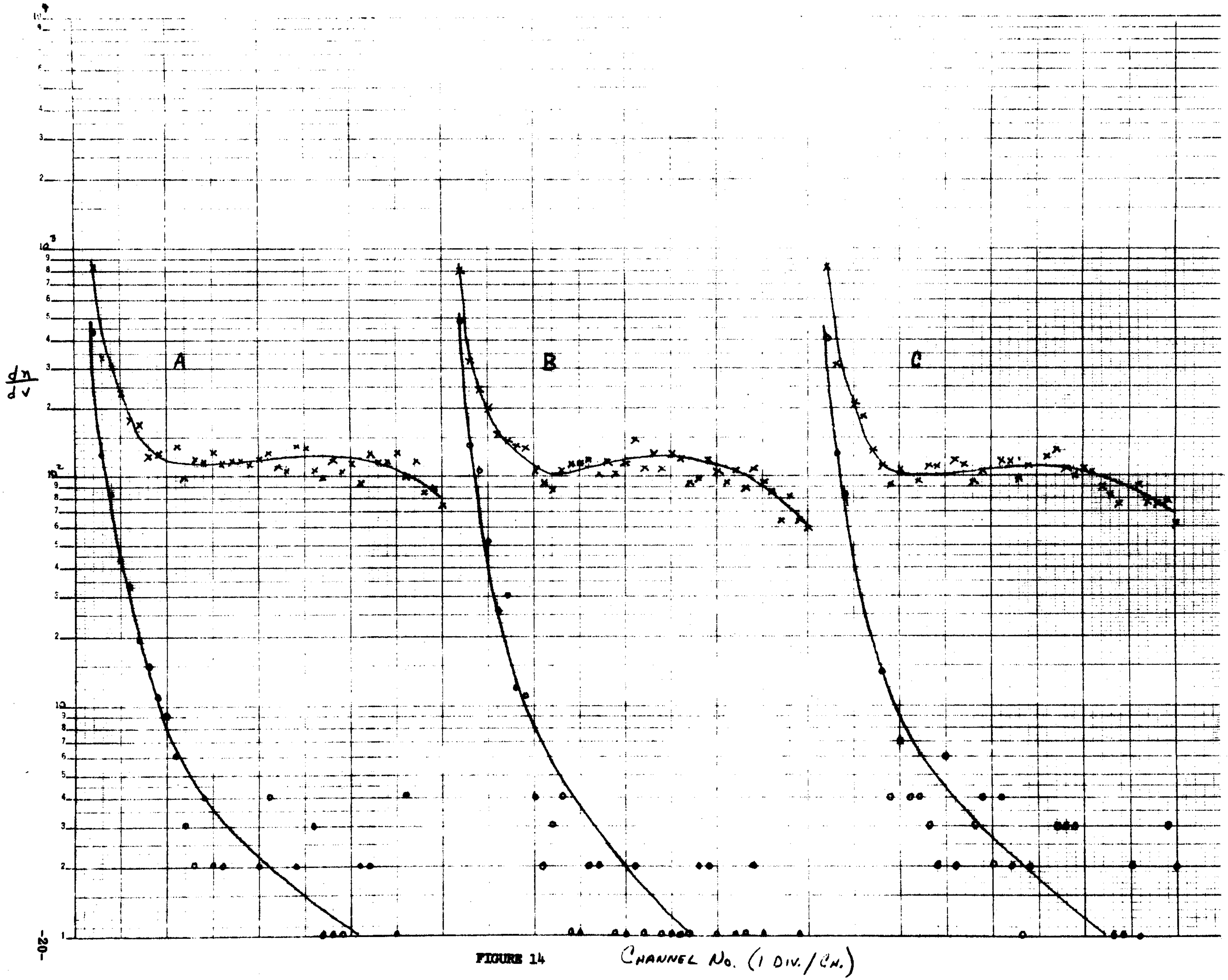


FIGURE 14

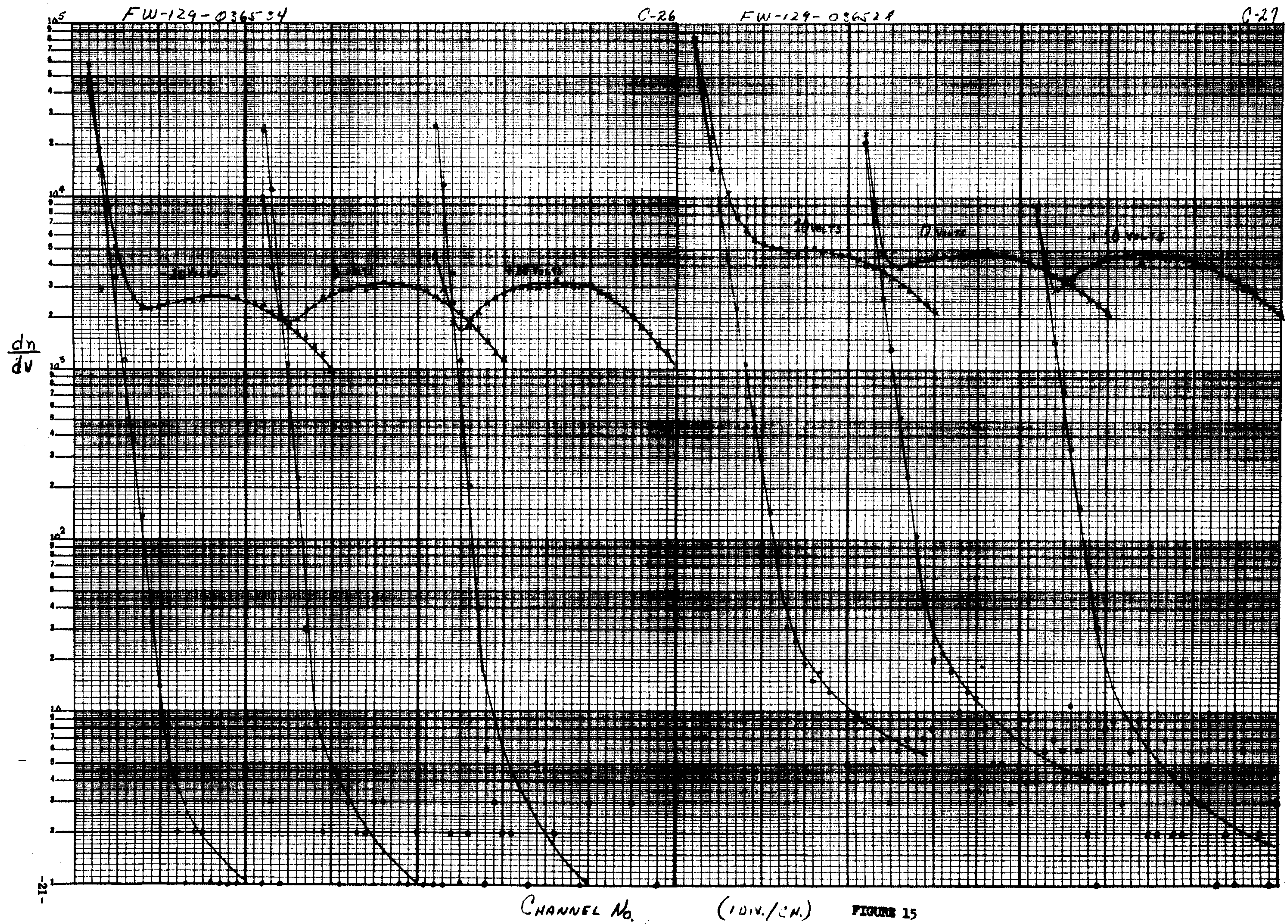

FW-129-036534
C-26
FW-129-036528
C-27
-10 VOLTS
0 VOLTS
+10 VOLTS
10 VOLTS
0 VOLTS
+10 VOLTS
dn/dV
CHANNEL No. (1 DIV./CH.)

FIGURE 15

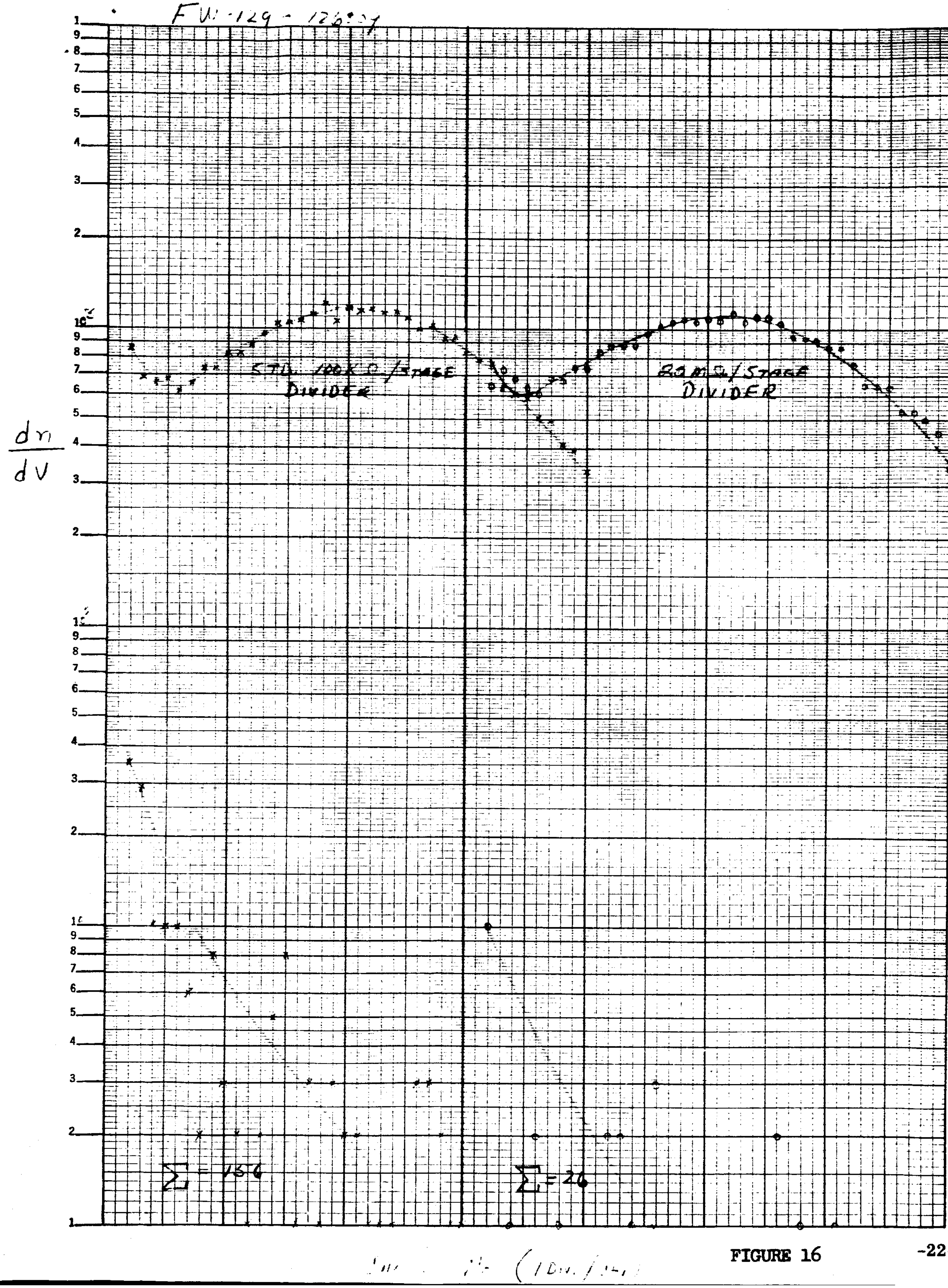

FW-129 - 126
STD. 100K Ω/STAGE DIVIDER
20 MΩ/STAGE DIVIDER
dn/dV
Σ = 136
Σ = 26

FIGURE 16