Memorandum M-102

Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

To: Director, Special Devices Center

6345

From: Jay W. Forrester

Subject: Storage Tube Program, Project Whirlwind

See Drawing List on last page

Date: September 15, 1947

This memorandum is in response to a request from Mr. Charles Doersam for information on the present status of Project Whirlwind Storage Tube research and for a comparison of the tube being developed at M.I.T. with the one constructed at the Naval Research Laboratory.

Comments will be considered in the following order.

a. M.I.T. Storage Tube Program

b. Comparison of M.I.T. and NRL Storage Tubes

M.I.T. Storage Tube Program:

The M.I.T. storage tube work is organized to produce a data storage system for the Whirlwind Computers. The Whirlwind Computers are to be of the parallel data transmission type and the storage must read and record all digits of a number simultaneously. The Whirlwind I computer will require operating storage by about November, 1948 and storage tube and circuit research are geared to this schedule.

A brief explanation of the tube will be given referring to Figure 1 which shows an elementary electrode arrangement. Deflection plates position the electron beam, prior to its being turned on, to the point on the dielectric surface at which writing or reading is to take place. The digits 1 and 0 are written as positively and negatively charged areas on the dielectric surface at the point of beam impact. The dielectric surface must have a secondary emission ratio greater than unity (a ratio of two or more is desired). To write the digit 1 the signal grid is made positive to collect secondary electrons from the dielectric resulting in a positive surface. Positive charging is accomplished by collecting the excess electrons above the number in the high velocity beam. To write the digit 0, the signal grid is made negative, no electrons are collected, and the surface charges negatively at the rate permitted by current flow in the primary beam. Secondary emission is not a necessary factor in negative charging.

Reading signals is accomplished by positioning the signal grid voltage midway between the two writing voltages and charging the dielectric positively or negatively toward this voltage. The output signal appears at the signal plate by capacitive coupling through the dielectric.

Permanence of the stored signal is insured by the regenerative action of a flood of low energy electrons operating on a principle which was, I understand, used in some German tubes and is employed in the RCA Selectron tube and in the NRL storage tube. Figure 2 shows how the self-sustaining effect is obtained from the holding gun. A positive area and a negative area are shown on the dielectric. The holding gun is at about the same potential as the negative areas and the signal grid is at about the potential of the positive areas. Consider the positive area: secondary electrons are emitted and a number just equal to those in the primary beam are collected by the signal grid, other secondary electrons return to the dielectric surface. If the surface should tend to become more positive, additional secondaries are pulled back to reduce the positive charge while, if the surface should tend to become less positive, more secondaries will be repelled to the signal grid to return the dielectric to its original point of stability. Considering the negative area: the area is approximately at holding gun potential and primary electrons, if they strike at all, will have low velocities and will emit few secondary electrons. If the surface becomes more negative, all primary electrons will be reflected and ohmic leakage will reduce the charge to the balance point while, if the surface becomes less negative, electrons from the primary beam will be collected to return the surface to the stable negative potential.

Results of research to date are compared with objectives of the program in Figure 3. Figures are based on basic research results and tests on one complete tube of small size which was constructed several weeks ago.

1. Feasibility of using the tubes in banks for parallel storage is shown by present results.

2. Signal levels obtainable from the present tube are more than adequate. Some of the present signal magnitude can be exchanged in future designs for faster writing speed. Signal level is shown for two methods of observation in Figure 4. The voltage division method gives higher output signals and will probably be used with this tube.

3. Writing speed in the present research tube is lower than will eventually be required. It is expected that speed can be increased a factor of 4 by changing to a surface with secondary emission equal to 2 or more in place of the present phosphor surface with secondary emission of 1.15; a factor of 2 to 4 by obtaining a lower first cross-over voltage of the secondary emission curve which can be reduced from the present 250 volts to less than 90 volts; a factor of 2 to 3 by increasing the primary beam current from the present 30 microamperes; and a factor of 2 by increasing the dielectric thickness. Such changes should result in about the proper writing speed.

4. Reading speed of the present tube is satisfactory for one polarity of signal and the higher secondary emission mentioned above will permit the same speed for both signal polarities.

5. The holding gun in the present tube appears to provide permanent storage. Quantative tests are not complete and further tests will be made.

6. Reliability of the first tube is good. Indications are that a tube of excellent reliability will result. Behavior does not appear critical with respect to any parameters.

7. During writing a signal is produced at the signal plate which can be used to check that storage was properly accomplished.

8. Resolution of the present tube is limited for geometrical reasons. The dielectric surface is of a cellular texture as shown in Figure 5. The present mosaic is coarse and, if retained in principle, will be reduced in mesh size.

9. Storage capacity of the present tube is limited by the target diameter of about 1 inch.

10. For greater reliability in reading, the tube and circuits are being designed to give opposite output polarities for the two binary digits.

11. Definition of the experimental tube is limited as discussed under Item 8. Storage tubes for computer use do not require the fine definition which is desired in such applications as radar. Since pictorial definition seems to conflict with essential computer characteristics, it is probable that no attempt will be made to obtain definition of pictorial quality. Usable computer definition will be limited by deflection circuit problems.

12. Reading and writing can be accomplished by switching the potential of only one electrode, either the signal grid or signal plate.

The experimental tube from which much of the above data was obtained is shown in Figure 6. The storage surface is at the small end of the tube and the writing-reading gun and the holding gun are in separate glass necks. The final tube design will resemble Figure 7 or Figure 8.

Design, construction, and testing of complete storage tubes represent only a fraction of the effort devoted to the storage problem. Much research has been directed toward the gathering of basic information, the study of deflection control circuits, tube construction techniques, and the design of special test equipment. All testing has been done on a pulse basis corresponding to the conditions under which the tube must eventually operate.

Approximate division of the Project Whirlwind staff follows.

	February, 1947		October, 1947	
	Staff Members	Per Cent of Total	Staff Members	Per Cent of Total
Storage Program	5	20%	8	20%
Circuits and Systems	20	80%	32	80%

Division of activity in the storage tube work is approximately:

	Per Cent of Storage Tube Staff	Per Cent of Total Staff
1. Design of Test Equipment and circuits	30	6
2. Study of Tube Construction Methods and Techniques	15	3
3. Basic Research into dielectrics, secondary emission, etc.	25	5
4. Circuits to be used with tubes for deflection, output reading, etc.	10	2
5. Actual construction and Test of Storage Tube Models	20	4

1. From the above table, design of test equipment (pulse generators, gate and delay circuits, sweep generators, and power supplies) has required more effort than any other phase of the storage division. As a result of this work, tests have been possible on a pulse basis and tube characteristics are available directly in terms of the computer application. Results of this work contribute also to other phases of the computer program.

2. Tube construction methods are of the upmost importance in storage tube work and techniques must be more carefully controlled than in commerical vacuum tube construction. Baking ovens, vacuum systems and an induction heater have been constructed or procured as shown in the laboratory views of Figures 9 and 10. Glass lathe work as in Figure 11 is required for tube construction. Personnel and the necessary background of experience will be available at M.I.T. to produce the tubes required for the Whirlwind I computer. For larger quantities of tubes the required training can be given to a tube manufacturer without delaying computer work while a new group solves the same difficulties already overcome by the research laboratory. With available equipment and personnel, tubes of any type required for testing can be constructed in a few days. The rate of advancement is set by procurement and analysis of data, not by tube construction.

3. Research studies have been conducted into the problems associated with storage tubes. The use of aluminum oxide as a dielectric and the preparation of the oxide surface has for many months occupied the time of one staff member. Surfaces as shown in Figure 5 are embossed on aluminum and anodized to produce a dielectric covering. The mesh of the dielectric surface is small compared to the beam diameter. Figure 12 shows the experimental anodizing apparatus and Figures 13, 14, 15, and 16 steps in the preparation of samples for testing. Since reliable tests of the dielectrics can only be made in high vacuum, it is necessary that samples be sealed into vacuum tubes for taking measurements.

4. Deflection of the cathode ray beam is one of the major problems in the type of tube being considered. Several kinds of circuits have been tested and the desired results appear within reach. Final selection of a deflection system from among several available will be made on the basis of properly balancing the requirements of accuracy and reliability against the amount of equipment involved. Test results show that deflection of banks of storage tubes in parallel can be achieved in 2 microseconds. Design of a deflection system has not been completed because available staff time was more urgently needed on other circuits.

5. Some 20% of the time devoted to the storage program or 4% of the project staff time has been expended on actual storage tubes. Tubes have been constructed as required for testing and coordinating the results of other research. Some of these tubes are shown in Figures 6, 17, and 18. The tube of Figure 6, first assembled in August of this year is the only one to be constructed to incorporate all the principles to be used in the final tube. It is the type of tube described last year at the Harvard Computer Symposium. Operation of this tube corresponds in all respects to predictions which can be made on the basis of geometrical and circuit considerations. It was

constructed for study purposes and after tests will be used for demonstration of principles and for life studies. Similar tubes will be built as required and will incorporate changes toward a final design.

Continued research in several directions will be required to develop the desired tube. 1) Work to the present has been on storage surfaces of aluminum oxide or one of the florescent phosphors. Neither of these has a sufficiently high secondary emission ratio. Satisfactory results seem indicated from the results obtained on oxides of beryllium and other metals which have been studied at other laboratories. Some evaporation tests have not yet been completed. A low first cross-over voltage, V_a Figure 19, on the secondary emission curve is desirable. This characteristic will in general accompany the greater secondary emission. A high second cross-over voltage, V_c, is desirable in order that a high primary beam voltage may be used to permit higher beam current. Based on the little information available, a high second cross-over voltage is expected to be a characteristic of beryllium oxide. Life studies must be initiated on the secondary emission surface as soon as a tentative selection is made. Some surfaces change their secondary emission behaviors due to contamination from the tube cathode and from residual gas in the tube. Additional circuit design will be required to develop output detection circuits which will receive the tube output but exclude the transients which are produced from grid switching during reading and writing. Resolution of the tube over that thus far demonstrated will be required but the problem appears less difficult than others and can be approached through smaller beam diameters, closer grid spacing, and a fine storage surface mosaic if the mosaic is retained in preference to a plane surface. It is probable that better electron guns should be procured than now available. Present work is done with commercial cathode ray tube guns; better guns are in use for other purposes in this country and in England and may prove satisfactory. An increase in gun current without loss of definition is desired. Special guns procured from England are available in the laboratory but have not yet been tested.

Comparison with the NRL Tube.

Full details on the operation and development plans for the NRL tube are not available at the Servomechanisms Laboratory but the following comments are in answer to the request.

The NRL tube was developed initially for the storage of pictorial information in radar applications. It shows considerable promise for this purpose although the tube is in the very early research stages and an evaluation would be difficult for some time. The characteristics which make the tube useful for radar are of doubtful value if not hazardous for computer application.

Figure 20 repeats the information of Figure 3 on the M.I.T. tubes and adds a column on the NRL tube.

1. No information has been released and the tube has probably not been tried for parallel digit transmission. The requirement for parallel digit transmission was not known to the NRL group while the tube was under development for radar and the concept of parallel operation has only recently been introduced since the tube was taken over by the Bureau of Standards on a contract to Raytheon. Difficulties in reading to a parallel bus with a stationary beam are discussed in the next paragraph. Tests to date have been for steady state scanning for picture presentation.

2. Signal levels thus far obtained from the NRL tube are the order of 1 millivolt. This will require signal detection amongst the switching transient noise of computer operation or else changes of a fundamental nature in the tube must be introduced. The voltage division method of signal detection pictured in Figure 4 is probably unsuited to the tube because signal and beam current are carried through the same electrode. Figure 21 shows the output signal comparison between the NRL tube and the two methods of signal detection in the M.I.T. tube. It is possible that changes in the NRL tube can be made for computer use to increase the present reading beam currents of about one microampere to the 100 microampere level of the M.I.T. tube.

3. No data is available on the pulse writing speed of the NRL tube although some conclusions pointing to the "microsecond range" have been drawn from steady state scanning tests.

4. The same comment applies to reading speed.

5. Storage time of the NRL tube is controllable over a limited range. This appears to be its principle unique feature which is valuable in some radar applications but of no value in computer work. In fact, precautions must be taken to insure that this feature cannot cause erasure and adversely affect the reliability of the tube for computer application.

6. Signal storage of the tube is presumed to be permanent under proper conditions but movies and demonstrations to date have shown unexplained skipping and erratic operation of the writing beam which must be overcome.

7. So far as known, the problem of checking signals has not been considered with respect to the NRL tube.

8. No data is available on resolution of the tube in computer terms since so far as known no tests of this type of storage have been made. Results of pictorial testing would indicate satisfactory resolution of the screen with the limit probably set as in other deflection tubes for computer use by the deflection circuits.

9. Storage capacity is probably adequate and the preceding comments apply.

10. Since the signal is superimposed on the part of the beam current which is collected by the signal screen, only variation in magnitude of this current is available for signal detection. Problems will exist in obtaining a signal variation for parallel tube operation and the situation will be aggravated by variations in primary beam current due to transients and cathode changes. Operation of the Project Whirlwind storage tube is possible with wide variations in beam current.

11. Pictorial presentation is a feature of the NRL tube which probably will not be possible with the M.I.T. tube.

12. Operation in the manner thus far described by NRL requires switching the potential of the entire gun and anode circuits. High capacitances must be driven by short voltage pulses and different control methods may be required.

Prior to the award of a contract to Raytheon, I discussed the NRL tube with Mr. S. N. Alexander of the Bureau of Standards and agree with him that the tube is sufficiently different from the M.I.T. work to justify its pursuit. I feel however that the tube has been grossly "oversold" with respect to its present status. The practical problems of using the tube have been dismissed as "mere engineering details" by its NRL sponsors while the tube is still subject to most of the research problems outlined for the M.I.T. tube in the last paragraph of the first section of this memorandum and has before it in addition the difficulties discussed in this section. These can doubtless be overcome but some research and considerable development still appear necessary.

The only new principle shown in the NRL tube is the variable decay time for radar work which is not required in the computer application. Permanence of storage through the use of low energy electrons is common to work abroad, the RCA Selectron, and Project Whirlwind. It is probable that the NRL tube will have less difficulty with secondary electron redistribution than the M.I.T. tube in which it has been necessary for some work to go to a matrix storage surface with electron barriers.

Tubes built at NRL have had three electron guns for reading, writing and holding. Since computer use would require the reading and writing guns to track nearly exactly for the same deflection voltages, which would be almost impossible for good definition, the Raytheon version of the tube will combine the reading and writing operations into one gun as is done in the M.I.T. tube.

Examination of the table given previously for the distribution of effort on the storage program will show that some 20% has been devoted directly to tube building and testing. This part of the work corresponds roughly to the NRL tube program since no test equipment for pulse studies has been used, tube construction was subcontracted to one research group and recently transferred to Raytheon under the Bureau of Standards so that to date the work has not resulted in personnel trained in construction methods, and no research and development has been directed toward use of the tube in computer circuits.

I have dwelt on the difficulties to be encountered by the NRL tube in some detail, not because of doubt that it has a useful future, but to call attention to what I feel is an unjustified impression gained by many that the tube is now ready for use. The history of storage devices has been one of overoptimism repeated as each new idea or design has been presented. The NRL tube appears to be among the brighter prospects for radar use and should be developed along its original lines for simulator use. In simulators where data is to come from a computer to be presented on a radar type screen, the separate write and read guns and adjustable decay can save much numerical computing time.

I am pleased to see the NRL tube continued under development and feel that it will receive careful guidance and evaluation from Mr. Alexander of the Bureau of Standards.

Drawing List Instructions - Put Figure Numbers on Prints

Figure 1	Drawing SA-30892
Figure 2	Drawing A-30885
Figure 3	Drawing A-30886
Figure 4	Drawing AAA-30887
Figure 5	Drawing A-31324
Figure 6	Drawing A-31325
Figure 7	Drawing B-30888
Figure 8	Drawing B-30889
Figure 9	Drawing A-31326
Figure 10	Drawing A-31327
Figure 11	Drawing A-31[illegible]28
Figure 12	Drawing A-31329
Figure 13	Drawing A-31330
Figure 14	Drawing A-31331
Figure 15	Drawing A-31332
Figure 16	Drawing A-31333
Figure 17	Drawing A-31334
Figure 18	Drawing A-31335
Figure 19	Drawing A-30893
Figure 20	Drawing A-30890
Figure 21	Drawing B-30891

JWF:vh

A-30892 USED IN C345 MEMO M-102

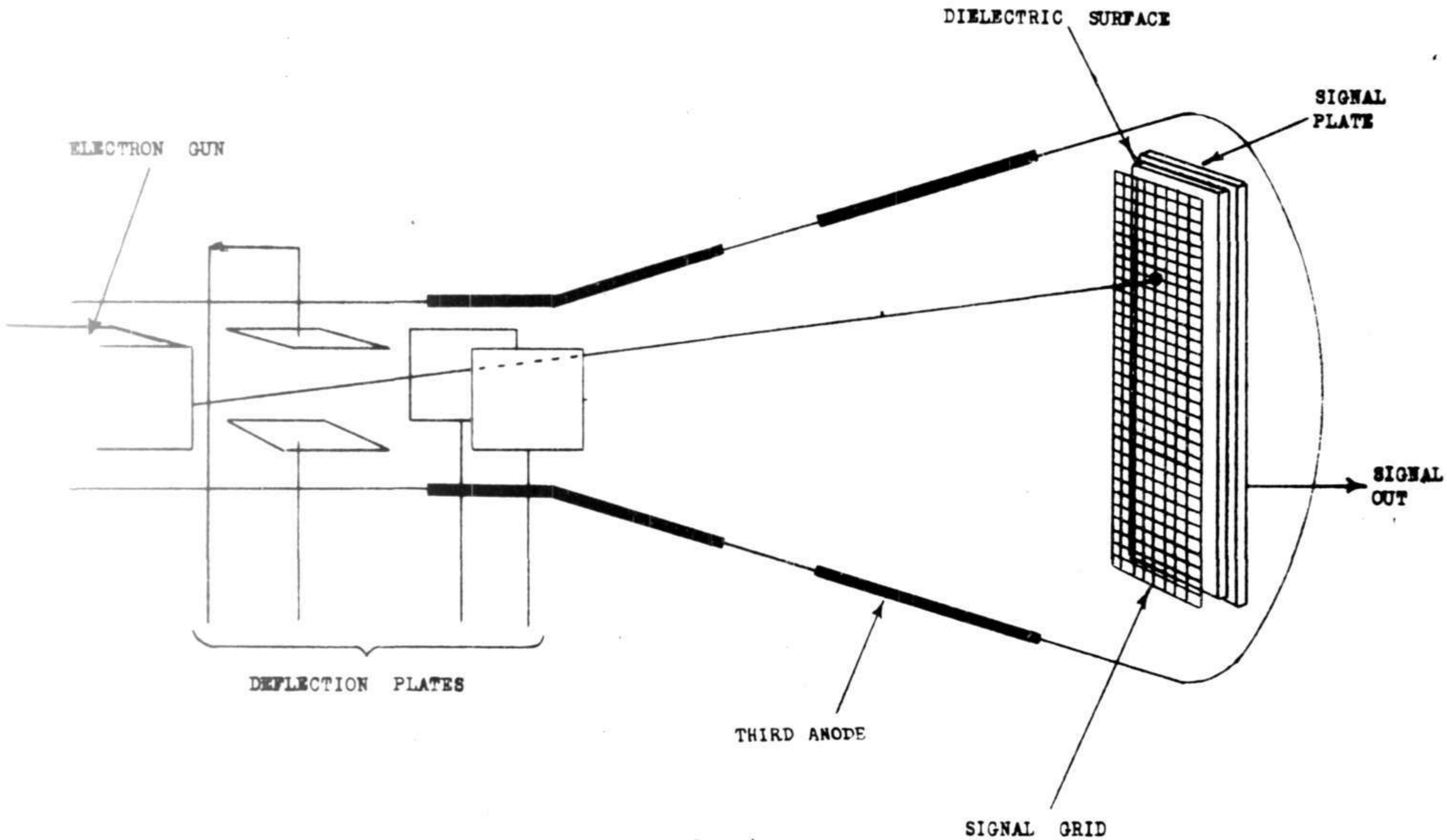


FIG. 1

ELECTROSTATIC STORAGE TUBE

A-30885 USED IN 63-5 MEMO M-102

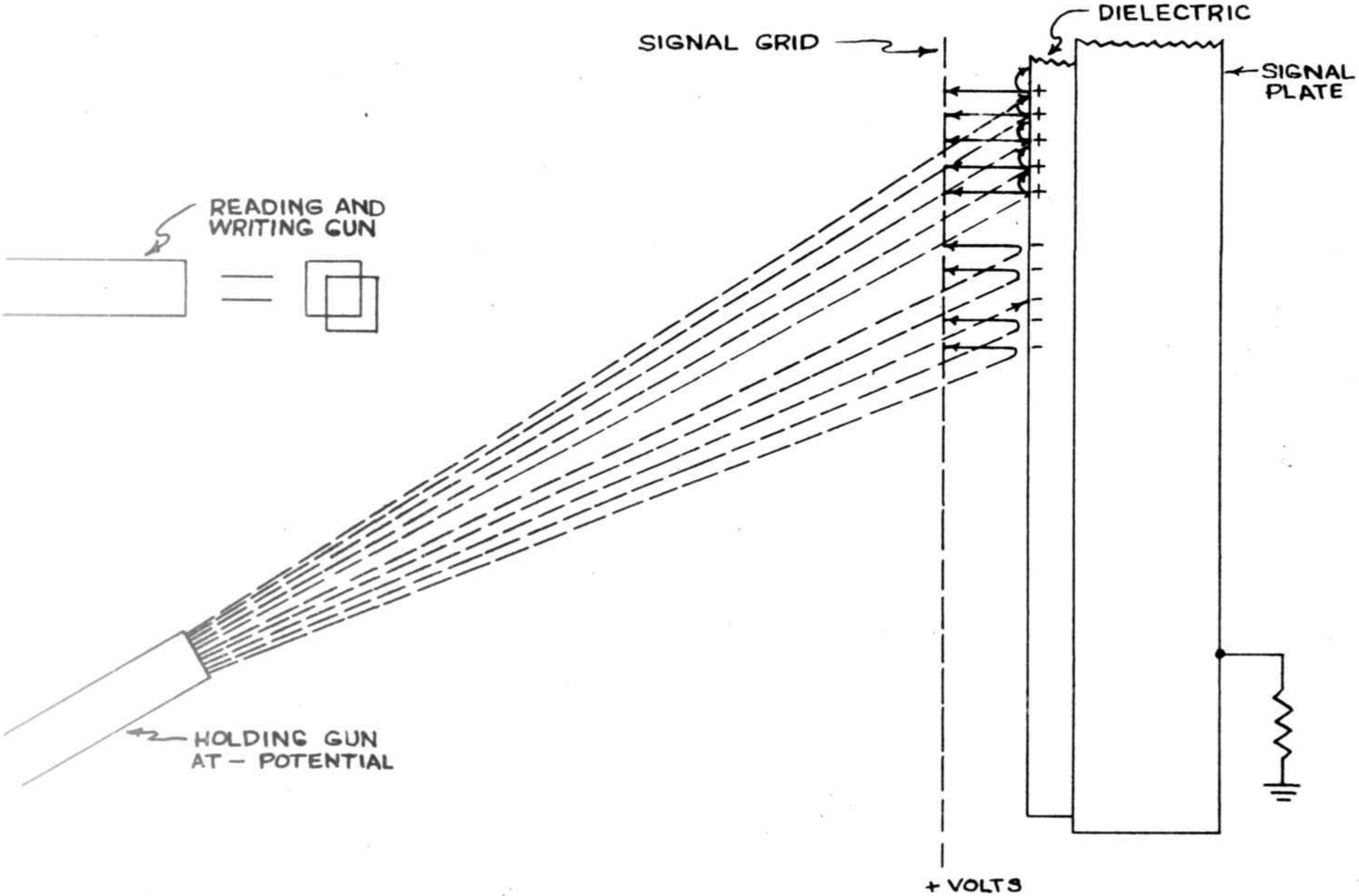


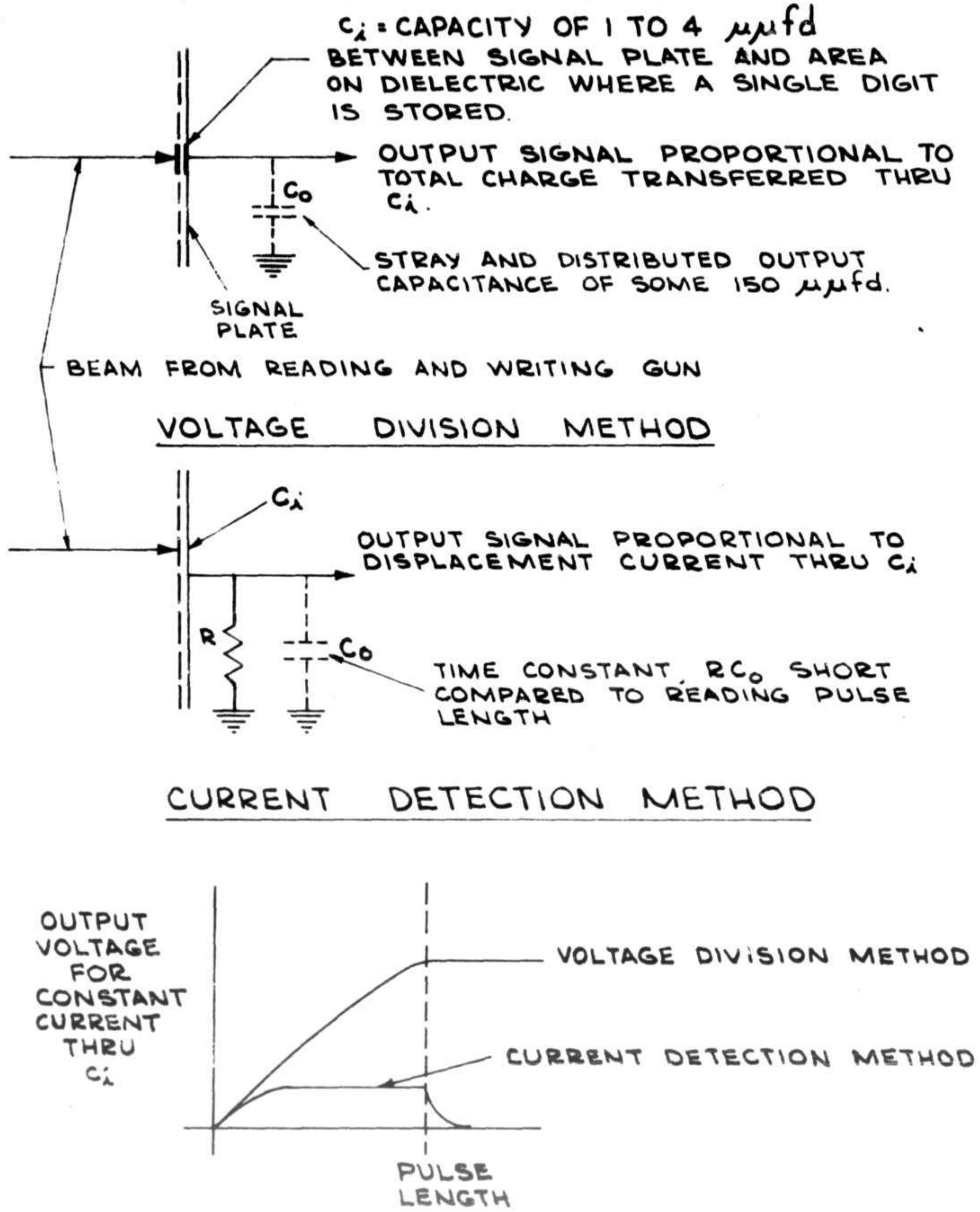
FIGURE 2

A-30886 USED IN 6345 MEMO M-102

OMPARISON OF PRESENT STORAGE TUBE RESEARCH RESULTS WITH FINAL OBJECTIVES

ARACTERISTIC	FINAL WHIRLWIND STORAGE TUBE	PRESENT M.I.T. RESEARCH RESULTS	
RALLEL DIGIT STORAGE	YES	YES	
GNAL LEVEL VOLTAGE DIVISION CURRENT METHOD	0.100 VOLTS MIN. .050 VOLTS MIN.	0.200 VOLTS 0.100 VOLTS	
RITING SPEED	1 TO 2 MICRO SEC.	50 MICRO SEC.	
EADING SPEED	1 TO 2 MICRO SEC.	1 TO 2 MICRO SEC.	
TORAGE TIME	PERMANENT	PERMANENT	
ELIABILITY	EXCELLENT	GOOD	
HECKING SIGNAL	YES	NOT TRIED	
ESOLUTION, DIGITS R INCH FOR MPUTER USE	10	5	
ORAGE CAPACITY	1024 DIGITS	16 (SMALL TARGET)	
OTH + ¢ - SIGNALS	YES	YES	
CTORIAL DEFINITION	PERHAPS	NO	
UST GUN POTENTIAL E SWITCHED	NO	NO	

FIG-3



SIGNAL LEVEL DETECTION

FIG. 4

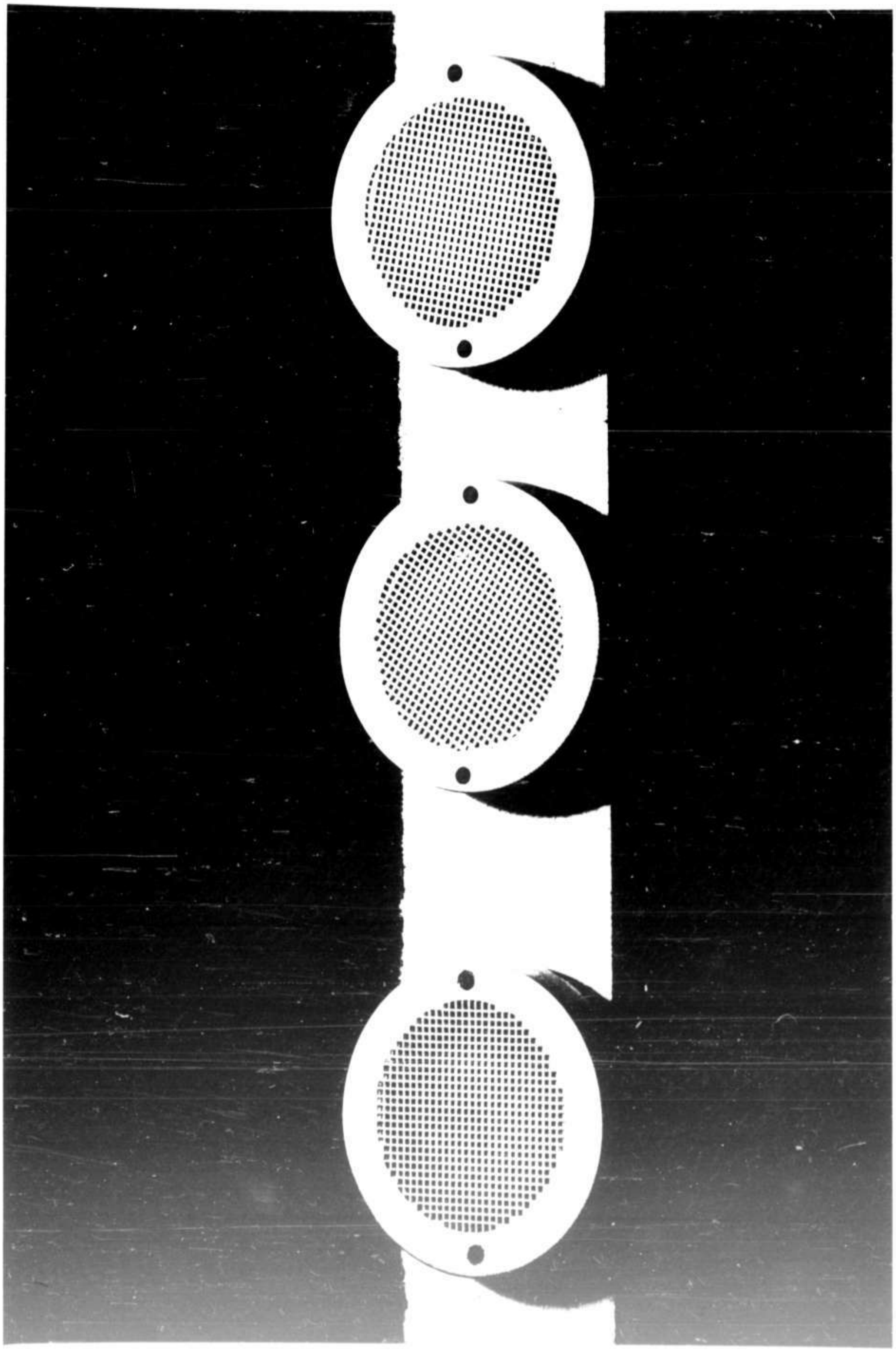


FIG. 5

IN M 130 & M 102

A-31325 USED IN M 130 & M 102

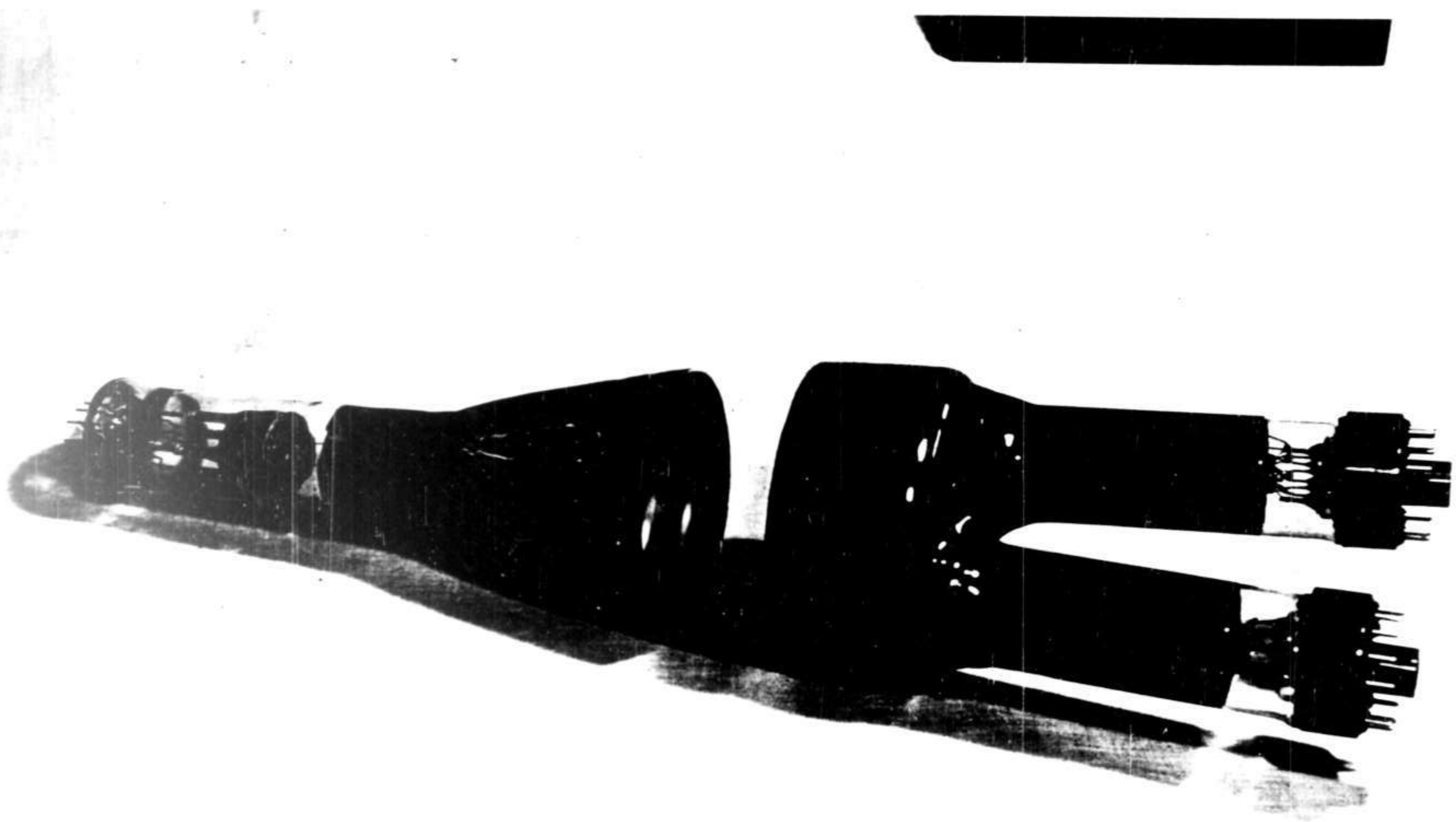


FIG. 6

B-30888 USED IN 6345 MEMO M-102

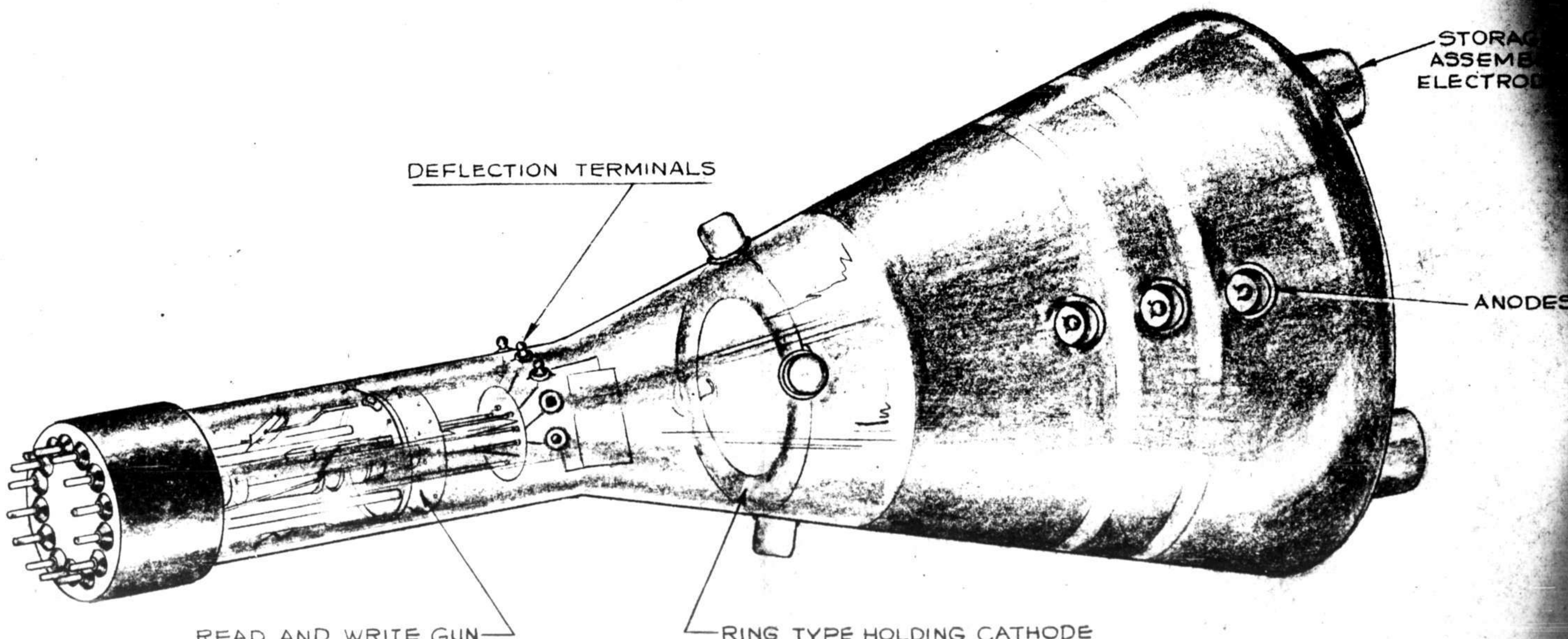


FIGURE 7

POSSIBLE FINAL STORAGE TUBE DESIGN

B-30889 USED IN 6345 MEMO M-102

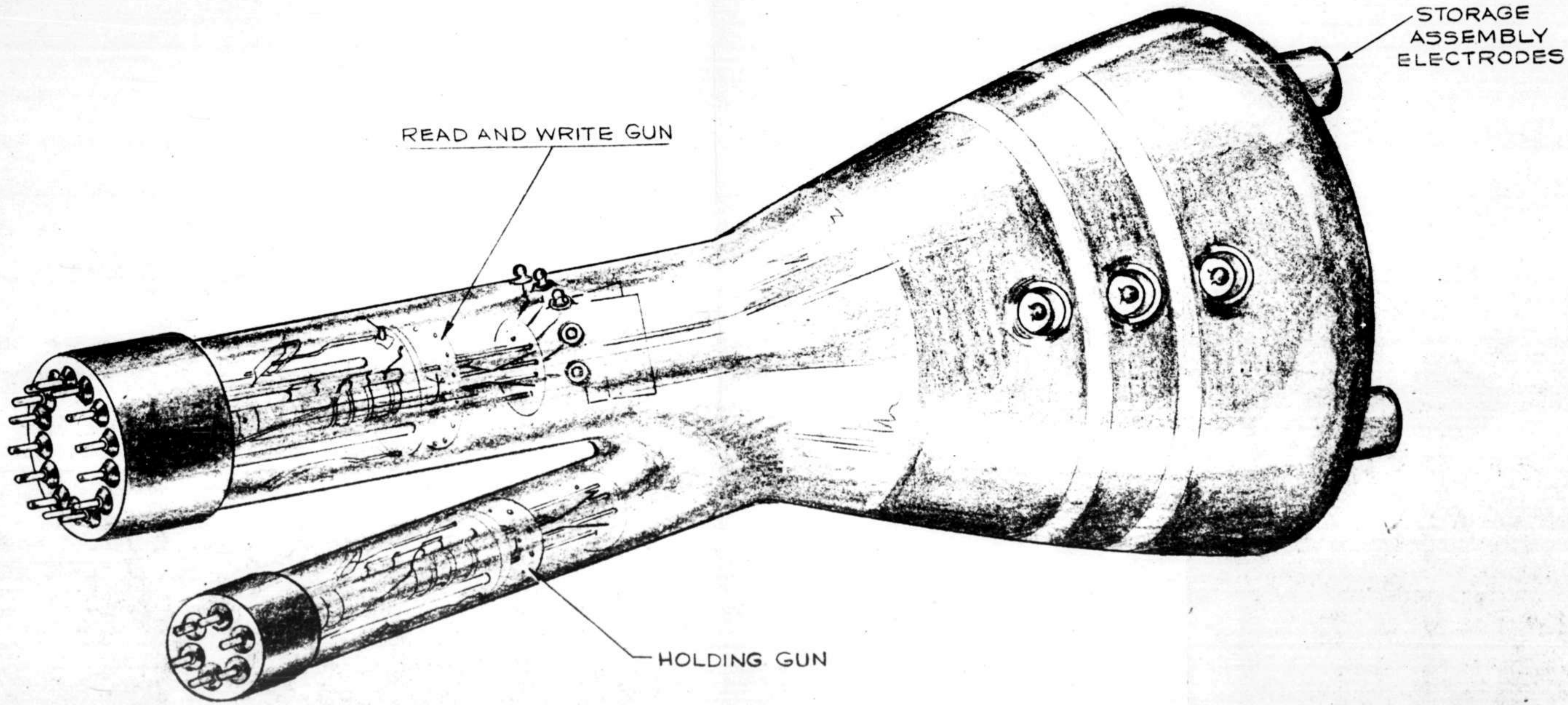


FIGURE 8

POSSIBLE INTERMEDIATE STORAGE TUBE DESIGN

A-31326 USED IN M130 & M102

FIG. 9

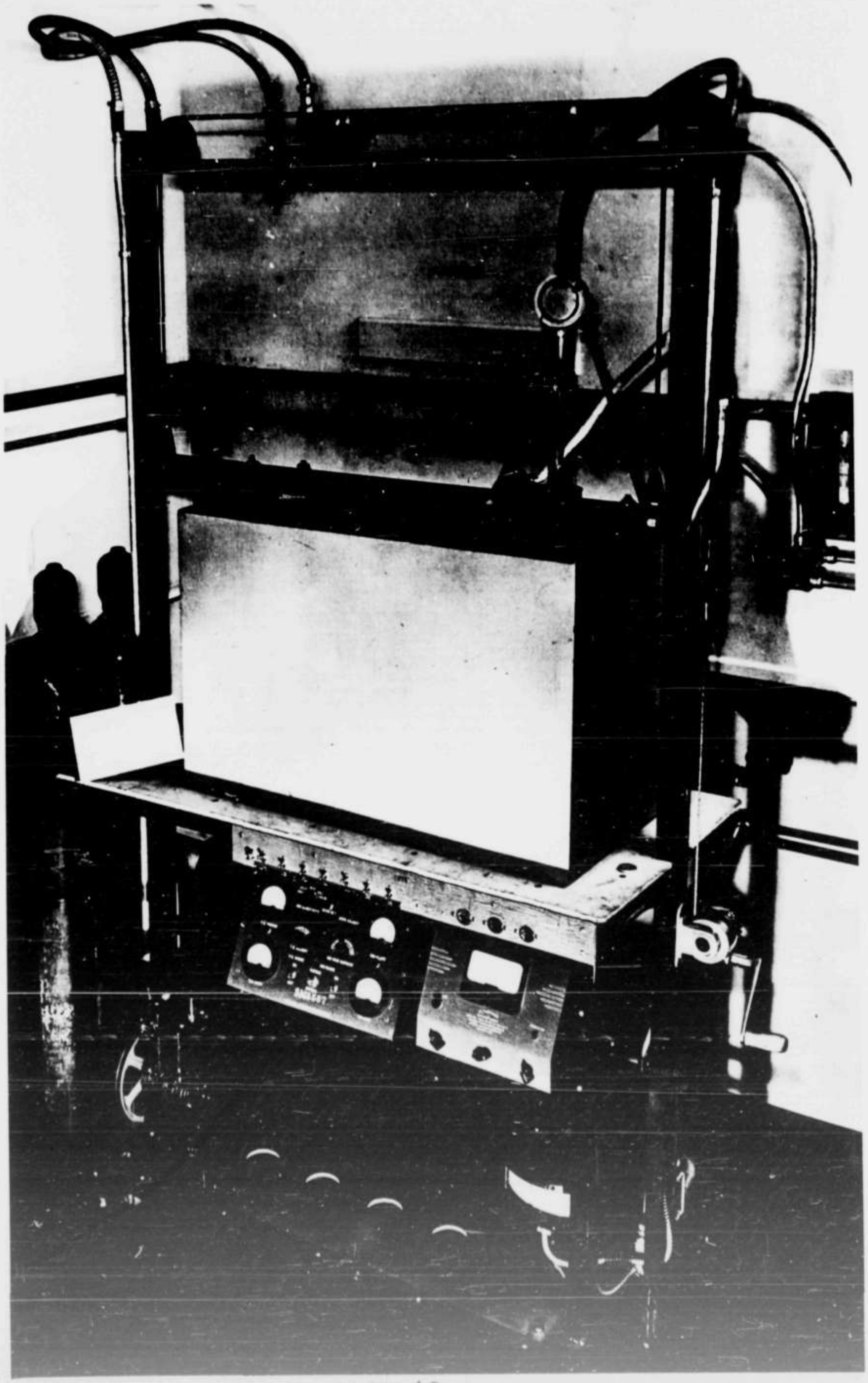


FIG. 10

USED IN M130 & M102

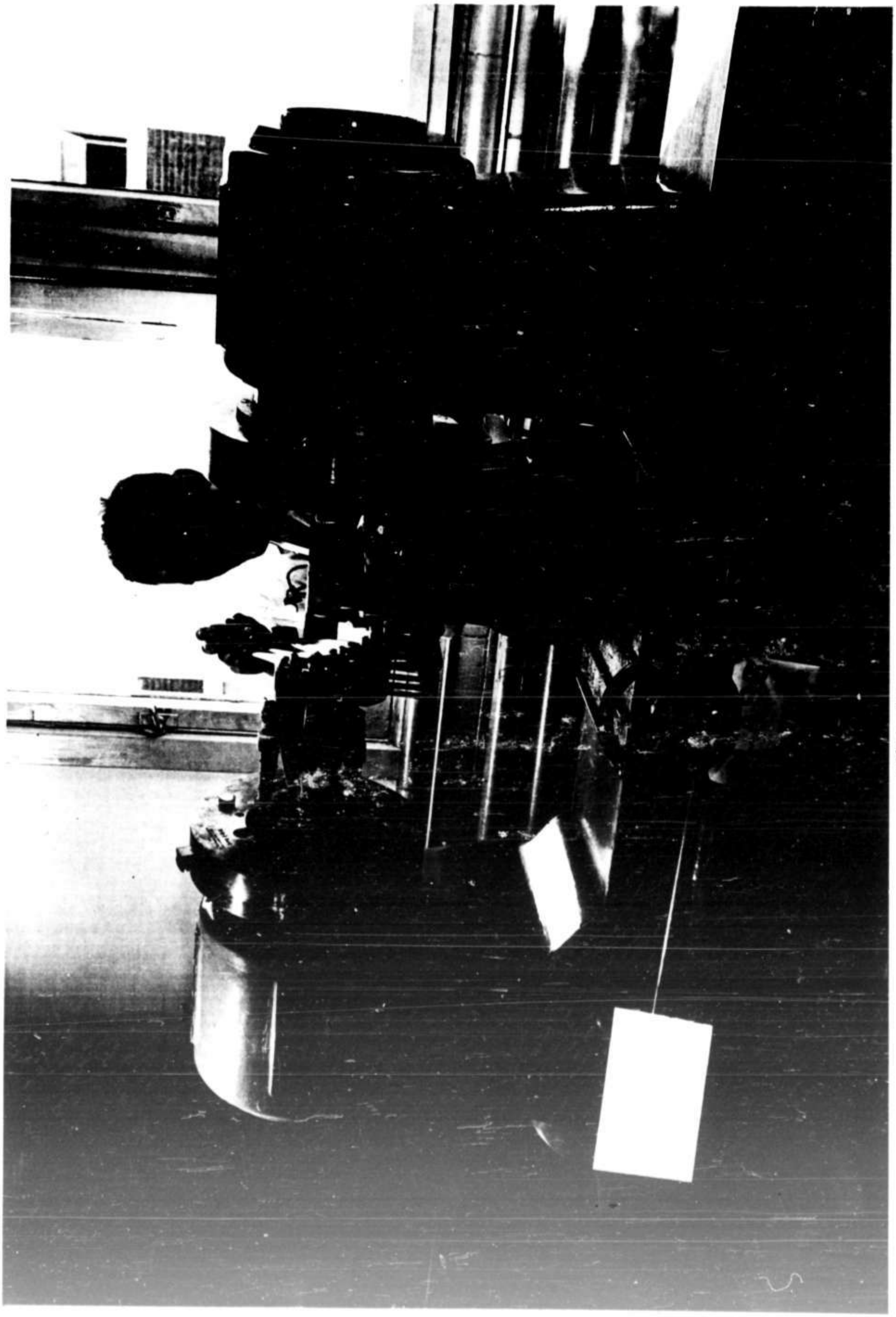


FIG. 11

USED IN M130 & M102

A-31328

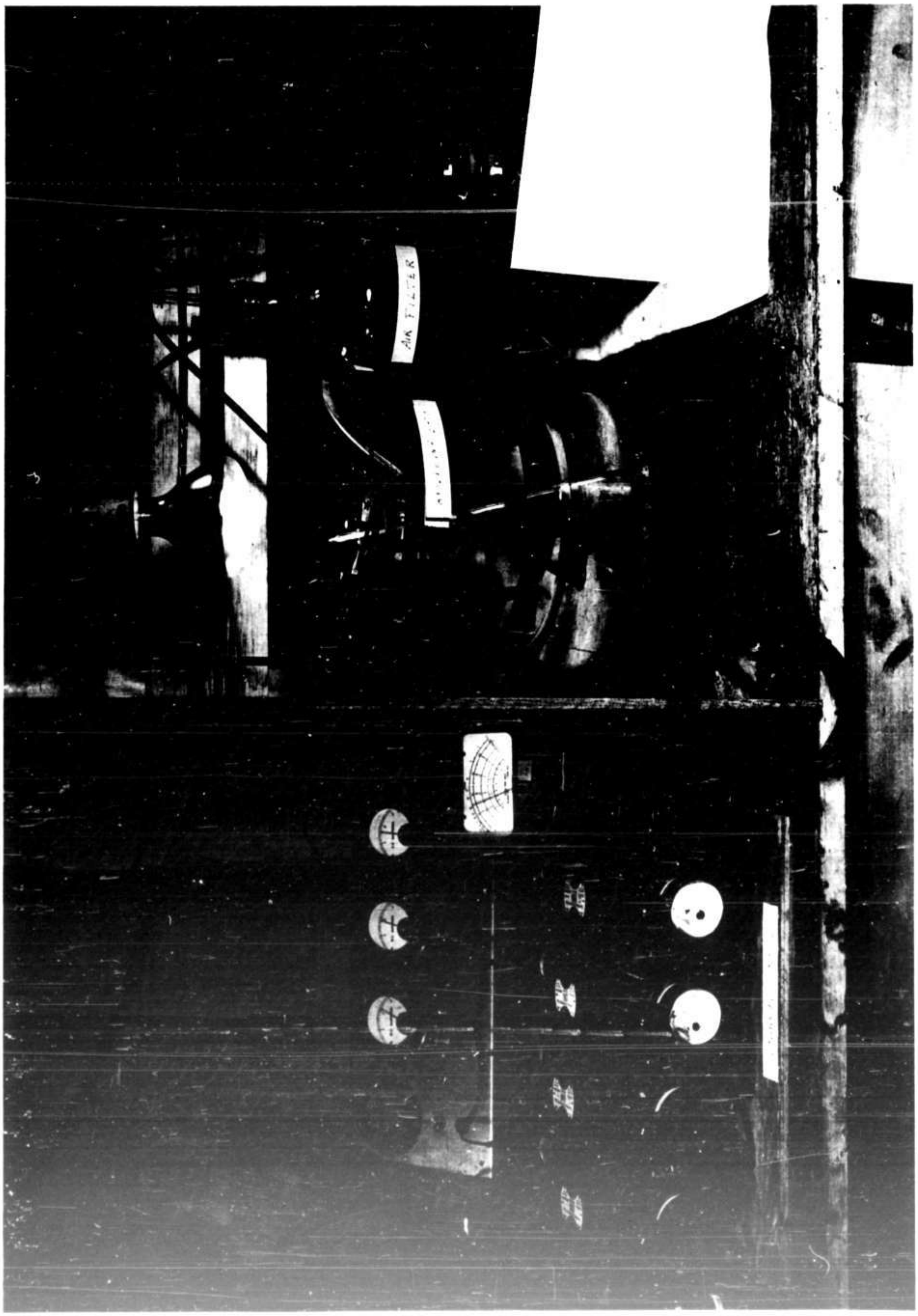


FIG. 12

A-31329 USED IN M130 & M102

FIG. 13

ED IN M 130 & M 102

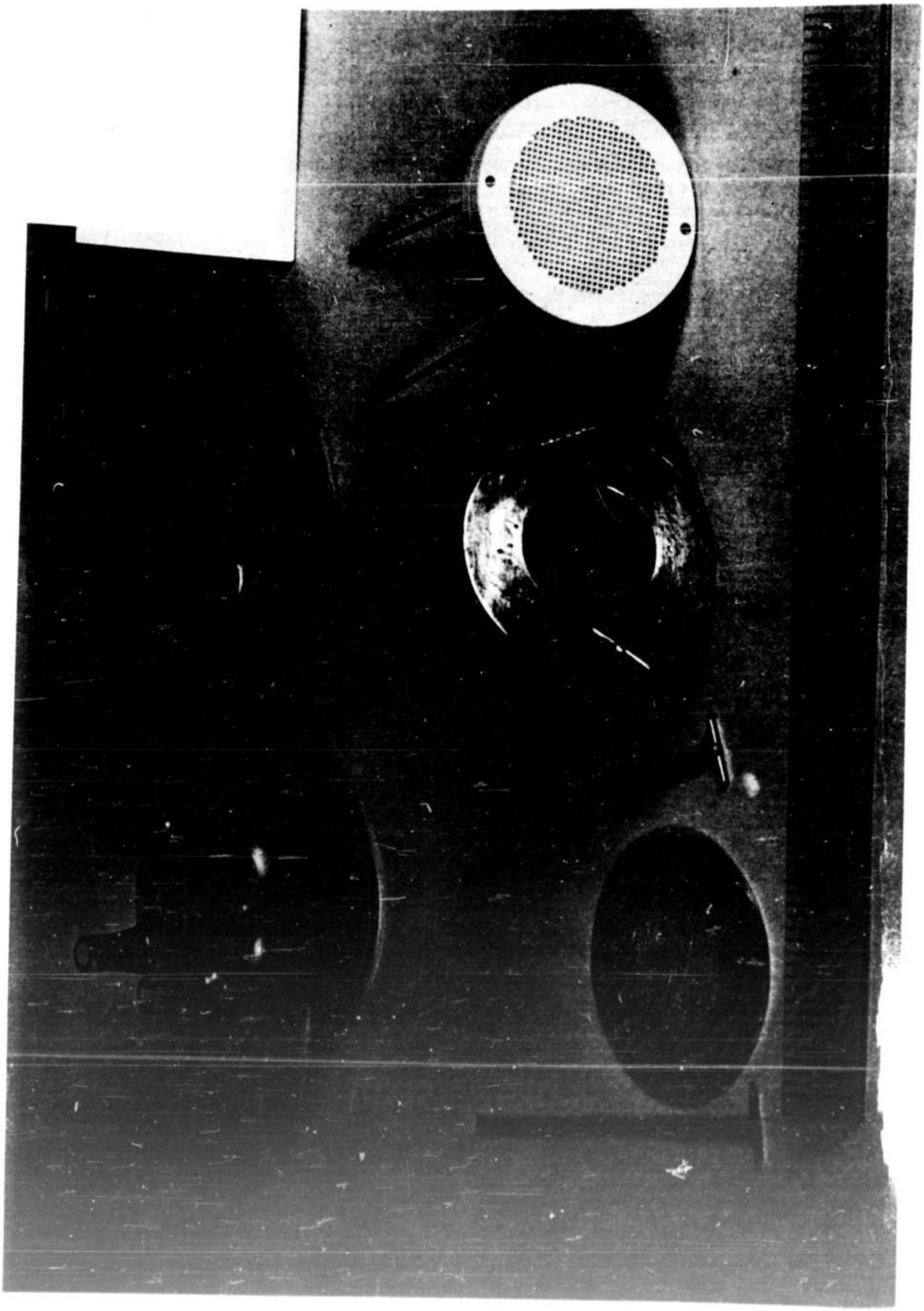


FIG.14

51332 USED IN M 130 & M 102

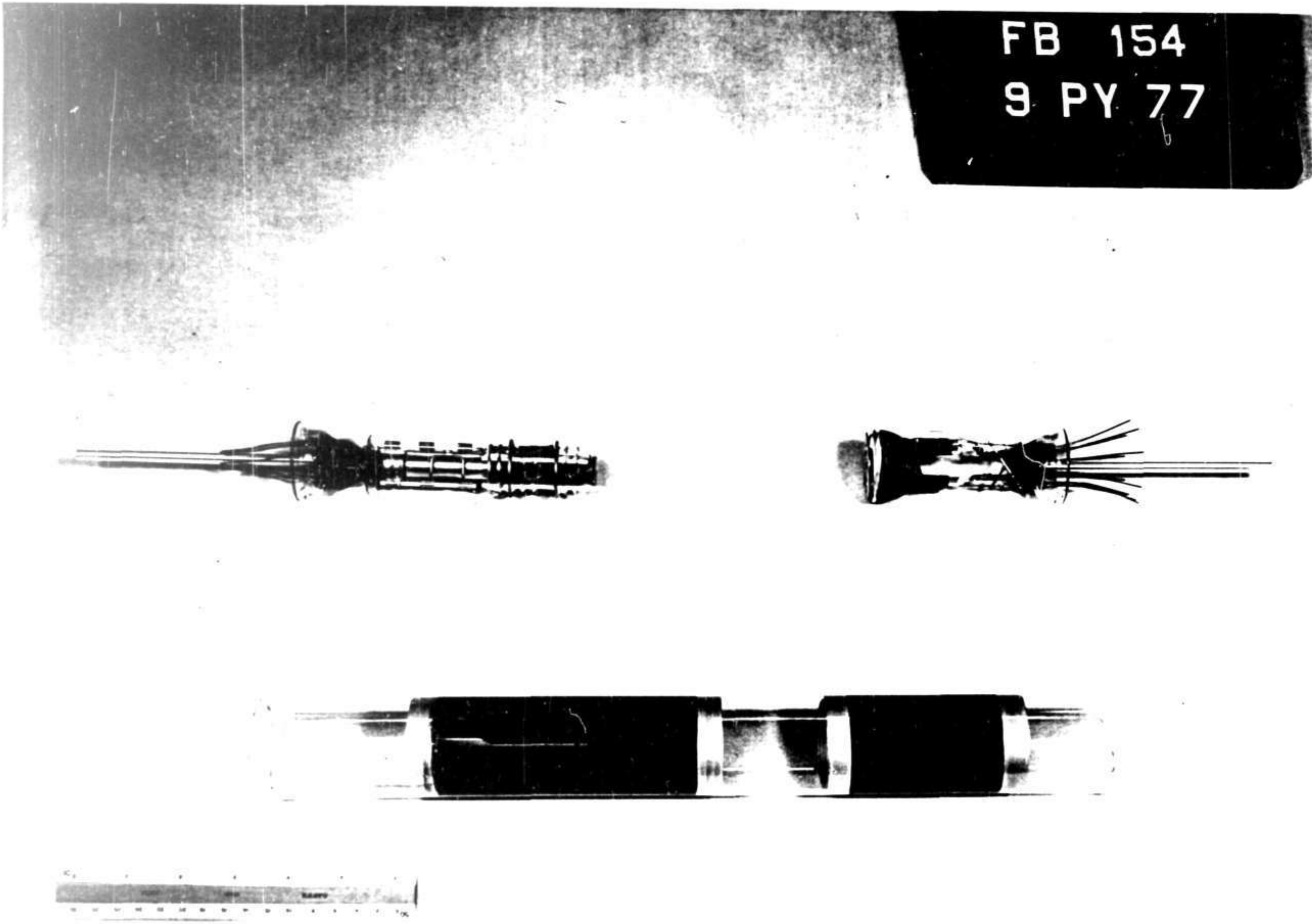


FIG. 15

A-31333 USED IN M 130 & M 102

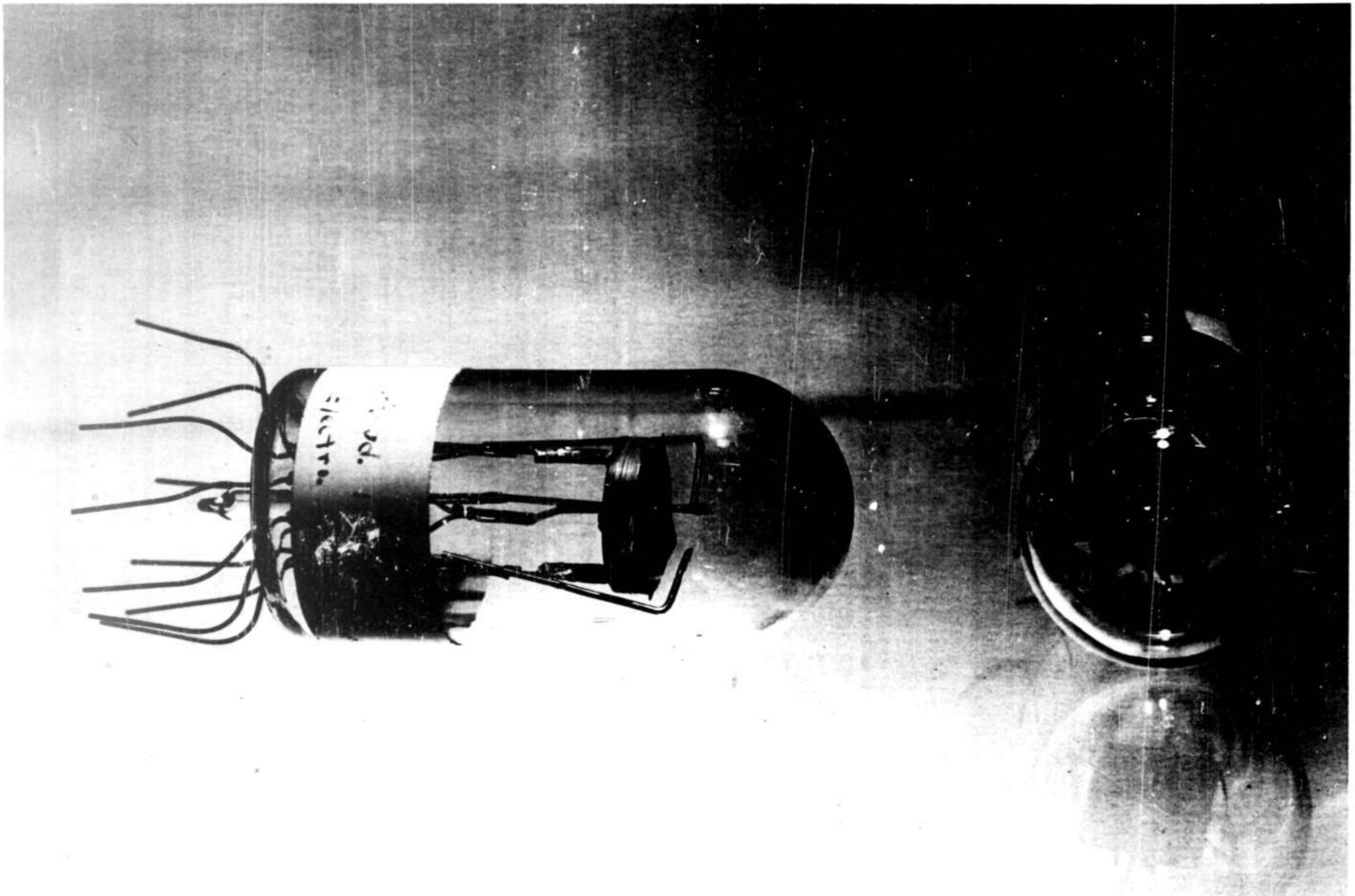


FIG. 16

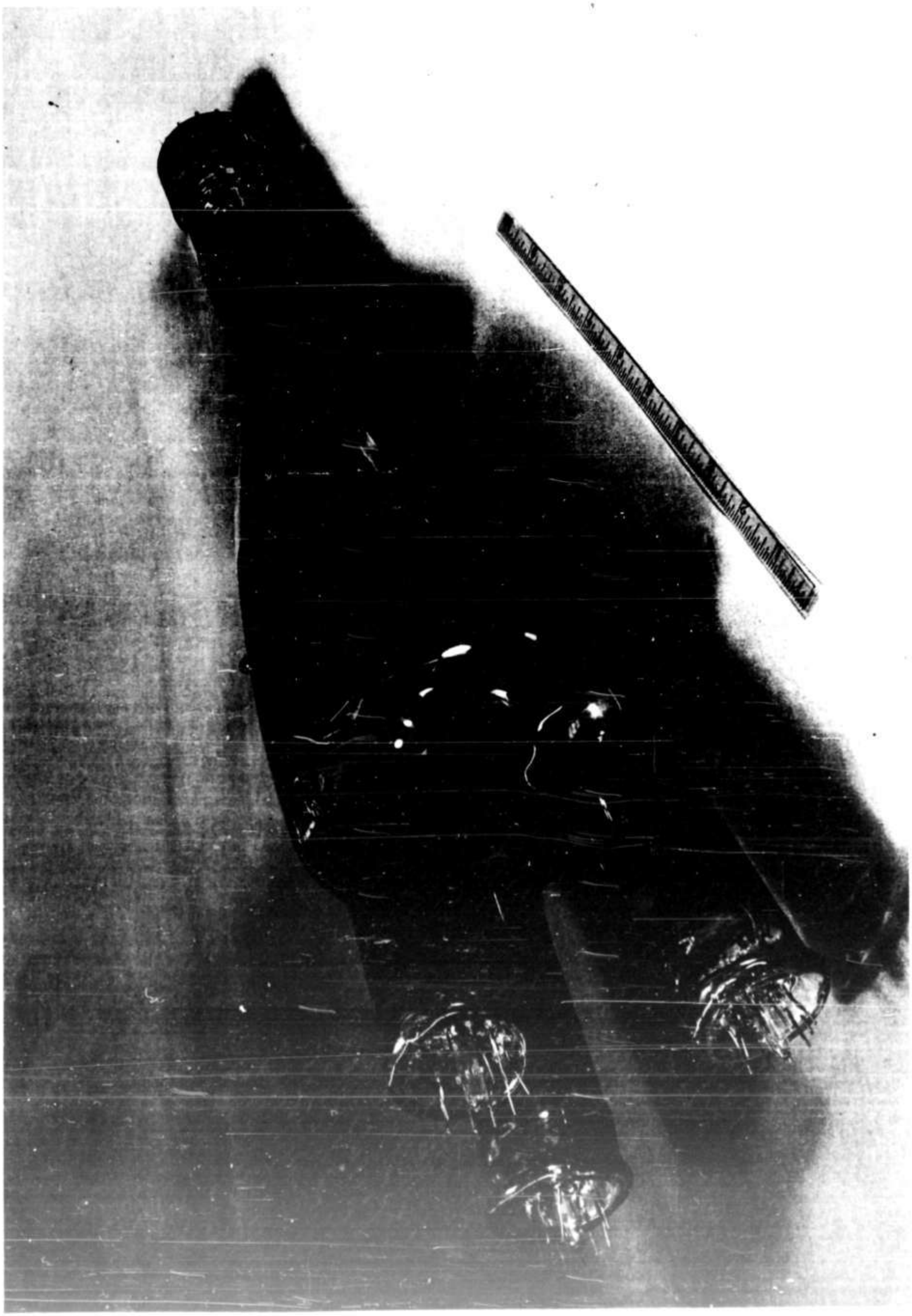


FIG. 17

USED IN M130 & M102

A-31334

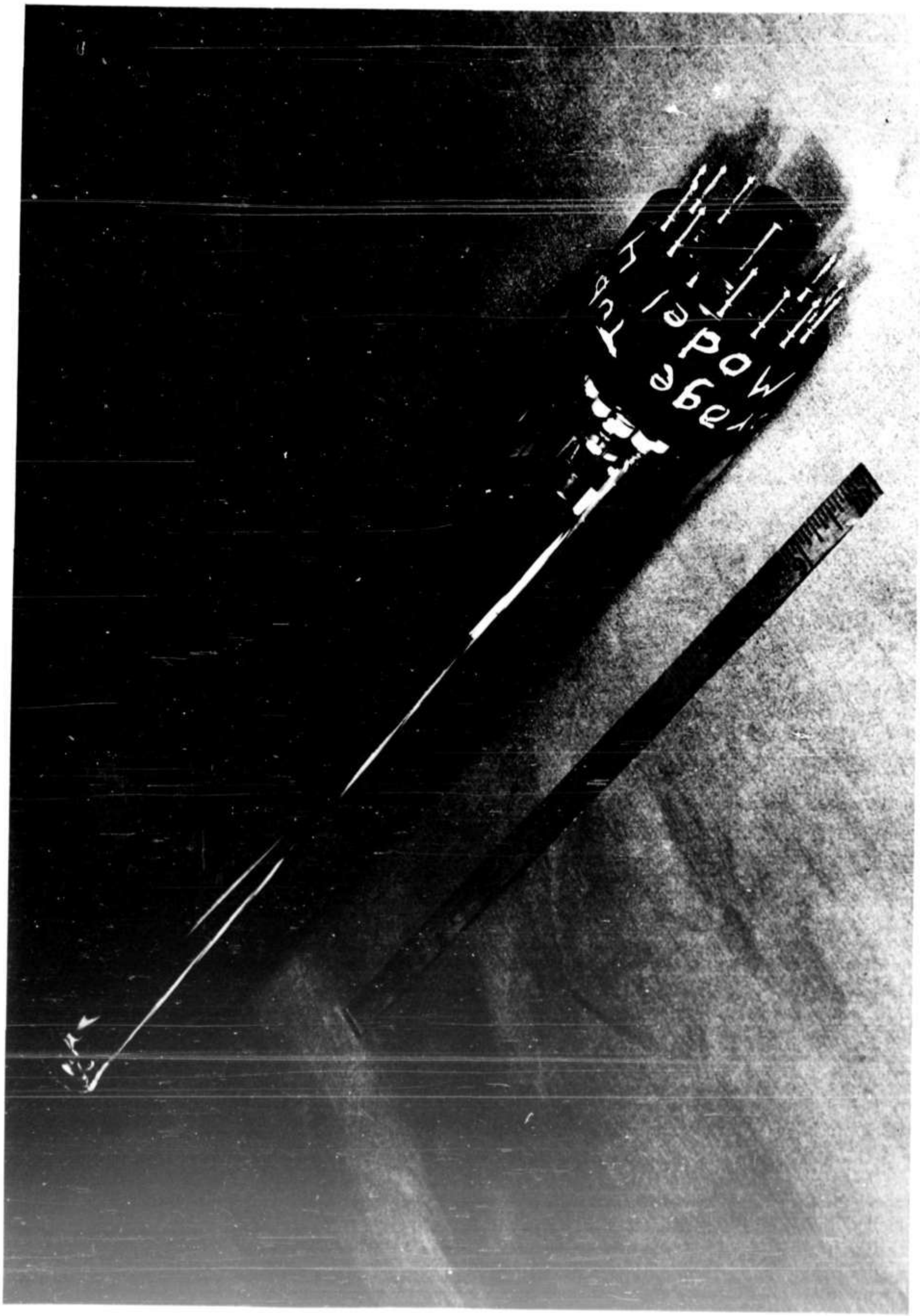


FIG.18

USED IN M130 & M102

A-30893 USED IN G3's MEMO M-102

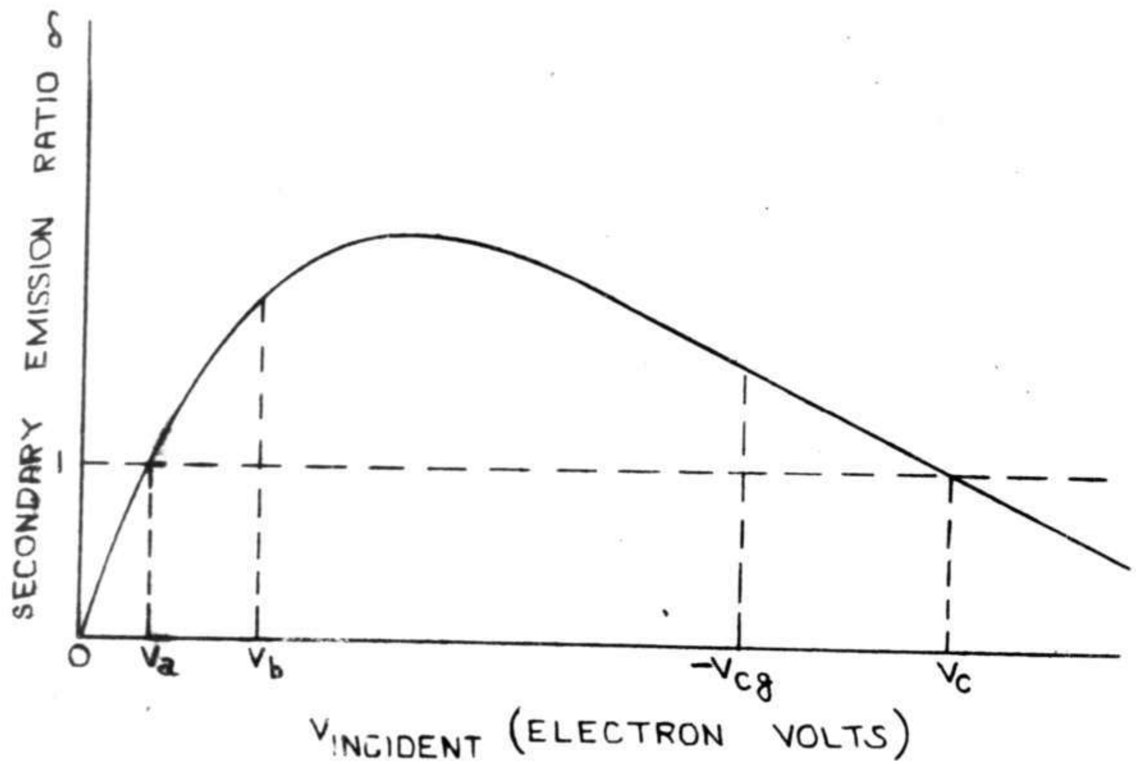


FIG. 19 SECONDARY EMISSION RATIO AS A FUNCTION OF THE ENERGY OF INCIDENT PRIMARY ELECTRONS.

A-30890 USED IN 6345 MEMO M-102

COMPARISON OF AVAILABLE DATA ON NRL TUBE WITH M.I.T. RESULTS AND REQUIREMENTS

CHARACTERISTIC	FINAL WHIRLWIND STORAGE TUBE	PRESENT M.I.T. RESEARCH RESULTS	PRESENTLY AVAILABLE NRL RESEARCH RESULTS
1. PARALLEL DIGIT STORAGE	YES	YES	NOT YET TRIED
2. SIGNAL LEVEL a. VOLTAGE DIVISION b. CURRENT METHOD	 0.100 VOLTS MIN. .050 VOLTS MIN.	 0.200 VOLTS 0.100 VOLTS	 NONE .001 VOLTS
3. WRITING SPEED	1 TO 2 MICRO SEC.	50 MICRO SEC.	NO DATA
4. READING SPEED	1 TO 2 MICRO SEC.	1 TO 2 MICRO SEC.	NO DATA
5. STORAGE TIME	PERMANENT	PERMANENT	VARIABLE
6. RELIABILITY	EXCELLENT	GOOD	DOUBTFUL
7. CHECKING SIGNAL	YES	NOT TRIED	PROBABLY NOT
8. RESOLUTION, DIGITS PER INCH FOR COMPUTER USE	10	5	NO DATA
9. STORAGE CAPACITY	1024 DIGITS	16 (SMALL TARGET)	NO DATA
10. BOTH + & - SIGNALS	YES	YES	NO
11. PICTORIAL DEFINITION	PERHAPS	NO	POSSIBLE
12. MUST GUN POTENTIAL BE SWITCHED.	NO	NO	YES

FIG. 20

B 30891 USED IN 6345 MEMO M-102

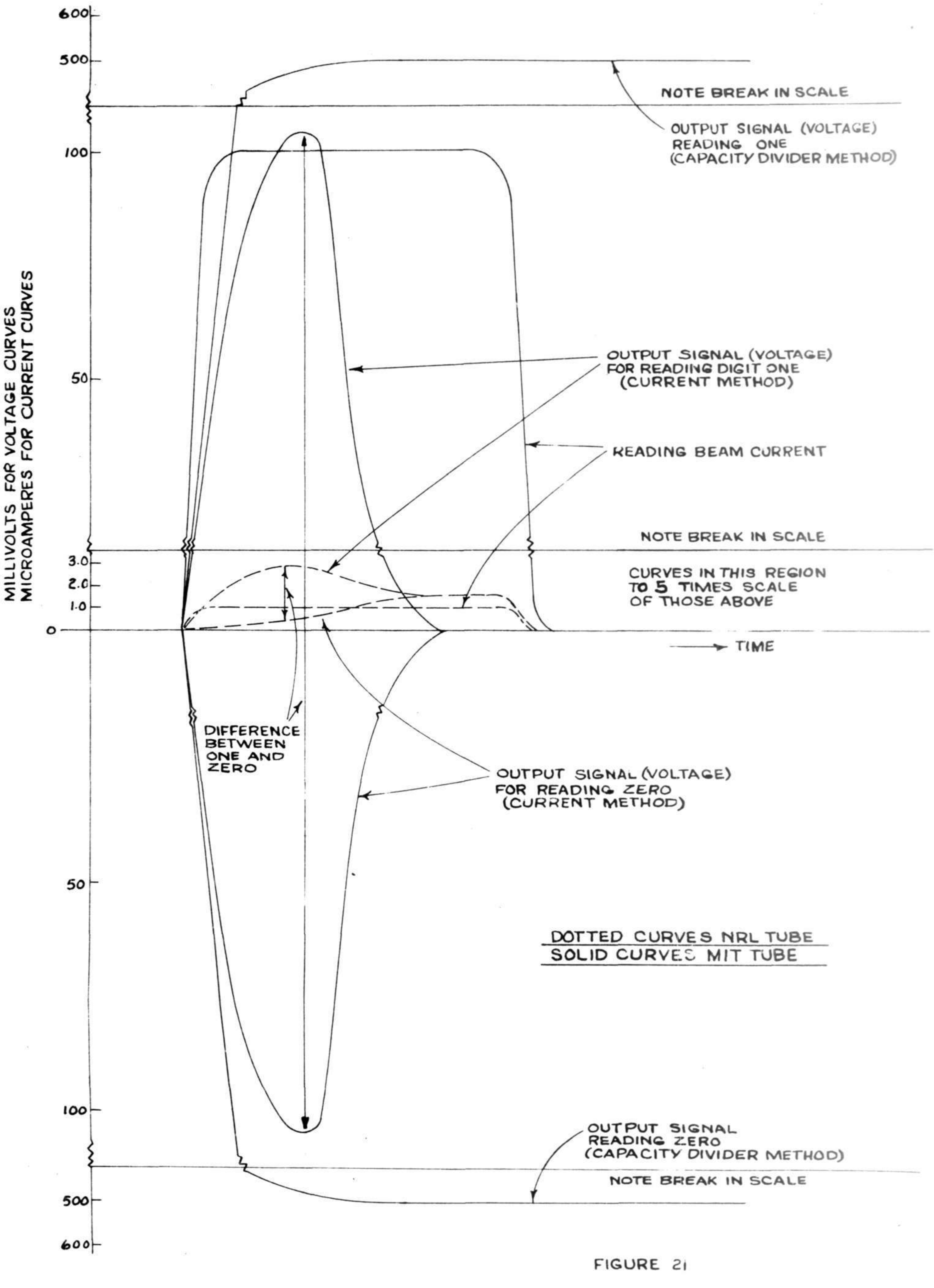


FIGURE 21