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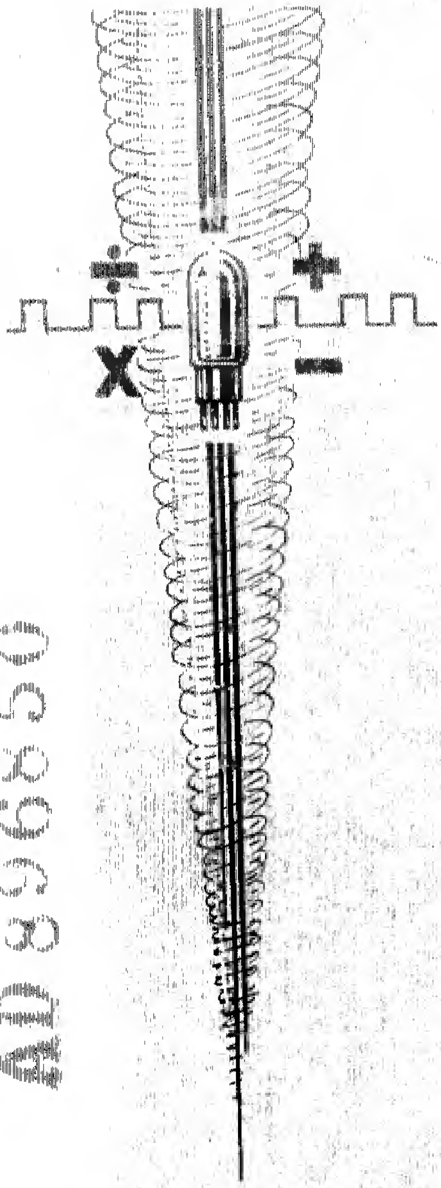

AD 896850

PROJECT
WHIRLWIND

Contract N5ori60

SUMMARY REPORT NO. 2

VOLUME 9

STORAGE TUBES
(PART I)

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Volume 9 o: 22 Volumes

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Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

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INTRODUCTION

Electrostatic storage tubes have been selected for the high-speed internal memory of the Whirlwind computers. The tubes are of the deflection type where a cathode ray beam writes on a dielectric surface. Both plus and minus signals are read out of the tubes representing the digit 0 and 1. Signals are stored permanently and are maintained by a holding gun.

The present tube status now lies between the research and the development phases. Large output signals of about 0.1 volts for a reading time of 3 microseconds has been obtained. Signal-to-noise ratio in most cases is excellent. The spacing between stored charges is good but should be reduced somewhat. Changes in gun current, the dielectric thickness, and the secondary emitting material should be made to reduce the writing time from the present 20 to 60 microseconds. Better independence of control on stored charges is desirable and techniques seem available for achieving independent control.

One tube has recently been tested which would store 12 data points in a three-quarter inch diameter circle. Tests on tube life and the life of secondary emitting surfaces are under way, but results have not yet been obtained.

Volume 9, M-159, summarizes the storage tube program to date. Memorandum M-130 discusses some results obtained on one of the first complete storage tubes. Better operation has been obtained with more recent models.

In R-110 is the storage tube presentation to the Harvard Computation Symposium in January 1947. The objectives outlined there still seem reasonable. The use of low energy electrons from a holding gun was discussed and this feature has been tested in trial tubes.

Volume 9, M-130, shows the division of staff time in the storage tube work. Test equipment is included in Volume 19. Much time has been devoted to vacuum tube techniques, some of which are discussed in Volume 9, M-159, M-112, and M-46. Some studies with an electrolytic plotting tank are reported in Volume 9, M-56 and R-130.

The study of aluminum oxide as a dielectric and preparation of satisfactory surfaces is discussed in the work by Macdonald, Volume 10, R-131 and R-128.

Deflection circuits for electrostatic tubes have been proven feasible. Deflection circuits and power amplifiers are reported in Volume 10, E-32, E-31, and R-120.

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Memorandum M - 159

Project Whirlwind
Servomechanisms Laboratory
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SUBJECT: STORAGE TUBE SUMMARY

To: Jay W. Forrester, H. Fahnestock, R. Everett, H. Boyd, Storage Tube Group

From: Stephen Dodd, William Nolan, Patrick Youtz

Date: November 10, 1947

The following sections of this memorandum trace the course of the project work on high-speed high-capacity internal storage through the following phases:

(1) Initial survey and new ideas.
(2) Serial digit-transmission storage tubes.
(3) Parallel digit-transmission storage tubes.
(4) Test equipment.
(5) Tube construction technique and high vacuum investigations.

What are they

I. INITIAL SURVEY:

As discussed elsewhere, the more common forms of internal storage were discarded as not meeting Project Whirlwind requirements. Vacuum tube flip-flops are impossible because of size and cost. Mercury delay lines and magnetic drums would require waiting time and would be too slow.

Supersonic mercury delay-line storage is now being used by some computer projects. The delay line consists of a column of mercury with crystal transducers at either end. One crystal receives an electrical pulse and transmits a supersonic pulse which travels the length of the mercury column. The second crystal picks up this pulse and reconverts it to an electrical pulse. This pulse is then reshaped and reinserted into the first crystal, thus allowing a stored pulse to circulate until it is necessary for the computer to use it. Since one must wait until the pulse comes to the end of mercury delay line before the stored pulse can be used, this results in a large amount of lost time. This lost time can, to a certain extent, be avoided by using long and short delay lines, and programming the insertion of the stored number so that it will be available at the correct time. An obvious disadvantage of this method is the complicated program and the extra switching required. With mercury delay lines there is a very rigid requirement on cleanliness, since any dirt collecting between the mercury and the crystal destroys the impedance match at this point. Also, the lines must be temperature controlled within close limits.

A matrix of photo-tubes was investigated as a conversion device in a data or program storage system. The numbers were represented by a matrix array of transparent and opaque areas on a lantern slide or film which could be projected by an optical system on an image plane. Photo-tubes were placed in a rectangular array with their cathodes lying in this image plane. Presence of light on a particular photo-tube would produce a current which could be detected, giving a video signal corresponding to the presence of a binary digit at a particular place on the data slide. The use of various commercial photo-tubes was investigated and it was found that the response of these circuits was satisfactory. Pulsed light sources to give short high-intensity pulses of light were also investigated as projection lights for these photo-tube matrices.

Another method of supplying input data to a high speed digital computer is to place a perforated opaque card across the face of a cathode ray tube provided with a suitable linear scanning circuit, so that as the beam sweeps over a row of holes in the card, the resulting light pulses may be picked up by a photo-tube and converted into a train of electrical pulses with the same distribution in time as the distribution on a line of the original perforation. Such a device has been termed a "scope reader" and was investigated to ascertain some of its capabilities and limitations. An investigation was also made to determine the desirability of using an iconoscope as a data conversion unit in place of the photo-tube matrix discussed above. The results of this investigation are given in the master's thesis written by M. Essigman entitled "Photosensitive Devices as Data Converters for Electronic Digital Computers".

At the time that different storage methods were being considered, RCA was developing an electrostatic storage tube for the Evans Signal Laboratory. This tube was based upon the orthicon-tube type of operation with magnetic deflection and focus. The storage surface was limited to a one-inch screen size, although the development could be extended to utilize a three-inch tube. The RCA storage tubes differed in characteristics rather widely from one tube to another, and required at least five sweeps of the electron beam to establish a steady-state storage condition. At the time considered, the tube was in an early development stage and not satisfactory for use in our computer.

II. SERIAL STORAGE

After reviewing the whole field, it was apparent that there were no suitable storage methods available commercially or under development, so it seemed necessary for us to develop our own storage system. The first digital computer considered by Project Whirlwind was of the serial digit transmission type.

The computer storage requirement was somewhat similar to the storage problems encountered in radar MTI work. The Radiation Laboratory had worked with an electrostatic storage tube, which while not adequate for our requirement, showed promise. For a time it looked as though an engineering extension of the Radiation Laboratory storage tube would solve the storage problem of a serial computer. The Radiation Laboratory storage for MTI work used the surface of the screen of a normal five-inch cathode ray tube. The outside of the tube face was covered with a half-silvered signal-plate so that although the spots that were charged were visible from outside the tube, the tube surface was covered with a conducting layer. A sweep voltage was applied to the horizontal deflection plates and the beam of the cathode ray tube intensity modulated as it swept across the screen to store a charge pattern on the line. A low current of constant intensity could then be swept across the line and the different charges established by the writing beam would be discharged. By capacitive coupling to the external signal plate, the output of the tube was read. By making the reading beam of very low intensity, it was possible to read the stored data several times before erasure. This type of storage inherently requires serial-type data transmission. Personnel who had worked on storage tubes at the Radiation Laboratory felt that it would only be necessary to develop refinements in circuits and test equipment used with this tube to obtain the results required by the computer application. Therefore, this project embarked on a program of developing adequate test equipment and circuits to investigate the tube. The results of these tests were unsatisfactory. Storage as had been demonstrated in Radiation Laboratory tests was observed. However, the stored signals were comparable to the noise level and storage phenomena appeared to depend only on second-order effects within the tube.

III. STORAGE FOR A COMPUTER USING PARALLEL DIGIT TRANSMISSION

On the basis of block diagram studies made during the period when equipment was being developed for testing the serial-type data storage, it became increasingly desirable from a speed and programming point of view to use parallel digit transmission for the WWI and WW2 computers. In the parallel system it is desirable to store only a single digit of any given number on each tube. Storage would depend upon control of the secondary emission from a surface bombarded by an electron stream and not upon the second order effects used as a storage phenomena in the serial tube previously described.

A new storage tube program was organized in October, 1946 to select a satisfactory operating principle for the tube and to develop this into an operating system. The selected plans contemplated storage on a dielectric surface in front of which was a perforated grid and behind which was a signal plate. Operation would consist of raising or lowering the signal plate voltage, after which the electron beam would be pulsed to bring the potential of a particular spot on the dielectric to the front grid potential. The signal plate could then be returned to its neutral position and the stored signal read capacitively from the charge when it is equalized by a second application of the electron beam. See R-110 and M-130 for a more complete description of the operating principle selected for use.

This program required the design, construction, and testing of experimental storage tubes. Much of the test equipment which was developed for use with the serial type storage tube was adequate for use with this tube. One of the first major problems in this program was the procurement of tube construction facilities. After investigation of the tube construction field it was decided that construction by sub-contract with a commercial firm would be unsatisfactory because this would require long waiting periods and construction methods not under our control. Project Whirlwind, therefore, set out to build its own tubes, using tube construction facilities available at M.I.T.

In the first steps of the program several tubes were constructed to study the basic storage phenomena. Test equipment was improved and the most important and difficult of the problems to be solved were identified. These tubes are discussed in the following sections.

Mod 1 Tube

An isometric drawing of the Mod 1 tube is shown in Drawing B-30311. The construction of the tube is similar to that of a 5CP1 cathode-ray tube. At the large end of the tube, two storage assemblies and a "beam catcher" were located in separate glass necks sealed into the face of the tube. Construction of the storage assemblies are shown in Drawing B-30310. The construction of some parts of the tube are also shown schematically in Drawings A-31014, A-30358 and A-39147.

Two types of storage assemblies were used in this tube, one in which the signal plate was a nickel plate pressed against the back of the mica dielectric, and the other having a signal plate consisting of platinum paint applied to the back of the mica dielectric. The dielectric was a mica sheet approximately 0.0038 inches thick. The screen was 15 mil nickel sheet perforated with thirteen 1/16-inch diameter holes spaced 3/16-inch apart. The front surface of this screen was coated with willemite to permit focus and positioning of the beam.

The beam current of this tube, when measured under static conditions, was found to be much lower than was expected. When operated with a low duty cycle, the beam current curve appeared normal. This was believed to be due to cathode poisoning, a belief which was strengthened by evidence of gas in the tube. Current measurements on the tube are shown in Drawings A-38304 and A-38303.

The tube was set up for storing and reading of microsecond pulses. A block diagram of the test equipment is shown in Drawing B-39132. Using writing gates of 50 volt amplitude it was possible to store and read one-microsecond pulses, the polarity depending on the polarity of the writing gate used. Storage for times up to 10 minutes was found possible without appreciable decrease of output signal.

It was observed that repeated storing and reading at one spot on the dielectric would erase signals stored at adjacent points. Attempts to determine the magnitude and causes of this effect by operation of the tube with screen potentials such as would tend to prevent the scattering of secondary electrons were not entirely successful. Repeated writing at one point with one microsecond pulses was used during these tests. The beam was then deflected to an adjacent spot and the charge measured by repeated reading.

Further tests with short pulses were then dropped and attempts were made to charge the surface with a single long pulse. It was also decided to switch the signal plate instead of the screen since switching the screen affected the deflection fields within the tube and required readjustment of the deflection voltages. With the signal plate set at one potential, 2500 microsecond pulses of beam current were repeatedly applied to the dielectric until no output signal could be observed. The signal plate potential was then changed by 50 volts, (either positive or negative) and the charging current to the dielectric surface measured.

The charging currents observed (shown in Drawings A-31102 to A-31113) were of such magnitude and duration as would be necessary to charge the entire storage surface. The charging in a negative direction was much faster, corresponding initially to collection of the entire beam current by the surface. This charging was complete in approximately 500 microseconds. Charging in a positive direction was relatively slow, requiring several pulses for completion. The initial charging current was only about 15% of the beam current. Charging in this direction represents a loss of electrons by the surface, which could probably take place only by emission of secondary electrons. It was believed that scattering of electrons having sufficiently high velocity to release secondaries accounted for this. Such electrons might originate from the point of impact of the beam on the dielectric or from the edges of the holes in the screen.

These tests indicated that any signal stored on the dielectric would be erased by scattered electrons after a few hundred operations. To determine the effect of greater mechanical spacing, a similar set of tests were performed by stabilizing on one storage assembly, writing on the other, and then returning to the first. Although this increased spacing decreased the rate of charging, the effect was still present. The problem of storage with this type of storage assembly is complicated by the fact that scattering of a very small fraction of the beam current will effect erasure of stored signals.

Mod 2 Tube

The envelope for the Mod 2 tube was nonex tubing with an outside diameter of two inches and a wall thickness of 1/16 inch. The tube was thirteen inches long. A cylindrical envelope was selected because it is the simplest type of envelope which lends itself to tube construction. Nonex was used because tungsten-glass seals could be made. A 5CP electron gun was assembled for this tube. The storage assembly consisted of a perforated nickel-sheet grid with thirteen storage holes of 1/16" diameter. The dielectric was Ruby African mica approximately .003" thick. The signal plate was an evaporated gold plating with a single terminal consisting of a nickel rectangle riveted to the mica, with gold washers to make contact with the gold plating. This storage structure is quite similar to the storage structure used in Mod 1 and shown on drawing B-30310. The electron gun and the grid structure were mounted on 10-pin nonex presses. The wall coating for the second and third anode was Doxana graphite suspension and sodium silicate (7% by weight). Water was added to give the proper consistency. A 5CP1 base and connections were used for the electron gun so that it would fit into the test equipment. The base was fastened to the glass with picene cement. Two connections were made through the storage structure press to the third anode coating by means of tungsten cantilevers.

The performance of the electron gun in this tube was identical with that of a regular 5CP1 cathode ray tube, thus showing that the cylindrical type of envelope could be used with this gun. The guns were not entirely satisfactory, however, because the intensity and focus of the 5 CP gun are interdependent. They were, however, the only guns immediately available. Tests on the tube indicated that there was no electrical connections between the signal plate and its lead. There was no indication in the tests that any signal plate was present in the tube. This restricted observations of the storage phenomena to the spot closest to the signal plate lead. No appreciable stored signal was observed in any other spot. The evaporated gold signal plate had evidently been destroyed during the baking-out of the tube. Storage at the single spot available indicated a time constant of decay of the stored signal of approximately two seconds.

Mod 3 Tube.

This tube was constructed in a standard 5-inch cathode ray tube envelope with three necks added on the screen end of the tube to hold three separate storage assemblies. These storage assemblies were each different, but were put in the same envelope for comparison purposes. One storage structure was the same as those used in Mod 1 and was used to check the Mod 1 tube operation and construction. A second storage assembly was the same as this one except that mica barriers were added between the nickel screen and the mica dielectric to provide isolation between the different storage spots. This type of storage assembly is shown schematically in Drawing A-31015. The third storage assembly was constructed with a wire mesh screen instead of the nickel plate. This screen was made of 40-mesh nickel wire and was assembled against the .004 inch thick mica dielectric. A silver coating was used for the signal plate.

Preliminary tests on the Mod 3 tube indicated that the spot focus was very poor and that quantitative storage tests were impossible, since the amount of beam current that entered the hole and the time distribution of charge entering the hole during a beam current pulse were unknown. Even qualitative tests were hard to interpret, so it was decided that some change in the tube would be necessary. The gun in the Mod 3 tube was changed from a 5CP to a 5 UP and the new tube labelled Mod 3A.

Mod 3A Tube

Tests on this tube indicated that there was no connection between the third-anode pin and the aquadag coating. The tube was therefore not usable and further tests were discontinued.

Mod 4 Tube

A Mod 4 tube was constructed as a replacement for the Mod 2 tube and was similar in all respects except that the signal plate was made from silver paint applied to the back of the mica dielectric. This tube was tested, and found to duplicate the characteristics observed in Mod 1.

Mod 5 Tube

The design of previous tubes had the undesirable feature of allowing stray electrons to flow to the unshielded signal plate, causing either positive or negative signals depending on the secondary escape ratio at the signal plate. This unwanted signal was often larger than the desired signal. The Mod 5 tube was designed to shield the signal plate from these stray electrons. The charging current to the mica dielectric surface and the mica resistivity measurement made on this tube were facilitated by this special design. The storage assembly consisted of a number of concentric cylindrical anodes, insulated from each other by mica barriers. An assembly of the electrodes is shown in Drawing B-39266. This storage structure was assembled with a 5CP electron gun in a 2-inch diameter cylindrical envelope. The tests on the Mod 5 tube showed the feasibility of measuring leakage resistance through the mica dielectric and the mica secondary emission ratio. The results of these tests showed a resistivity of about 10^{15} ohm-centimeters and a maximum secondary emission ratio of about 1.8 at 300 volts accelerating potential.

How measured

Mod 6 Tube

This tube was constructed as a replacement for the Mod 3 tube. The three storage assemblies were of the same construction except for the assembly with the mica barriers between holes. In this assembly the mica barrier was replaced by a pyrex barrier. Tests on this tube indicated that the operation of the storage assembly of the type used in Mods 1, 2, and 4 showed little deviation from the operation of those tubes. The storage assembly with the pyrex varriers indicated an isolation between spots which was better than that of Mod 1 by a factor of approximately two. The storage assembly with the wire mesh screen showed characteristics intermediate between these two surfaces as far as isolation of spots was concerned.

The operation of tubes Mod 1 through 6 indicated that the main difficulty in the use of such tubes for practical storage lies in the fact that repeated operations of reading and writing at one point would eventually discharge or erase signals at surrounding points.

COMPLETE STORAGE TUBES:

Tests on the previous tubes had provided sufficient information to justify constructing a complete tube with holding gun supplying low energy electrons as mentioned in R-110. This principle is the same as used in certain German storage tubes and in the RCA Selectron. The use of an auxiliary gun, acting as a holding gun, to supply these low velocity electrons, was therefore decided upon. The principle of operation of the holding gun is described on page 2 of Memorandum M-130. In addition to a holding gun, isolation of stored charges from secondary redistribution was desired.

Mod 7 and Mod 9 Tubes

The use of the holding gun principle required storage surfaces with much more closely controlled secondary emission characteristics than existed in previous tubes. Mod 7 and 9 tubes were constructed not as storage tubes but to measure the secondary emission ratios and leakage resistance characteristics of aluminum oxide and beryllium, respectively. It should be realized that the aluminum oxide and beryllium are not pure but are contaminated by air and other materials. The signal plate and storage dielectric on Mod 7 and Mod 9 consists of an aluminum plate 1 3/8 inches in diameter and 1/4 inch thick, half-hard, 2S aluminum, and anodized using the techniques described in Report R-128. Drawing A-39367 shows the construction of the signal plate for Mod 12 which is a tube with a storage assembly similar to those of Mods 7 and 9. Drawing A-31197 is the Mod 12 storage assembly which is substantially the same as that used for Mod 7 and Mod 9.

Measurements of the secondary emission ratio from Mod 7 gave a maximum of 2.1 at approximately 350 volts accelerating potential. This ratio decreased to approximately 1.3 at 2,000 volts. The first crossover potential was approximately 90 volts. There was reason to suspect that this surface might be badly contaminated with willemite phosphor so that the secondary emission curve just quoted would not apply to pure aluminum oxide. The secondary emission curve for the beryllium surface in Mod 9 had a maximum of 2.3 at approximately 350 volts and a secondary emission ratio of 1.5 at 2,000 volts. The first crossover of this curve was at about 55 volts. These curves were not entirely reproducible and experiments are still being conducted to determine a method of obtaining curves which can be reproduced from day to day so that life tests can be undertaken. On the basis of an observed time constant of decay of a charge stored on the dielectric of both Mod 7 and Mod 9, and on the basis of the method of anodization of the dielectric, it was computed that the volume resistivity of the aluminum oxide was approximately $3X10^{12}$ ohm-centimeters. This resistance is rather low but as yet the tests are not general enough to draw definite conclusions.

Mod 8 Tube

The Mod 8 storage tube had both a high velocity gun and a holding gun and two storage assemblies, one storage surface being plain aluminum oxide while the second was aluminum oxide coated with willemite. Drawing A-31196 for the Mod 11 storage assembly shows how both of the Mod 8 storage assemblies were constructed.

After being sealed off, this tube developed gas and could not be tested. New presses and electron guns were sealed into the tube and a second attempt made to pump it. This new tube, designated Mod 8A also developed gas and could not be tested. The envelopes used for these tubes had a much greater area than any of the previous tubes and also a large number of lead seals. Both these factors increase the possibility of pinholes permitting air to leak in. Lack of pre-baking of the coated envelope may also have contributed to the difficulty.

All the early tubes in this storage tube series had mica dielectric surfaces. These were satisfactory from a dielectric standpoint but were not effective in isolating the secondary electrons that were liberated at each of the storage points from erasing adjacent points. The results of tests on Mod 6 indicated that an improvement was possible by the use of mechanical barriers. A storage surface having a fine grain structure so that it was essentially continuous as far as the beam diameter was concerned but which had this mechanical barrier feature was desired. To produce such a surface, aluminum was embossed with an embossing die so that the surface had a large number of small recessed pockets separated by thin dividing walls. Such a griddle surface was then anodized to form an aluminum oxide surface. Much experimenting was done to obtain a method of anodizing which would yield good film thickness, resistivity, dielectric constant, and breakdown strength.

Mod 10 Tube

The Mod 10 tube was a replacement for Mod 8. It had two electron guns and one storage assembly, using a griddle-type aluminum oxide surface with a coating of willemite. Tests on this tube indicated that the holding gun operation was satisfactory. Initially, the reliability was excellent.

Reading and writing at one point had no effect on signals stored at adjacent points, provided writing was not done at such a high repetition rate as to overcome the holding beam action. The combination of willemite and aluminum oxide had a high first crossover potential, thus requiring switching pulses of about 450 volts for writing. The resolution in this tube was approximately 5 spots per inch. The wire mesh screen in Mod 10 was probably in contact with the tops of the ridges of the griddle-type dielectric surface. From the way in which the holding beam illuminated this surface and from the storage characteristics at certain points on the surface it appeared desirable to move the screen a short distance away from the storage surface.

Mod 11A Tube

Storage tube 11A, was the same as the Mod 10 storage tube except that the screen was moved about 15 mils from the tops of the ridges of the griddle surface, and the second anodes of the two guns were not connected. The tests which were made on this tube indicated the following:

1. The operation of the second anodes of the two guns at widely differing potentials was not satisfactory.

2. The operation of the tube was very sensitive to variations of holding beam velocity and current density.

3. Writing time and resolution were about the same as Mod 10 tube.

Mods 12 and 13 Tubes

Tubes Mod 12 and Mod 13 were constructed similar to Mods 7 and 9 respectively. These tubes are to be used as life-test tubes to determine the secondary emission ratio of the aluminum oxide and beryllium surfaces as a function of time. This life test has not been started at present.

Mod 14A Tube

Storage tube Mod 14A is similar to storage tube Mod 11A except that it has a flat dielectric of aluminum oxide with willemite instead of the griddle surface. This assembly is shown in Drawing A-31198. The operation of Mod 14A was approximately the same as of Mod 11A showing a similar operation of the griddle and flat surfaces.

Mod 15 Tube

Tube Mod 15, was constructed similar to storage tube Mod 14A except that it had a 40 mesh mosaic of beryllium spots on aluminum oxide as a storage surface. The screen is 100-mesh nickel wire cloth. This assembly is shown in Drawing A-31199. Tests on Mod 15, indicate a greater stability of storage than observed in any of the previous tubes. However, there seems to be some difficulty in changing the charge from one polarity to the other. This could be caused by too large spots of beryllium in the mosaic, by secondary emission from the wire mesh screen, or by a difference in the first crossover of the secondary emission curve of the beryllium and of the aluminum oxide.

The storage tube output waveforms shown in Drawing A-31187 are voltage drops across 2700 ohm resistors.

Mods 16 to 20 Tubes

Storage tubes Mods 16 through 20 have been designed and are in the process of construction. These tubes are described on pages 3 and 4 of Memorandum M-121.

IV. TEST EQUIPMENT

Serial Storage:

The test equipment for the serial storage investigation required the design and construction of several high performance video circuits. Power supplies, usually a simple problem, required special consideration so that tube measurements could be carried out with a minimum of extraneous influences. The video circuits required consisted of gate generators, delayed trigger generators, linear sweep generators and amplifiers, "capacity cancelling" amplifiers as pre-amplifiers on the tube outputs, video amplifiers for the P-4 Synchroscopes, intensity (beam current) controls for the storage tube, and a number of incidental circuits used with this equipment. The power supply requirements included both regulated low and high voltage supplies of various types.

1. In order to provide voltage pulses to various elements in the tube, a standard gate and delay unit was developed, (Drawing B-39081). This consists of a conventional single-shot delay multivibrator preceded by a buffer amplifier to prevent reaction on the trigger source and followed by a buffer amplifier or cathode follower, depending on the use of the circuit. A switch was provided so that either a positive gate from the plate of one of the multivibrator tubes, or a positive trigger obtained by differentiating the trailing edge of the gate, was available at the output. In this way a single type of unit could be used either as a gate generator or as a delayed trigger generator. The gate or delay time was continuously variable from 4 to 3000 microseconds. About 12 of these circuits have been built, either singly or in pairs, on small chassis.

2. A linear sweep generator and amplifier giving a sweep length of about 50 microseconds was built, (Drawing C-39064). This consisted of a conventional bootstrap sweep generator, operative only when a gate was applied to the input terminals. Provision was made for using a gate of either polarity.

The sweep voltage generated was applied to an inverter driving the grids of the push-pull output stage. Direct coupling was used throughout the amplifier and sweep generator, making the entire circuit independent of a repetition rate. Considerable care was taken to obtain a high degree of linearity--(better than 1%) in the output circuits.

3. The output circuit from the storage tube had a high capacitance, which in conjunction with the low currents available for reading necessitated a high input resistance to the video amplifier. In order to obtain satisfactory reproduction of microsecond pulses, a capacity cancelling amplifier was constructed along the lines of a similar circuit developed at Radiation Laboratory. One of the several circuits developed is shown in Drawing B-31193. This is a 2-stage amplifier with negative feedback for stabilization and positive feedback to the input to reduce the apparent capacitance of the storage tube signal plate at that point. A decrease in the apparent input capacitance by a factor of 10 was observed.

4. A video amplifier (Drawing B-31194) having a gain of about 40 db and a bandwidth of about 3 mc was built to drive the P-4 synchroscope used to observe the output signals.

5. Reading or writing was done by varying the beam current in the tube. Several circuits were tried in an effort to obtain independent control of current during reading and writing sweeps. The one actually used is shown in Drawing A-39051. Another circuit developed is shown in Drawing B-39179.

6. A number of incidental circuits such as gate inverters and mixers and a frequency divider to provide triggers synchronized with the clock pulses used for writing were developed. Circuits for some of these are shown in Drawings A-39053, B-39054, and A-39050.

7. The power supply system originally planned included regulated supplies for +300, -300, and -405 volts d.c. for operation of gate generators, amplifiers, and other low voltage equipment. These voltages were supplied by modified Western Electric Type CW20AAE power supplies. It was later found that +500 volts was needed for operation of some equipment. This was obtained from a Radiation Lab. P-1 power supply acting as a booster on the +300 volt circuit. With the addition of a +150 volt circuit regulated by a VR tube from the +300 volt line, this system has proved completely satisfactory to the present time.

8. For operation of electron guns, a high voltage supply was necessary. A regulated 2000 volt supply with a capacity of 0.5 milliamperes was built and used during tests with serial storage. Connected to the high voltage (negative) terminal of this supply was a variable (150 to 300 volt) regulated supply having a capacity of about 60 milliamperes. This was used to supply power for bias of the electron-gun control grid and for operation of the intensity control circuits.

9. A control box provided independent switching of both the high voltage and low voltage lines and of the heater supply and 110 volt a.c. circuits on the test benches. Distribution of power to test equipment was through outlet boxes and receptacles along the test benches. Separate receptacles were used for the high voltage and low voltage system.

Parallel Storage:

The change from serial storage to parallel storage initially required very little change in the test equipment, but as the problem became clearer, new test equipment was necessary.

1. Three new high voltage power supplies were developed. These are shown in Drawings C-39104, D-31085, and D-31027. These have much better voltage regulation than the previous units, wider range of output voltages (500-2500 volts) and higher current ratings. Ripple voltage is in all cases less than 0.1 volt. Included are current regulators which prevent severe damage to equipment in case of insulation breakdown and reduce the danger to personnel.

2. Static deflection circuits providing several preset deflection voltages, balanced with respect to ground, were built. For use where a deflection circuit balanced about ground was not suitable, the floating deflection circuit shown in Drawing B-31195 was developed. The deflection circuits shown here are insulated for 3000 volts.

3. A number of adjustable voltage sources of low impedance were necessary for setting the potential of the 3rd anode and storage assembly electrodes. A cathode follower source shown in Drawing B-39187 was developed for this purpose.

4. Improvements on the microsecond pulse generator used for serial storage were also desirable. The circuit shown in Drawing C-39087, a modification of a Radiation Laboratory design, was developed. This unit will provide positive or negative pulses of 50 volt amplitude. The pulse length is variable from 0.05 to 1.5 microseconds and the rise time is less than 0.02 microsecond.

5. A trigger generator shown in Drawing B-39184 was developed. Two preset repetition rates, each adjustable from 1 to 1500 pps are available from this unit. The repetition rate is checked on a cathode ray tube built into the unit. Single trigger-pulses initiated by a push button are also available in these units.

6. Several of the first storage tubes showed poor emission and a change of characteristics with use. For investigating this change, a static test setup was constructed. This permitted life tests of tubes, with continuous indication of all electrode currents. Simultaneously, a portable test circuit, Drawing B-39181, was built to permit similar measurements to

be made while the tube was being pumped. Included in this portable unit were power supplies for degassing and activation of the cathode prior to sealing off the tube.

7. The measurement of charge supplied by the electron beam to various electrodes and surfaces within the tubes required an amplifier with very high input resistance and low capacitance. To meet this requirement, several cathode followers and cathode-coupled amplifiers were developed. The circuit for one of these is shown in Drawing B-39180. The input resistance is approximately 40 megohms. A circuit having a similar input, a cathode-coupled amplifier with a gain of about 10, and a cathode follower output was also developed. The low signal level at which these units operate necessitated DC power for the heaters. The power supply units developed for this are shown in Drawing A-39243.

8. The need for a pulse generator to cover the range from 1 to 10 microseconds was frequently felt during the course of the storage tube studies. Although the gate and delay units would provide pulse lengths as short as 4 microseconds, their rise time was in many cases not short enought. Work was done spasmodically on a 1 to 10 microsecond pulse generator and the design is now complete. It will provide 100 volt pulses of either polarity variable in length from 0.5 to 100 microseconds. The rise time is less than 0.05 microsecond. Great care has been exercised to make the pulse length and amplitude independent of p.r.f. and to prevent reaction of the pulse length on amplitude.

9. A gate amplifier to provide gates of approximately 400 volt amplitude for writing signals on storage surfaces having high first crossover potential was required. An amplifier circuit capable of this, and with a rise time of about 0.5 microsecond is shown in Drawing C-30998.

10. A demonstration unit to permit a simple display of storage tube operation has been designed. For the most part, this is merely a rearrangement of circuits already developed for testing. The control unit and switching unit, Drawings C-30940 and D-30990, include some new circuits. The equipment will be built into two 5 ft. cabinets and will provide push-button operation for storage or reading, with indicator lights to display each signal as it is read out. Deflection circuits are provided to permit the selection of any one of 16 storage points in a 4 x 4 array. A block diagram of these circuits is shown in Drawing B-30999.

V. TUBE CONSTRUCTION TECHNIQUES AND HIGH VACUUM INVESTIGATIONS

Tube Construction Facilities:

There were tube construction facilities at M.I.T. to take care of the needs of the Research Laboratories for Electronics (RLE) arrangements were made to use these facilities when not needed by RLE. As the tubes were constructed and processed it became evident that we should design and set up our own tube-making facilities, even though we were able to construct tubes much faster using RLE facilities than we could have obtained them from a commercial concern. Some of the difficulties encountered were that considerable time was required to synchronize our tube construction program with the RLE program, and it was impossible to modify their equipment to meet our specialized needs despite their excellent cooperation. It was also desirable to examine new variables more quickly and control processes more carefully. In view of these considerations the decision was made to obtain glass-working and vacuum equipment.

Although this equipment was difficult to procure, a glass lathe and an RF bomber were obtained from the War Assets Administration. These pieces of equipment were repaired and modified to meet the program. A spot-welder was obtained and modified for tube work and glass-working facilities were set up. A vacuum system was designed that would process large tubes to a high vacuum and could be modified later for gas data-storage work and analysis work with a spectograph. One of these systems has been completed. The second system is under construction. An oven was designed for annealing [illegible] and an analyzer was designed to exhibit strains in glass. These last two items are under construction. Finally a chemistry hood and bench was set up for general chemical work, electrolysis, and anodizing.

Tube Construction Personnel:

One of the engineers on the project was experienced in tube design and construction. Initially, he designed and constructed all of the experimental pulsed light sources used in the data converter mentioned earlier in this report. In collaboration with Professor Nottingham, who had built numerous research cathode ray tubes, the techniques to be used in constructing and processing the first storage tubes, were worked out. Early in the construction program, Dr. Hilary Moss of Electronic Tubes, Ltd. in England, visited the project. As one of the foremost authorities in England on cathode ray tube construction and electrostatic electron gun design, he was able to give valuable assistance in the form of both information and suggestions.

Professor Harris was consulted on evaporation techniques and gave freely of his personnel and facilities. Professor Breckenridge was consulted on the subject of dielectrics. Dr. Eisenstein gave considerable assistance on the subject of oxide-coated cathodes and general high vacuum techniques. The personnel of RLE's tube construction group gave valuable assistance and loaned their facilities and personnel liberally.

The objective was to construct these tubes under carefully controlled and closely observed conditions. In the beginning the lack of trained technician help in this field hampered the work to a considerable degree since it required a great deal of staff time to train technicians. Although this reduced the amount of basic research which might have been done, this training improved the design of equipment and eventually provided well trained personnel. Fortunately, several months ago, a technician who had ten years of tube experience and considerable glass-working ability was obtained. Another engineer with considerable experience with high vacuum systems also joined the staff, forming the nucleous for a very capable tube construction group. Another highly qualified technician has been trained to fabricate tube parts with the requisite care and skill. As mentioned in M-130 "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".

Procurement of Components for Tube Construction:

Earlier storage tubes were fabricated with material from the stock room of M.I.T. and the American Television Laboratory Vacuum Tube Research Group. Now we have procured our own stock of components and have supplies for most foreseeable needs, although special fabrication of nonex and pyrex is dependent on the Corning Company as the sole supplier.

a. Electron Guns

At first, we constructed the electron guns with the help of A.T.L. facilities to get the program started. These were patterned after the 5CP type of gun because those components were most readily available. However, the focus and intensity controls were not independent. Therefore a supply of 5UP or type 5CP-A electron guns was obtained from RCA. These guns have an accelerating grid between the control grid and first anode, and were designed for finer focus and higher beam current than the 5CP guns. Six electron guns were also purchased from L. Crosser in England, upon the recommendation of Dr. Moss. These guns are designed for very high intensity, fine focus and low reflection of high velocity electrons from the gun itself. The British gun was designed to minimize the production of the secondary electrons from the gun itself, as is characteristic in the 5CP guns. Tests will be made on these guns in the near future.

The design of the 5UP gun was modified to meet the requirements for a holding gun. The deflection plates were set farther apart and several apertures were enlarged to permit high beam current at low accelerating voltages.

In cooperation with the RLE group, we experimented with our own oxide coated cathodes but found RCA's cathodes adequate for the present electron gun design. The group realizes that the design of a gun to meet the specialized needs of the program is desirable. Since the 5UP guns meet our present research needs, the problem of gun design has been postponed for the moment.

b. Glass

Procurement of blown bulbs was impossible for our early needs. It was necessary to take standard glass components and rework them. With the help of S. W. Ryan of Ryan, Velluto, and Anderson, some satisfactory bulbs were prepared. Conventional nonex blown bulbs, used for constructing five-inch cathode ray tubes were used. To these were added lengths of 50 mm nonex tubing as necks on the face of the tube. (See isometric B-30311.) The stems were nonex glass sealed directly to the necks. This required the use of a glass lathe and careful annealing after assembly. The large number of metal-to-glass seals and reworking of the glass requires a high order of skill. The technicians are gradually taking over this phase of the activities, originally carried on by an engineer. Conferences with the Corning Company to clarify procurement of blown bulbs to the required specifications are progressing.

Meanwhile, we have been able to obtain a supply of conventional 5-inch cathode ray tube pyrex bulbs. These can be reworked to new designs with the addition of nonex stems because of the large number of metal-to-glass seals. This requires the use of graded seals from the pyrex to the nonex. Uranium glass is used for the graded seal.

Tube Construction and High Vacuum Techniques:

a. Fabrication of Metal Parts

The requisite supplies and technicians help for fabrication of the metal parts is available. Constant effort is being made to construct more effective assemblies. Representatives of Callite Tungsten have been most helpful with this work. Dr. L. H. DeWald of M.I.T.'s Metal Processing Laboratories has also given some assistance.

b. Coatings

Considerable effort was expended in finding the best type of coating to use on the glass envelopes, and satisfactory methods of application. It was desired to produce a good conducting coating having a low secondary emission ratio which would process well under a vacuum and during baking. Numerous concerns and groups were consulted on this subject. Although we now have processes satisfactory for our present needs, this phase of our work is still active. The procedure now used is described below.

The envelopes are coated inside with a suspension of aquadag containing a small amount of sodium silicate. This coating is applied with a brush as the envelope rotates in a glass lathe. The coating is air dried for several hours, then baked with a heating lamp. Finally it is baked in an oven for several hours at 450°C with air circulating through it.

Nut 5/

Methods of making connections to thin conducting films on dielectrics, and the production of these films were extensively studied.

Coating of phosphors on dielectric surfaces was performed by precipitation. This method has been developed to give a uniform coating of any desired thickness.

The coating of phosphors on metal parts is done by spraying. The metal parts are covered with a light "tacky" binder and then sprayed with the phosphor. Excess phosphor is blown off the metal.

Considerable attention has been given to production of suitable dielectrics for storage surfaces by spraying coatings of the dielectric, by precipitation of the dielectric, by anodizing to form the dielectric, and by evaporation.

c. Evaporation

In the earlier phases of our work we used the evaporation facilities and techniques of Professor Harris. Later, similar facilities were set up. These facilities were never pumped below a pressure of about one micron and the material to be evaporated was heated in a helix of tungsten wire. This method had certain disadvantages. Some materials melted before they evaporated and kept falling out of the coil. Many materials dissolved the coil. It was finally decided to do all the evaporation in a very high vacuum. We were also interested in producing mosaic surfaces by masking the surface with a wire mesh and evaporating the mosaic material through it. Very clean surfaces were desired and impurities from the material to be evaporated must be driven out. Our final evaporation procedure is to prepare a small metal cup and mount it on a stem. This stem is then sealed in one end of a tube. The choice of the metal for the cup depends on the material to be evaporated; e. g. Tantalum is satisfactory for evaporating beryllium. Since the targets were small, one cup was sufficient. The target is sealed in the other end of the tube. This tube is put on a high vacuum system. The metal cup is heated by means of a RF Bomber. This system has numerous advantages over the filament type of heating in our experience.

The target is cleaned by a glow discharge. Gas in the tube can then be ionized by the RF Bomber if the pressure is about one micron. After the target is cleaned with a glow discharge, the tube is baked at about 450°C. and allowed to cool. Then the cup is heated slowly with the bomber to drive all gas out of it and out of the material to be evaporated. Finally, the cup is heated with the bomber until the material evaporates. It was found that several thin films thrown on the target at intervals of several minutes will not creep under a mask as will one heavy layer thrown on at one time.

Helium can be introduced into the system and cleaning of surfaces done by a glow discharge. Further research is planned to develop the possibilities of this technique.

d. Cleaning of Metal Parts

All metal parts are thoroughly cleaned and handled only with gloves or tongs. Many of the metal parts are then heated in hydrogen to remove surface contamination and displace other gasses absorbed or adsorbed by the metal. This hydrogen comes off readily when the parts are subsequently heated in a vacuum with the RF Bomber. All components under construction are stored in a desiccator when not actually being worked on. The utmost cleanliness must be maintained in the laboratory at all times.

e. Processing of the Tube

It is common experience in the tube construction industry that to obtain satisfactory emission from an oxide-coated cathode the outgassing of the bulb and various parts inside it must be carried out in a special order and the correct pumping procedure has to be found for each type of tube by a separate series of experiments. Apparently, during outgassing, various factors are in operation, which afterwards influence the emission produced by the cathode. Different workers often arrive at different procedures which give the same apparent results. However, when components are changed for each tube and different materials are used, it is necessary to fix upon a procedure which will produce good average results. Later, when the design of the tube has been fixed we will conduct a series of experiments to determine the best activation procedure.

After consultation with Professor Nottingham and Dr. Hilary Moss, and drawing on the experience of our own staff, we have arrived at the following activation and exhaust schedule: The tube is sealed to the vacuum system as soon as possible after assembly. This reduces the effect of harmful water vapor which collects in the bulb while being assembled. This also permits the glass to be heated soon after being worked, thus reducing the possibility of breakage from dangerous strains.

The exhaust tubulation is at the storage assembly end of the tube so that the cathodes will not be contaminated by gases given off while baking and during activation. After pumping has started the tube is baked at 450°C. for two hours. The metal parts are then brought to a dull red heat with the RF Bomber and then allowed to cool. This heating cycle is repeated until no appreciable amount of gas is driven off. The cathode is degassed by operating the heater at 3 volts (normal voltage 6.3) for five minutes and then increasing it to 12 volts in one-volt steps, allowing two-minute intervals at each voltage. The voltage is then reduced to 7 volts in one-volt steps lasting one minute each. After being held at 7 volts for five minutes the voltage is slowly reduced to zero over a two-minute period.

After outgassing the cathode, the oven is brought up to 450°C and allowed to cool to 150°C. Then liquid nitrogen is put in the freeze-out trap. Again all metal parts are bombed to remove gas. The heater voltages used in outgassing are then applied with the same schedule except that when six volts is reached a positive grid voltage of four and one-half volts with respect to cathode is applied for the remainder of the activation. After activation, the cathode and first grid are held at ground potential and an accelerating potential of 250 volts is applied to the second grid. The heaters are operated at seven and a half volts until the emission current stabilizes. This ageing process may take as little as five minutes or as much as a day. The tube is operated at normal voltages to test beam current and focus, and is then ready to be sealed off. The exhaust requirements for the storage tube are severe. We have tried to keep the final seal-off pressure below 5×10^{-7}mm of mercury. After seal-off the tube is based with 14 pin bases which fit the test equipment.

VI. BASIC RESEARCH

Many of the problems arising in the design, construction, and testing of storage tubes have necessitated basic research in chemistry and physics. To obtain a dielectric surface satisfactory for the storage tube work, an extensive program of study of aluminum oxide was undertaken. The results of this study are given in Reports R-128 and R-131. Many of these investigations required the construction of special tubes for measurement of leakage resistance under high vacuum conditions.

Since the secondary electron redistribution problem was very difficult to solve, it seemed necessary to get maps of the electric field around the storage tube electrodes. To this end, an electrolytic tank, described in Memorandum M-56 and Report R-130, was constructed. Different electrode configurations were simulated and the potential field about these electrodes was mapped. The results, among other things, showed the feasibility of controlling the field at the bottom of the pockets of the griddle-type surface.

Careful search is being conducted to investigate all possible materials that might have satisfactory characteristics as a storage surface in our particular type of operation. Technique for producing these surfaces are simultaneously being investigated.

Much of the data on secondary emission from conductors and insulators is contained in foreign technical articles. A translation of the article "Secondary Emission of Solid Bodies" by R. Kollath, was made from Physikalische Zeitschrift, 1937, Pp. 202-224. This article gives a detailed discussion of the energy distribution of the secondary electrons, the angular distribution of secondary electrons, secondary emission in general and secondary emission from insulators, action of the high velocity primary electrons, theoretical formulation of the process of release of secondary electrons, the industrial significance of the secondary electron, and a rather complete bibliography. Curves of the secondary emission of a large number of materials with a discussion of each are included.

An article by R. Warnecke entitled, "Secondary Emission of Pure Metals", was translated from Le Journal de Physique et le Radium, 1936, volume 7, series 7, pp. 270-280. In this article the author gives the secondary emission characteristics of different metals between 0 and 1,500 volts primary accelerating potential. By comparison he deduced some considerations of the mechanism which seems principally to govern the phenomenon. Data for the secondary emission of different materials are included as tabular results.

An article entitled "A Method of Direct Measurement of Secondary Electron Emission from Insulators" by W. Heimann and K. Geyer was translated from Elektrische Nachrichten Technik 17, 1940, pp 1-5. This article discusses the technique of measuring secondary electron emission from insulators by stabilizing the electric potential at the second crossover and switching the accelerating potential so that a transient measurement of the emission could be obtained. "The Theory of Secondary Electron Emission from Metals" by Herbert Frohlich was translated from Annalen der Physik, April, 1932, Vol 13, pp 229-248. This article treats theoretically the phenomenon that the secondary electron emission velocity is to a large extent independent of the primary electron velocity. "New Investigations on the Electrolytic Valve Effect" by A. Guntherschulze and H. Betz was translated in two parts from Zeitschrift fur Physik, vol 37, 1931, pp 580-585 and pp 726-734. Part 2 of this article discusses the oxide layer of Sb, Bu, W, Zr, Al, Zn, and Mg. This part of the article deals with the formation of an insulating surface layer on a metal in a weak electrolyte. Part 3 of this article is entitled "The Dielectric Constant of the Al_2O_3 Boundary Layer" and discusses the testing of an aluminum oxide layer formed by methods outlined in part 2.

An article entitled "The Motion of the Ionic Lattice of Insulators in Extreme Electric Field Intensities" by A. Guntherschulze and H. Betz was translated from Zeitschrift fur Physik, vol. 92, 1934, pp 367-374. This article discussed the subject of the relationship between lattice conduction velocity and electric field intensity in freshly formed layers of aluminum and tantalum oxide. "Electrolytically Produced Oxide Protective Layers on Aluminum" by H. Rohrig was translated from Zeitschrift fur Elektrochemie", vol. 37, 1931, pp 721-724. This is a survey of the methods of formation of aluminum oxide by various investigators. "On the Dielectric Constant of an Oxide, Hydroxide, and Oxihydrate" by Oscar Glemser was translated from Zeitschrift fur Elektrochemie", vol. 45, 1939, pp 865-870. Measurements were made on aluminum, beryllium, magnesium, zinc, and iron compounds. The results of these measurements were analyzed in the article.

From studies of these published data it was found that the secondary emission characteristics of the same material varied widely depending upon the investigator. This variation in the literature indicated the necessity of measuring the secondary emission characteristics of storage surfaces under conditions similar to those which would eventually be encountered in the storage tubes. To meet this requirement a thesis was begun to study the secondary emission life on several of the more promising looking materials.

While work on electrostatic storage, which is surface storage was progressing it was decided to investigate the possibilities of volume storage. This is discussed in M-70. A thesis was started to investigate the possibility of using glow discharges which might permit three-dimensional storage arrays to be compactly spaced.

VII. CIRCUIT ASSOCIATED WITH THE STORAGE TUBE IN THE COMPUTER.

During computer operation, it will be necessary to switch some of the storage tube electrodes over a range of voltages of approximately 100 volts. The capacitively coupled transients from these switchings must be suppressed at the output so that they will not actuate the output flip-flop. To do this it will be necessary to develop a clamping circuit. The preliminary work done on this circuit shows that it may involve quite a long development program. It is planned at the present time that this development program will form the basis for an Electrical Engineering Master's Thesis.

S. H. Dodd
S. H. Dodd

P. Youtz
P. Youtz

W. J. Nolan, Jr.
W. J. Nolan, Jr.

LIST OF DRAWINGS

B-30310
B-30311
A-30358
C-30940
D-30990
C-30998
B-30999
A-31014
A-31015
D-31027
D-31085
A-31102
A-31103
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A-31109
A-31110
A-31111
A-31112
A-31113
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A-38303
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A-39367

B-30310

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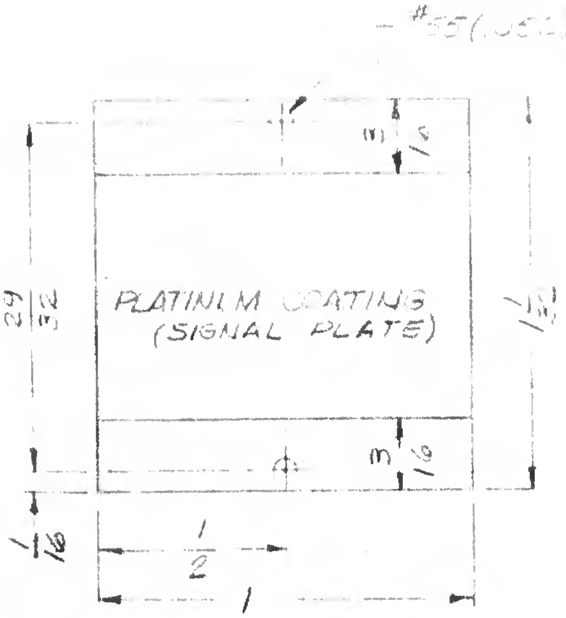
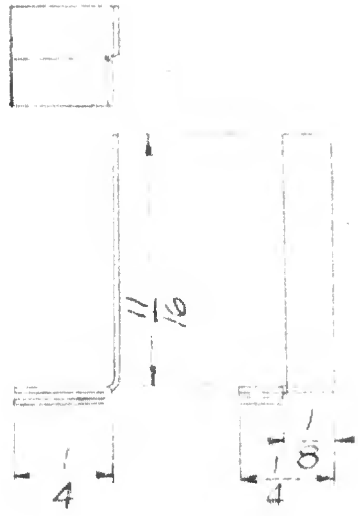
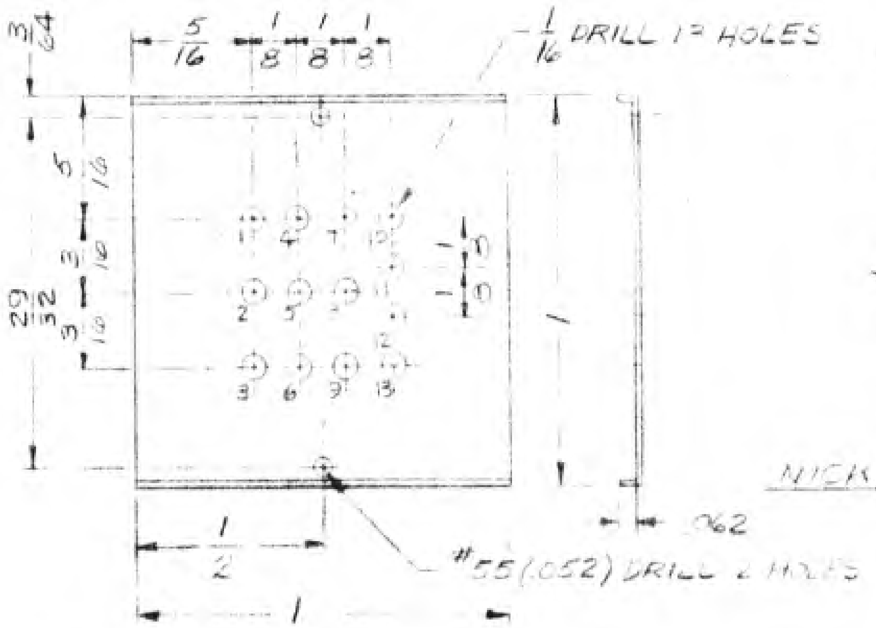


DIELECTRIC SUB-ASSEMBLY
(RUBY AFRICAN MICA .0038)

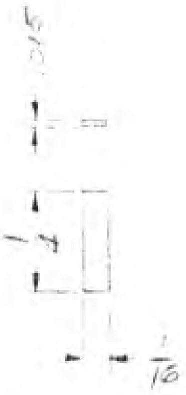


NICKEL ANGLE (.015)

NICKEL
(PERFORE



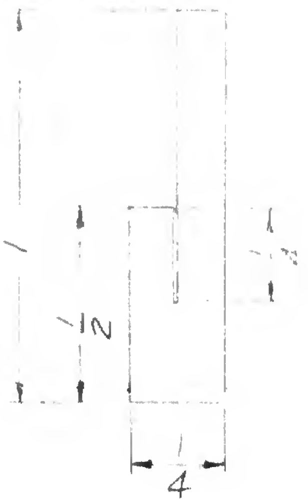
NICKEL SCREEN (.015)



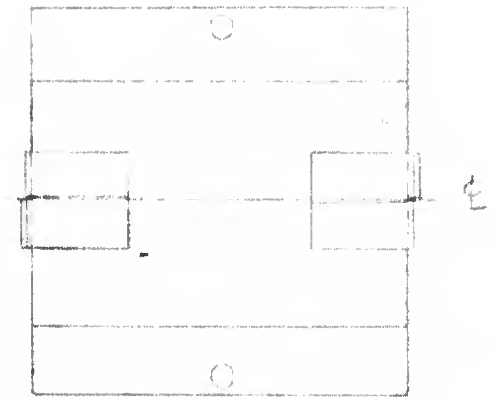
NICKEL STOP

* — SPOT WE

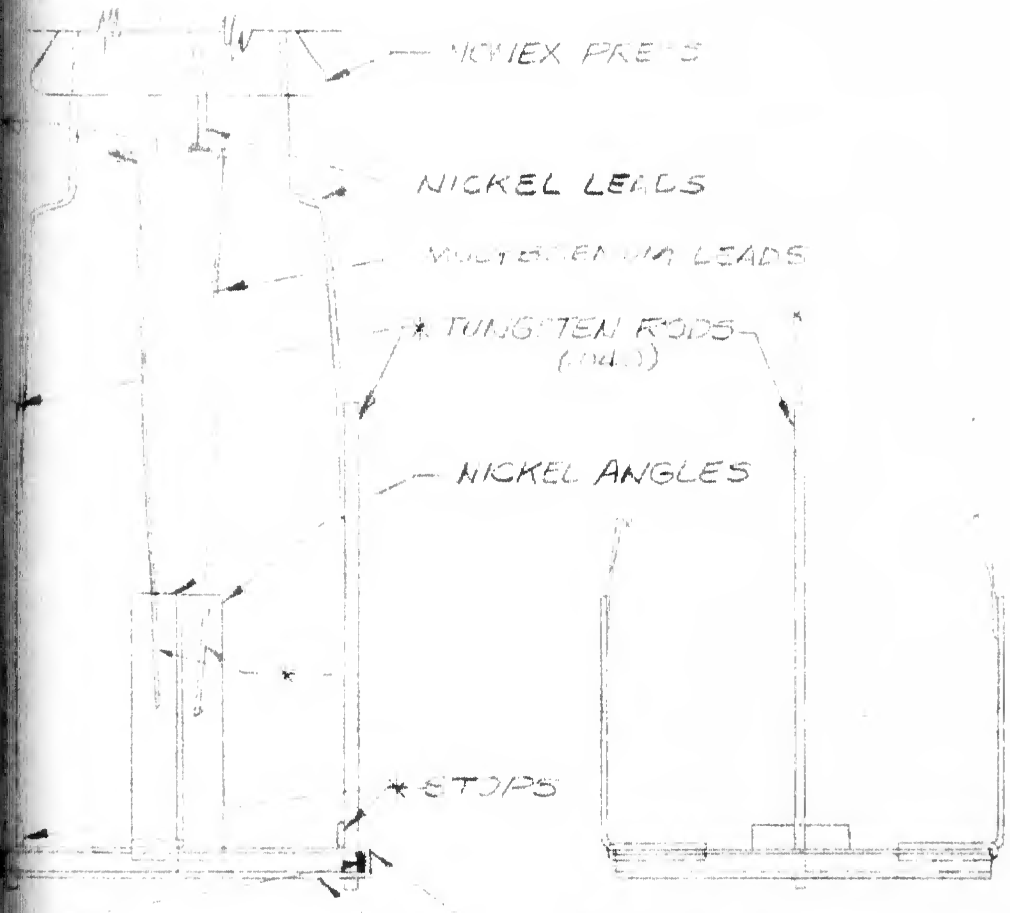
USED IN 5845 REF



NICKEL ANGLE
(BEFORE BENDING)



DIELECTRIC ASSEMBLY



STORAGE ASSEMBLY

1. NICKEL ANGLE CLAMPED ON MICA DIELECTRIC AND MAKES CONTACT WITH PLATINUM SIGNAL PLATE.
2. STOPS SPOT-WELDED TO TUNGSTEN RODS HOLDING MICA AGAINST NICKEL SCREEN.

STORAGE TUBE
MODEL 1 ASSEMBLY 2

SCALE 2:1

MASSACHUSETTS INSTITUTE OF TECHNOLOGY SERVOMECHANISMS LABORATORY		
D. I. C. NO. 6345	DR. CTS 1/23/47	CK. [illegible] 1-30-47
ENG. [illegible]	APP.	B-30310

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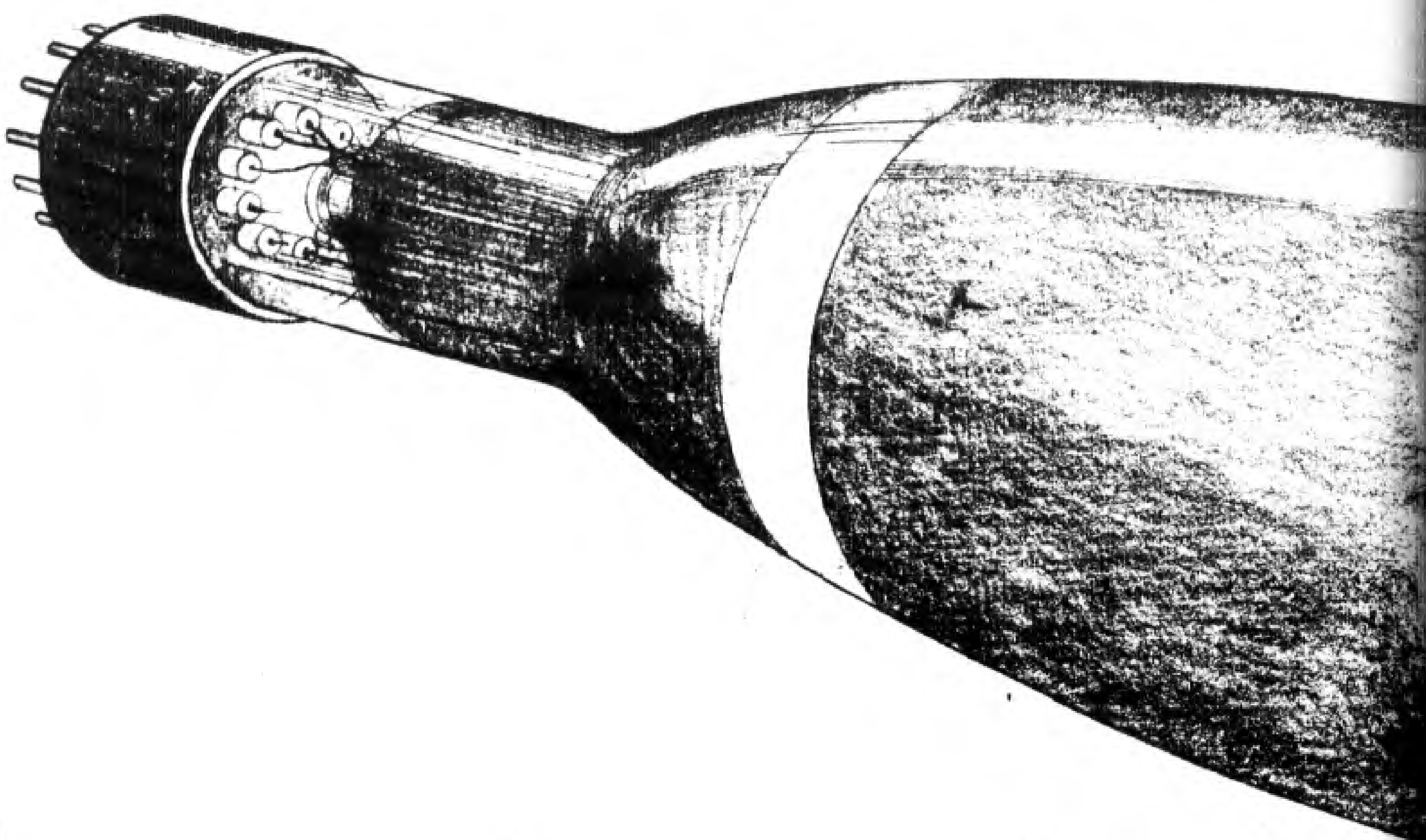
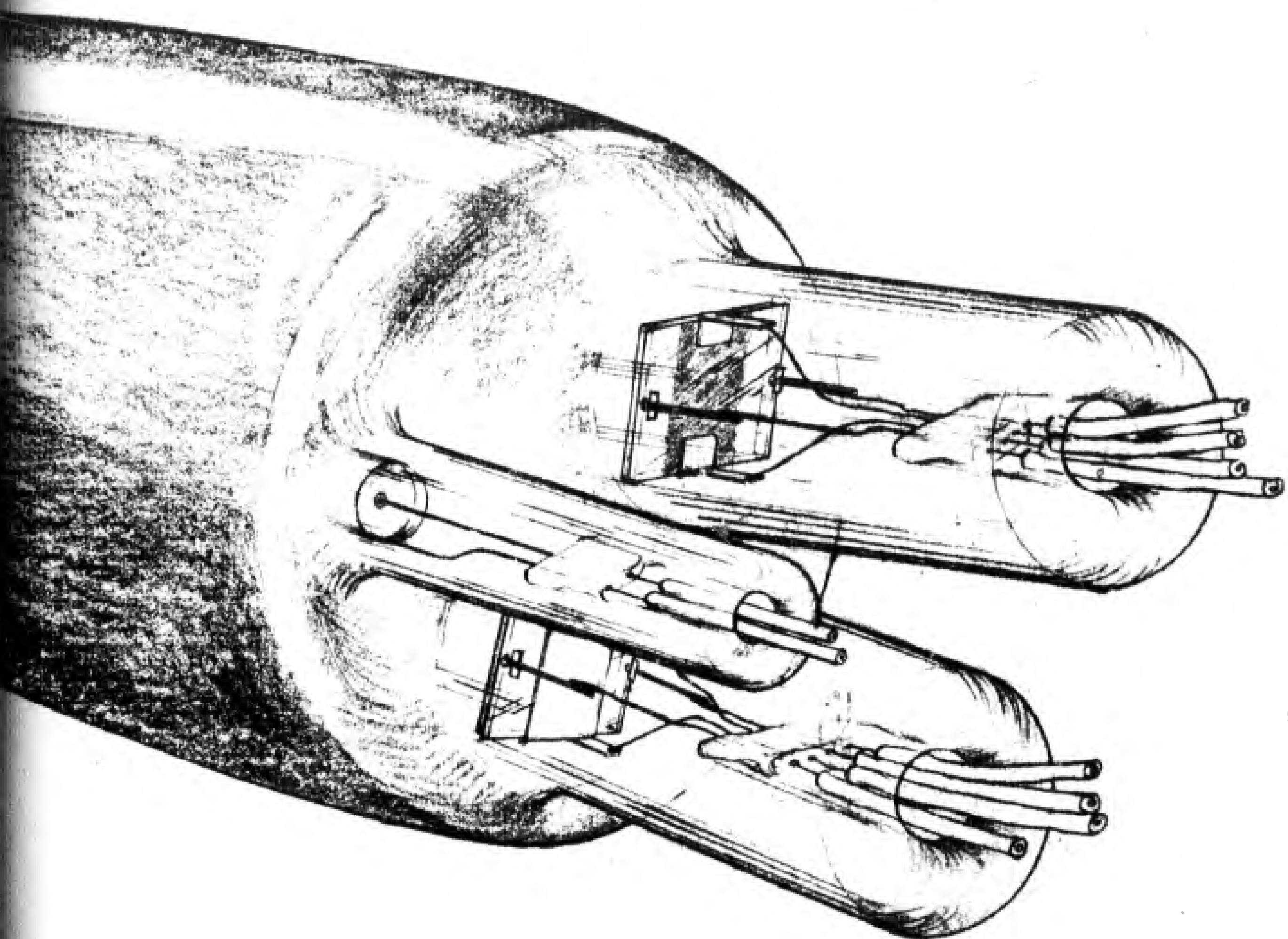
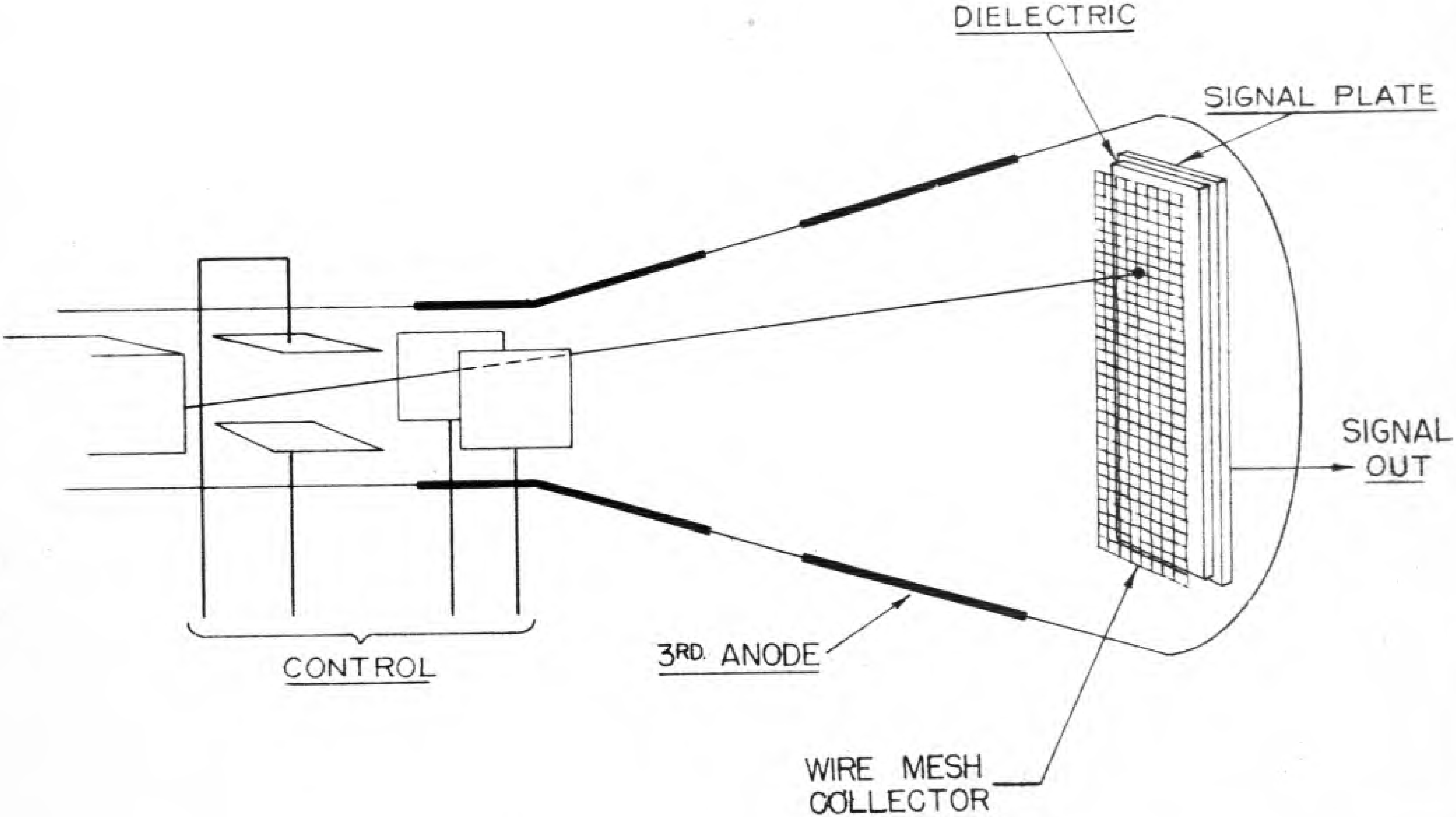




ISOMETRIC VIEW OF
STORAGE TUBE MODEL I

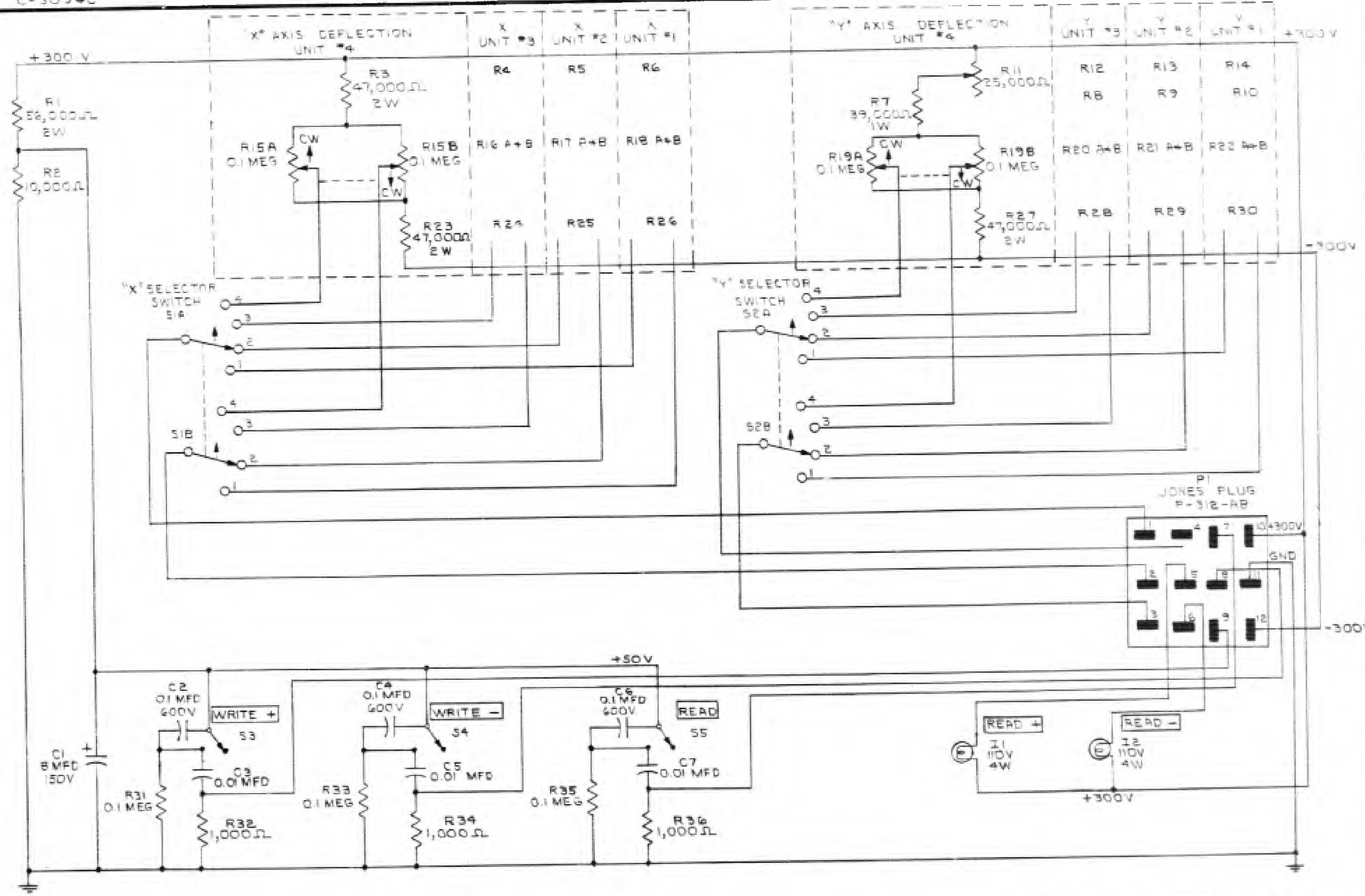
MASSACHUSETTS INSTITUTE OF TECHNOLOGY SERVOMECHANISMS LABORATORY		
D.I.C. NO. 6345	DR. F. B. 1-21-47	CK.
ENG.	APP.	B-30311

A-30358-1



MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SERVOMECHANISMS LABORATORY
D.I.C. NO. 6345
DR.
A-30358-1

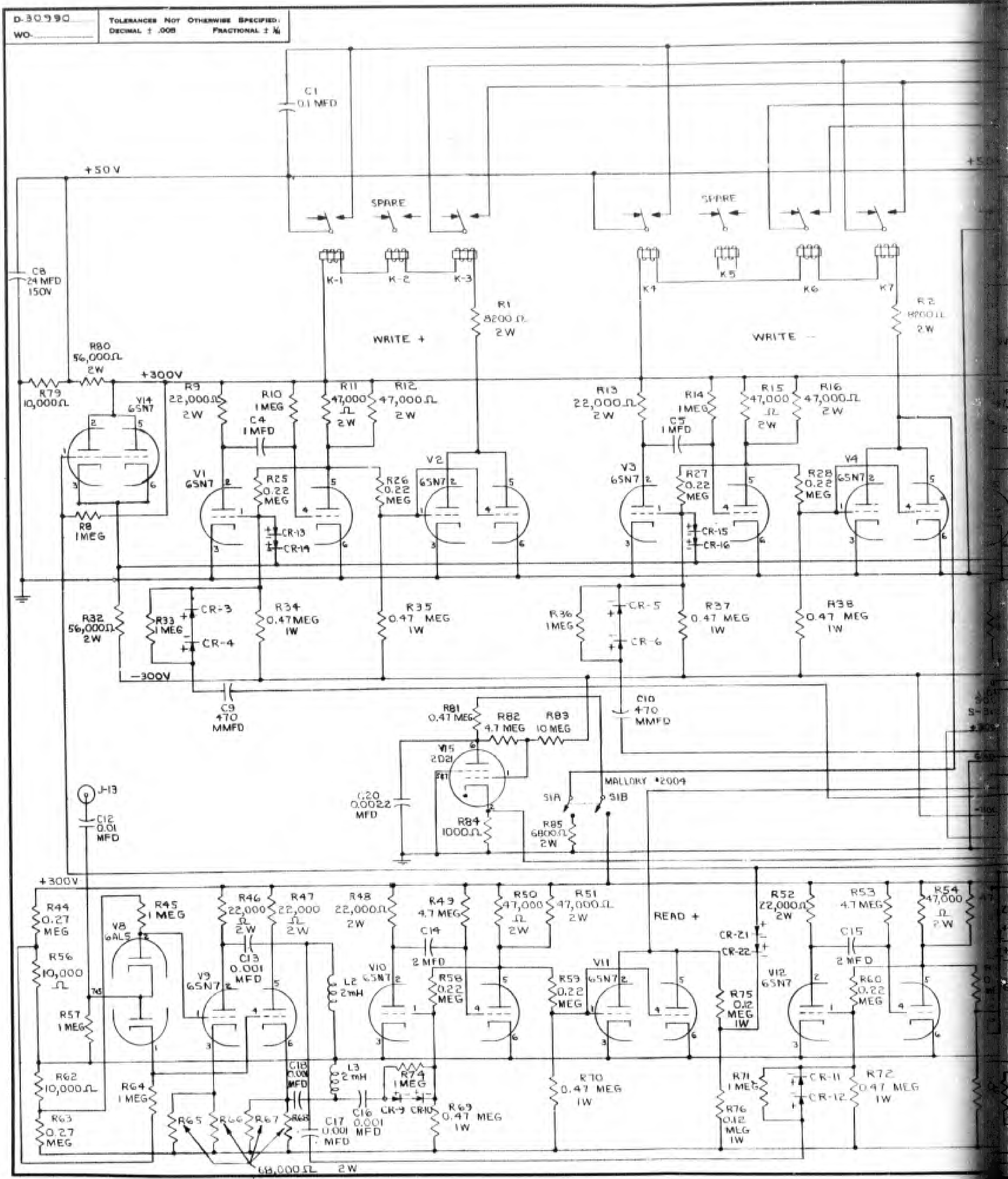
C-30940



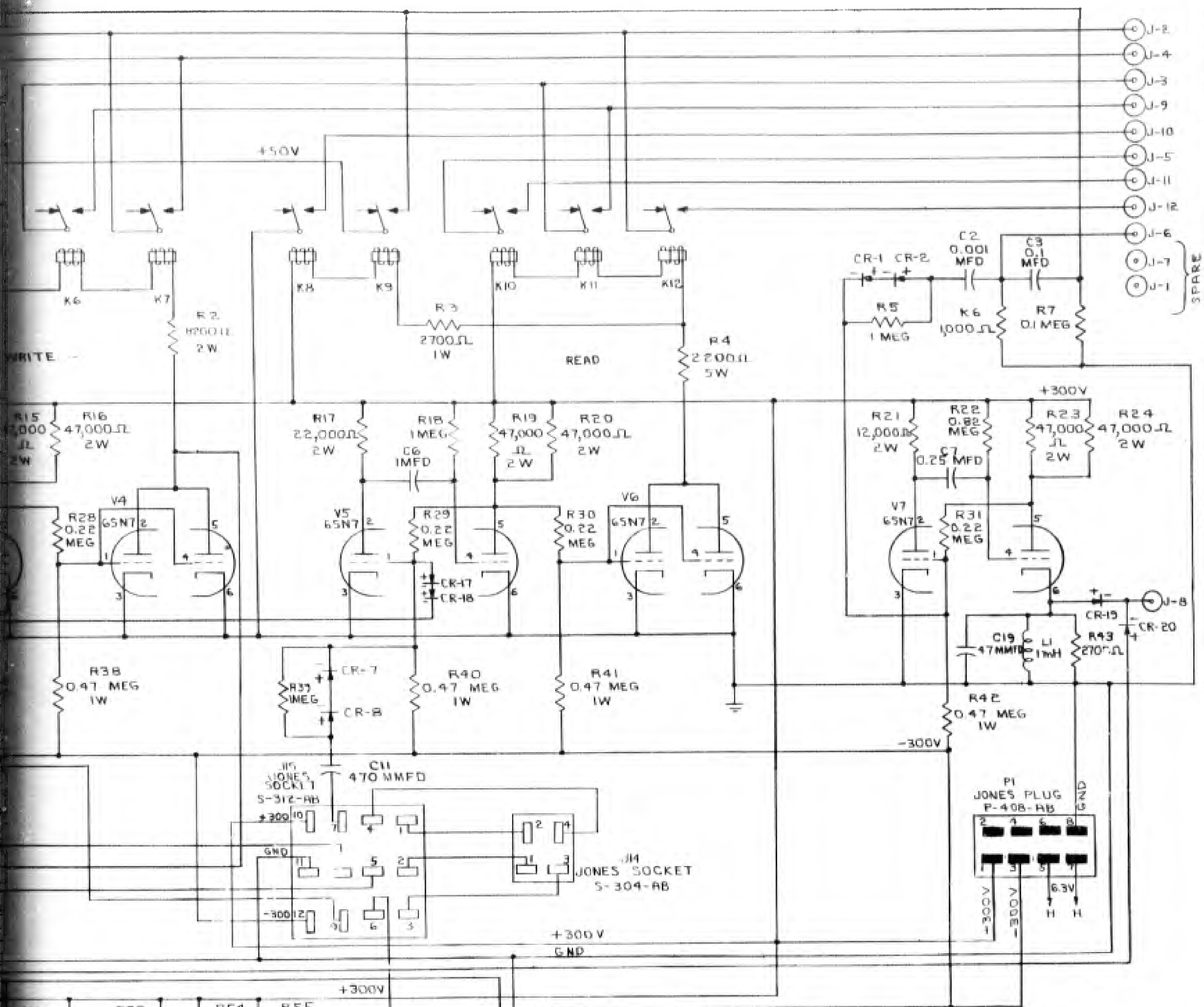
NOTE: FOR MECHANICAL ASSEMBLY SEE C-30941.
ALL RESISTORS ARE $\frac{1}{2}$ WATT UNLESS OTHERWISE SPECIFIED.
ALL CONDENSERS ARE 600V UNLESS OTHERWISE SPECIFIED.

SERVOMECHANISMS LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345	
E.S.T. DEMONSTRATION UNIT CONTROL BOX CIRCUITS	
SCALE: DR. D.L.O. 9-16-47 CK. APP.	C-30940

1


D-30990
WO-
TOLERANCES NOT OTHERWISE SPECIFIED:
DECIMAL ± .005
FRACTIONAL ± 1/64
C1 0.1 MFD
+50V
SPARE
SPARE
C8 24 MFD 150V
K-1
K-2
K-3
K4
K5
K6
K7
R1 8200 Ω 2W
R2 8200 Ω 2W
WRITE +
WRITE −
R80 56,000 Ω 2W
R79 10,000 Ω
+300V
V14 6SN7
R8 1MEG
R9 22,000 Ω 2W
R10 1MEG
C4 1MFD
R11 47,000 Ω 2W
R12 47,000 Ω 2W
V1 6SN7
R25 0.22 MEG
R26 0.22 MEG
V2 6SN7
CR-13
CR-14
R13 22,000 Ω 2W
R14 1MEG
C5 1MFD
R15 47,000 Ω 2W
R16 47,000 Ω 2W
V3 6SN7
R27 0.22 MEG
R28 0.22 MEG
V4 6SN7
CR-15
CR-16
R32 56,000 Ω 2W
R33 1MEG
CR-3
CR-4
R34 0.47 MEG 1W
R35 0.47 MEG 1W
R36 1MEG
CR-5
CR-6
R37 0.47 MEG 1W
R38 0.47 MEG 1W
−300V
C9 470 MMFD
C10 470 MMFD
R81 0.47 MEG
R82 4.7 MEG
R83 10 MEG
V15 2D21
C20 0.0022 MFD
R84 1000 Ω
MALLORY #2004
S1A
S1B
R85 6800 Ω 2W
J-13
C12 0.01 MFD
+300V
R44 0.27 MEG
R45 1MEG
V8 6AL5
R56 10,000 Ω
R57 1MEG
R46 22,000 Ω 2W
R47 22,000 Ω 2W
C13 0.001 MFD
V9 6SN7
R48 22,000 Ω 2W
L2 2mH
R49 4.7 MEG
C14 2 MFD
V10 6SN7
R58 0.22 MEG
R50 47,000 Ω 2W
R51 47,000 Ω 2W
READ +
R59 0.22 MEG
V11 6SN7
R75 0.12 MEG 1W
CR-21
CR-22
R52 22,000 Ω 2W
R53 4.7 MEG
C15 2 MFD
R54 47,000 Ω 2W
V12 6SN7
R60 0.22 MEG
R62 10,000 Ω
R64 1MEG
R63 0.27 MEG
R65
R66
R67
R68
68,000 Ω 2W
C18 0.001 MFD
L3 2mH
C16 0.001 MFD
C17 0.001 MFD
R74 1MEG
CR-9
CR-10
R69 0.47 MEG 1W
R70 0.47 MEG 1W
R71 1MEG
CR-11
CR-12
R76 0.12 MEG 1W
R72 0.47 MEG 1W

2



NOTES
ALL RESISTORS ARE $\frac{1}{2}$W UNLESS OTHERWISE SPECIFIED.
ALL CONDENSERS ARE 600V UNLESS OTHERWISE SPECIFIED.
J1-J19 ARE BNC UG-290/U CONNECTORS
CR1-CR24 ARE 1N34 CRYSTAL DIODES
K1-K12 ARE PRICE ELECTRIC CORP. RELAYS #1001-C 24 V.D.C. 1920 Ω
FOR MECH ASS'Y SEE D-31128

P				Q					ITEM	MATERIAL - DESCRIPTION	PART NO.	QUAN.
N				F								
M				E								
L				D								
K				C								
J				B								
H				A								
	WAS	APP.	DATE		WAS	APP.	DATE					

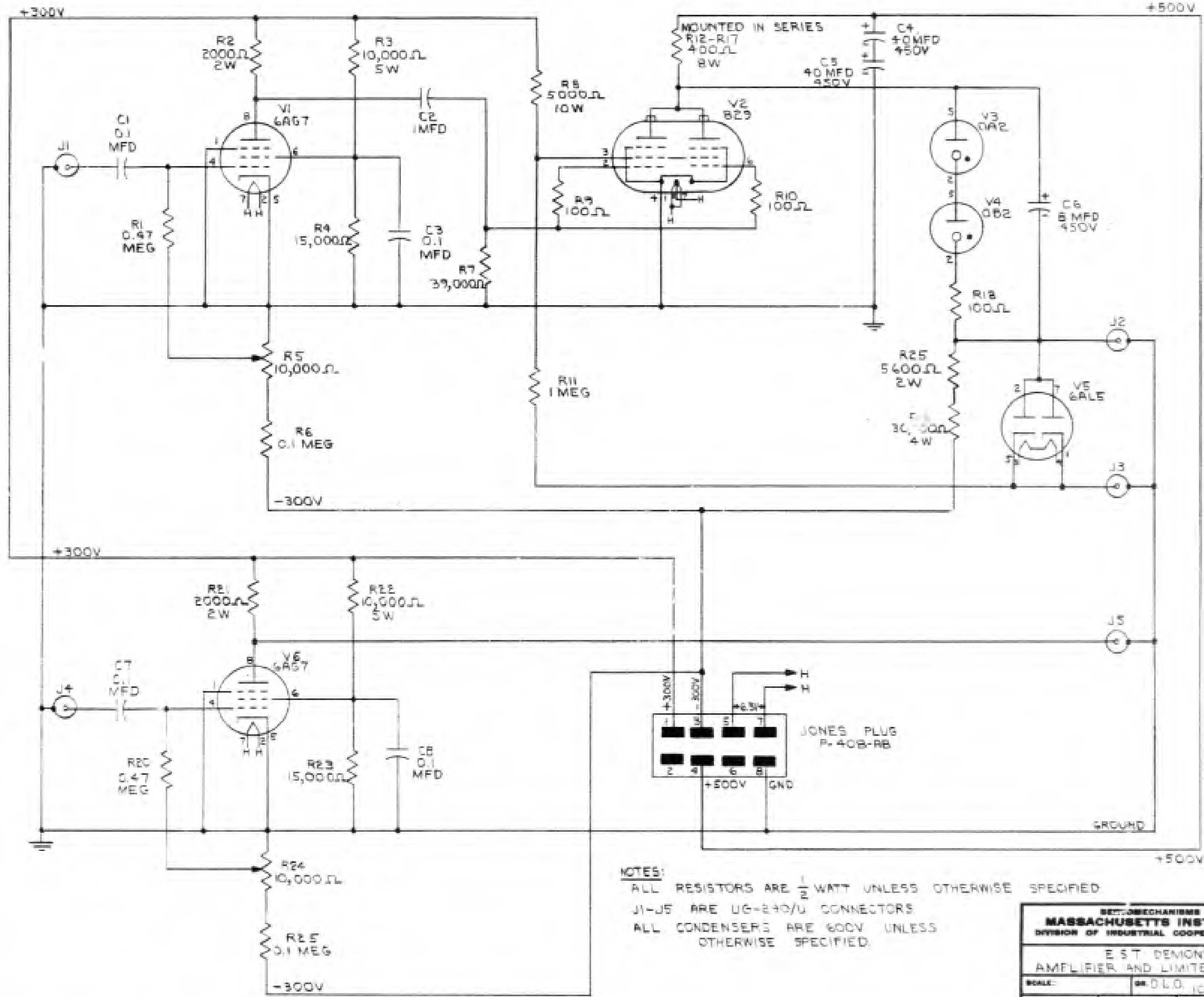
SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

E.S.I. DEMONSTRATION UNIT
SWITCHING UNIT SCHEMATIC

SCALE: | DR. D.L.C. 3-8-47 | TR. | CK. | APP. JMS

D-30990

C-30998

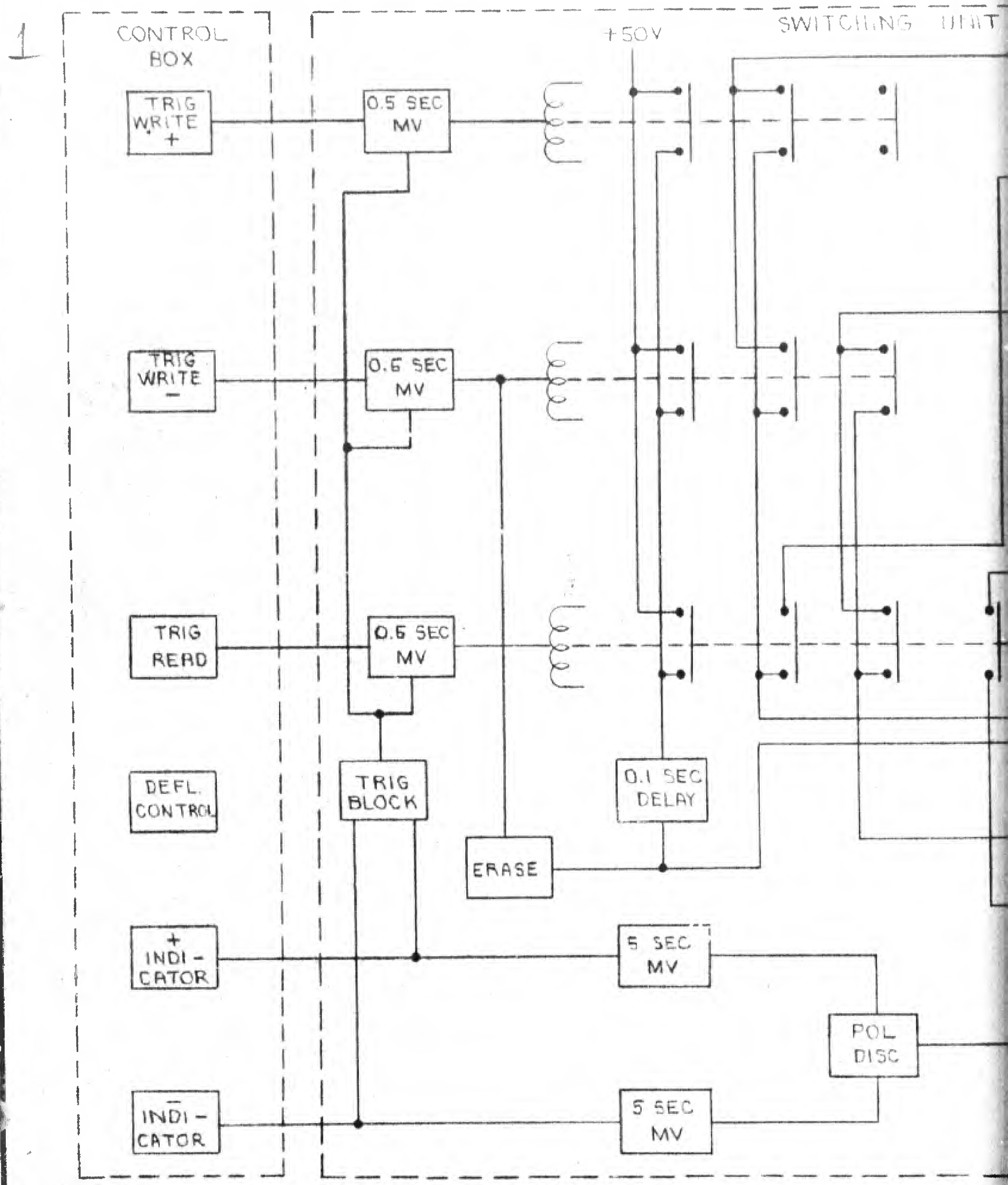


NOTES:
ALL RESISTORS ARE $\frac{1}{2}$ WATT UNLESS OTHERWISE SPECIFIED
J1-J5 ARE UG-290/U CONNECTORS
ALL CONDENSERS ARE 600V UNLESS OTHERWISE SPECIFIED

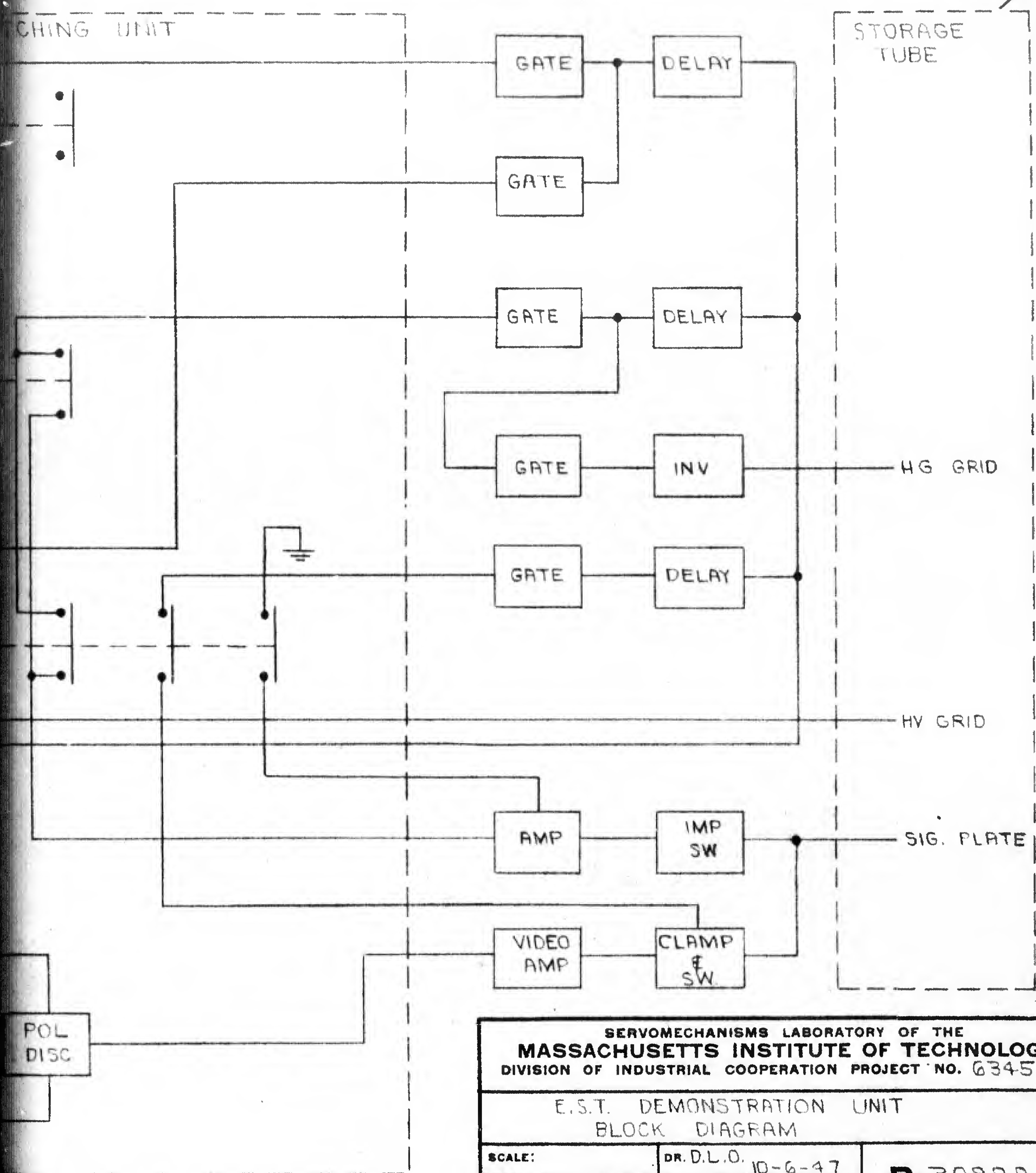
SERVOMECHANISMS LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345			
E.S.T. DEMONSTRATION UNIT AMPLIFIER AND LIMITER CIRCUIT SCHEMATIC			
SCALE:	DR. D.L.O. 10-31-47		C-30998
ENG.	CK.	APP.	

B-30999

1



"ALBANENE" NO.109L K&E CO. N.Y.
REG. U.S. PAT. OFF.



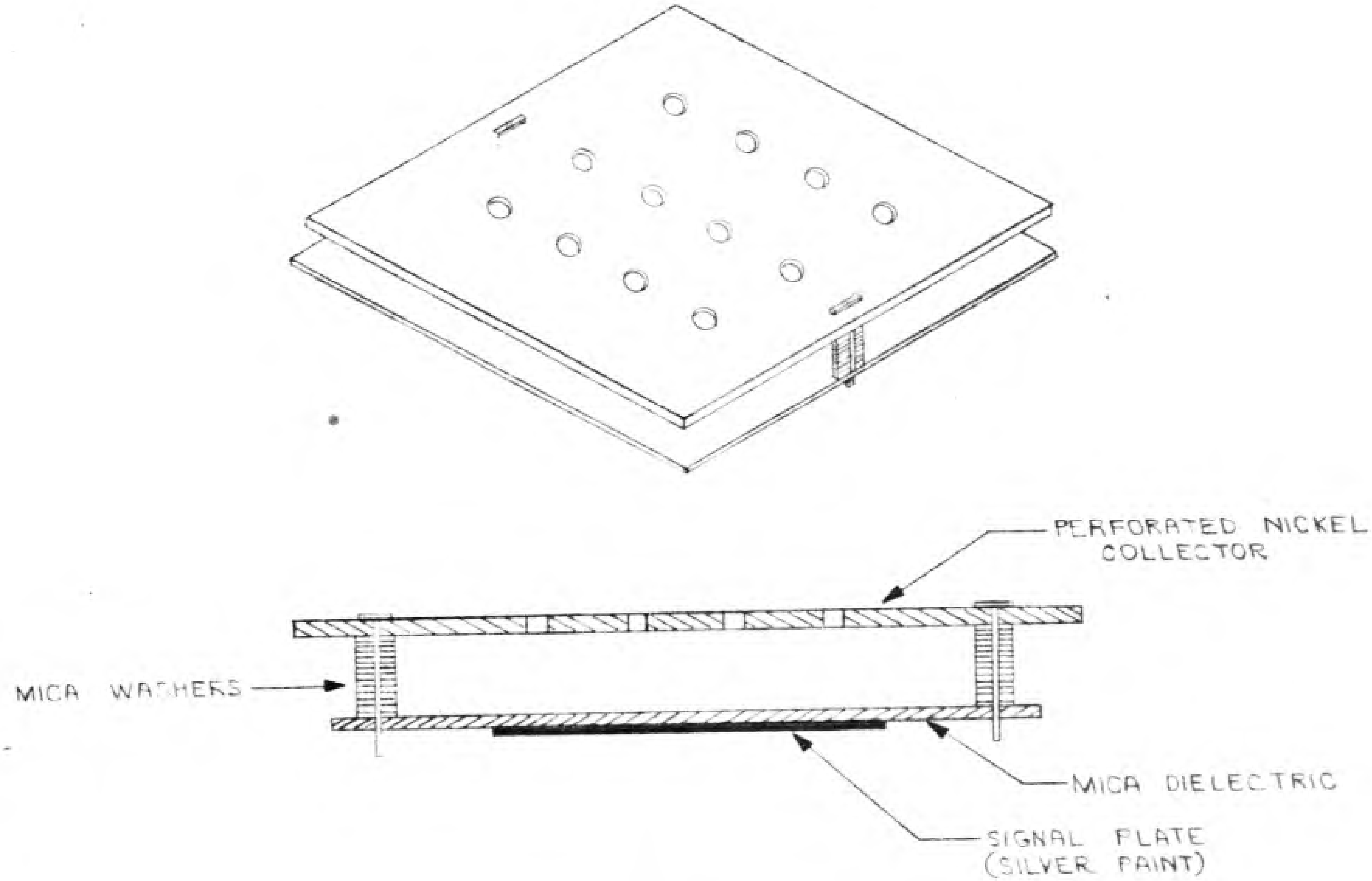
SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

E.S.T. DEMONSTRATION UNIT
BLOCK DIAGRAM

SCALE: DR. D.L.O. 10-6-47
ENG. M.J.R. CK. APP.

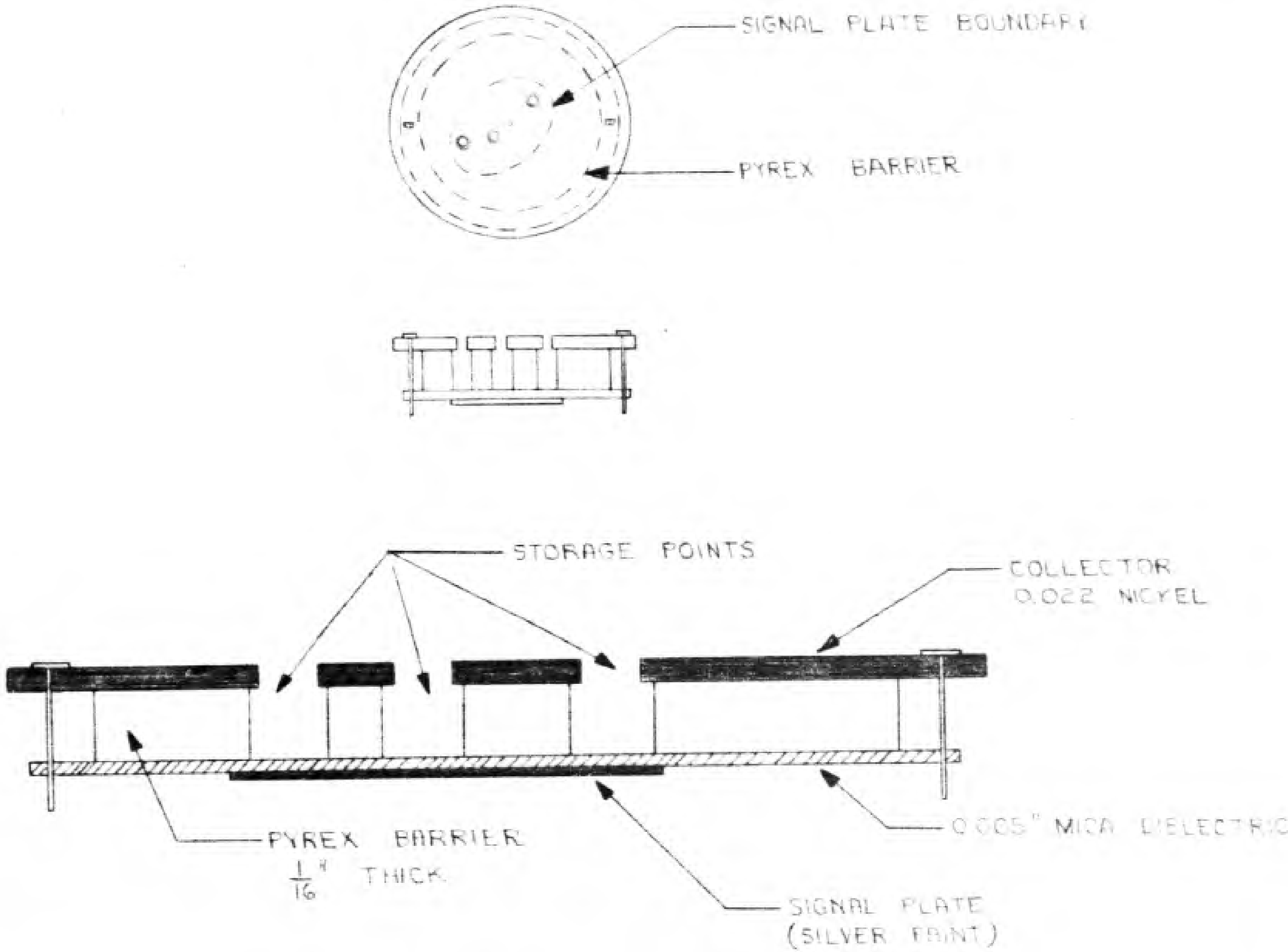
B-30999

A-31014



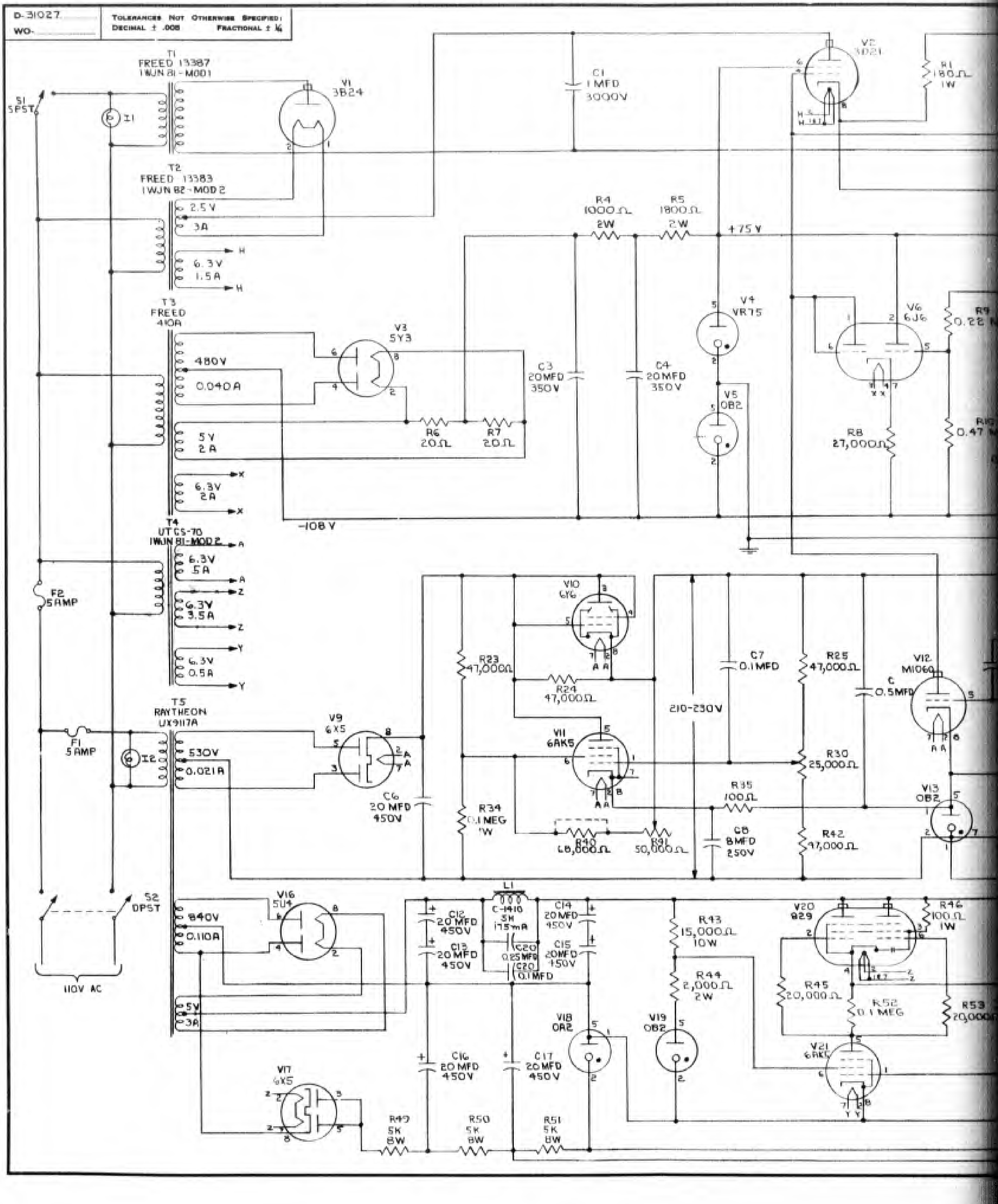
STORAGE ASSEMBLY #2
E.S.T. MOD I

6345 O.L.O. 10-8-47
A-31014

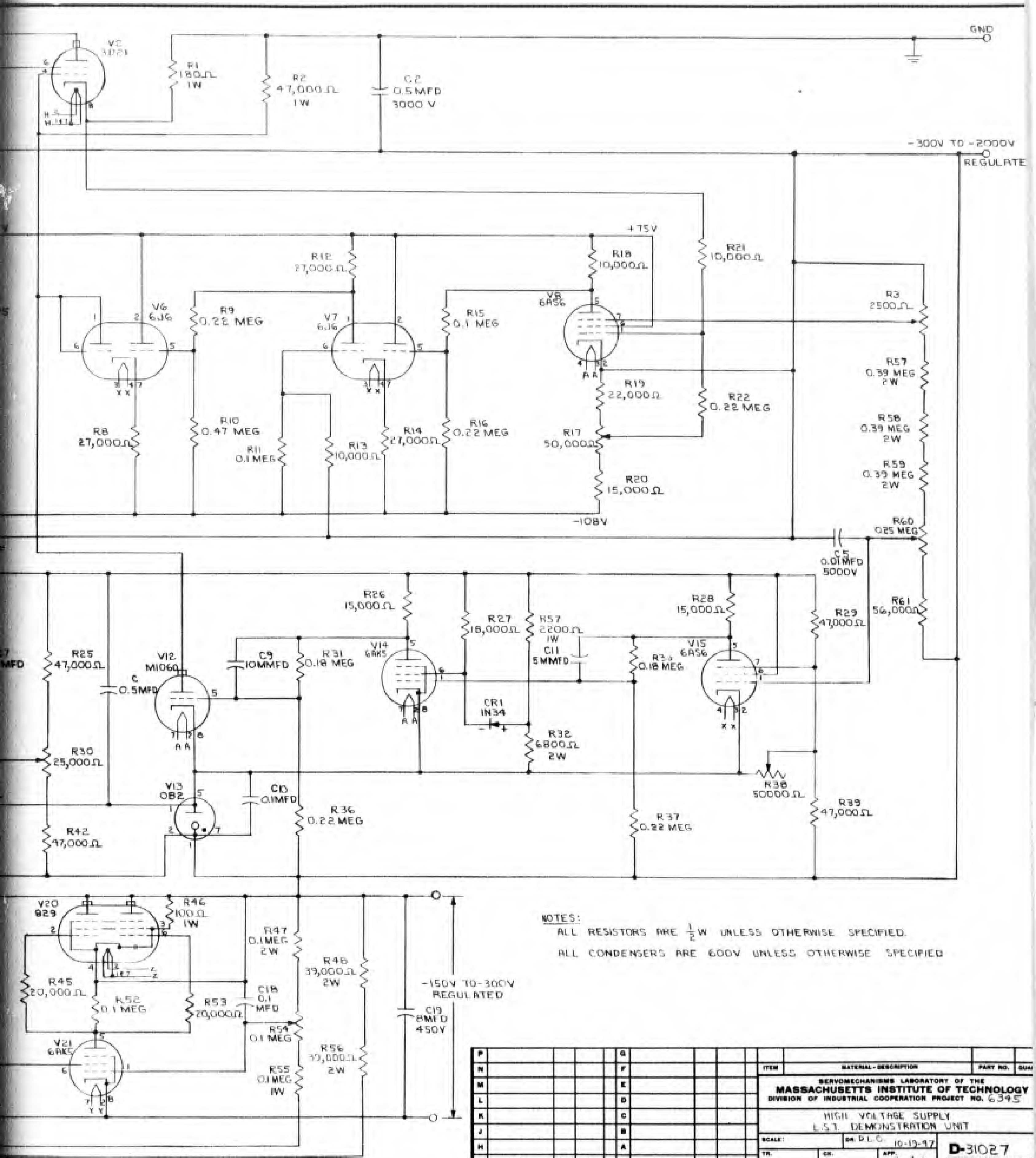


STORAGE ASSEMBLY #3
E.S.T. MOD 6

6345


D-31027
WO-
TOLERANCES NOT OTHERWISE SPECIFIED: DECIMAL ± .005 FRACTIONAL ± 1/64
T1 FREED 13387 1WJN 81-MOD 1
V1 3B24
S1 SPST
I1
C1 1 MFD 3000V
V2 3D21
R1 180Ω 1W
T2 FREED 13383 1WJN 82-MOD 2
2.5V 3A
6.3V 1.5A
R4 1000Ω 2W
R5 1800Ω 2W
+75V
T3 FREED 410A
V3 5Y3
480V 0.040A
5V 2A
6.3V 2A
R6 20Ω
R7 20Ω
C3 20MFD 350V
C4 20MFD 350V
V4 VR75
V5 0B2
V6 6J6
R8 27,000Ω
R9 0.22
-108V
T4 UTC S-70 1WJN 81-MOD 2
6.3V 5A
6.3V 3.5A
6.3V 0.5A
F2 5AMP
V10 6Y6
R23 47,000Ω
R24 47,000Ω
210-230V
C7 0.1MFD
R25 47,000Ω
C 0.5MFD
V12 M1060
T5 RAYTHEON UX9117A
530V 0.021A
F1 5AMP
I2
V9 6X5
V11 6AK5
R30 25,000Ω
R35 100Ω
C6 20MFD 450V
R34 0.1MEG 1W
R40 68,000Ω
R41 50,000Ω
C8 8MFD 250V
R42 47,000Ω
V13 0B2
S2 DPST
110V AC
V16 5U4
840V 0.110A
5V 3A
L1 C-1410 5H 175mA
C12 20MFD 450V
C13 20MFD 450V
C20 0.25MFD
C20 0.1MFD
C14 20MFD 450V
C15 20MFD 450V
R43 15,000Ω 10W
R44 2,000Ω 2W
V20 829
R46 100Ω 1W
R45 20,000Ω
R52 0.1MEG
R53 20,000
V18 0A2
V19 0B2
V21 6AK5
V17 6X5
C16 20MFD 450V
C17 20MFD 450V
R49 5K 8W
R50 5K 8W
R51 5K 8W

2



NOTES:

ALL RESISTORS ARE ½W UNLESS OTHERWISE SPECIFIED.

ALL CONDENSERS ARE 600V UNLESS OTHERWISE SPECIFIED

ITEM	MATERIAL - DESCRIPTION	PART NO.	QUA

SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

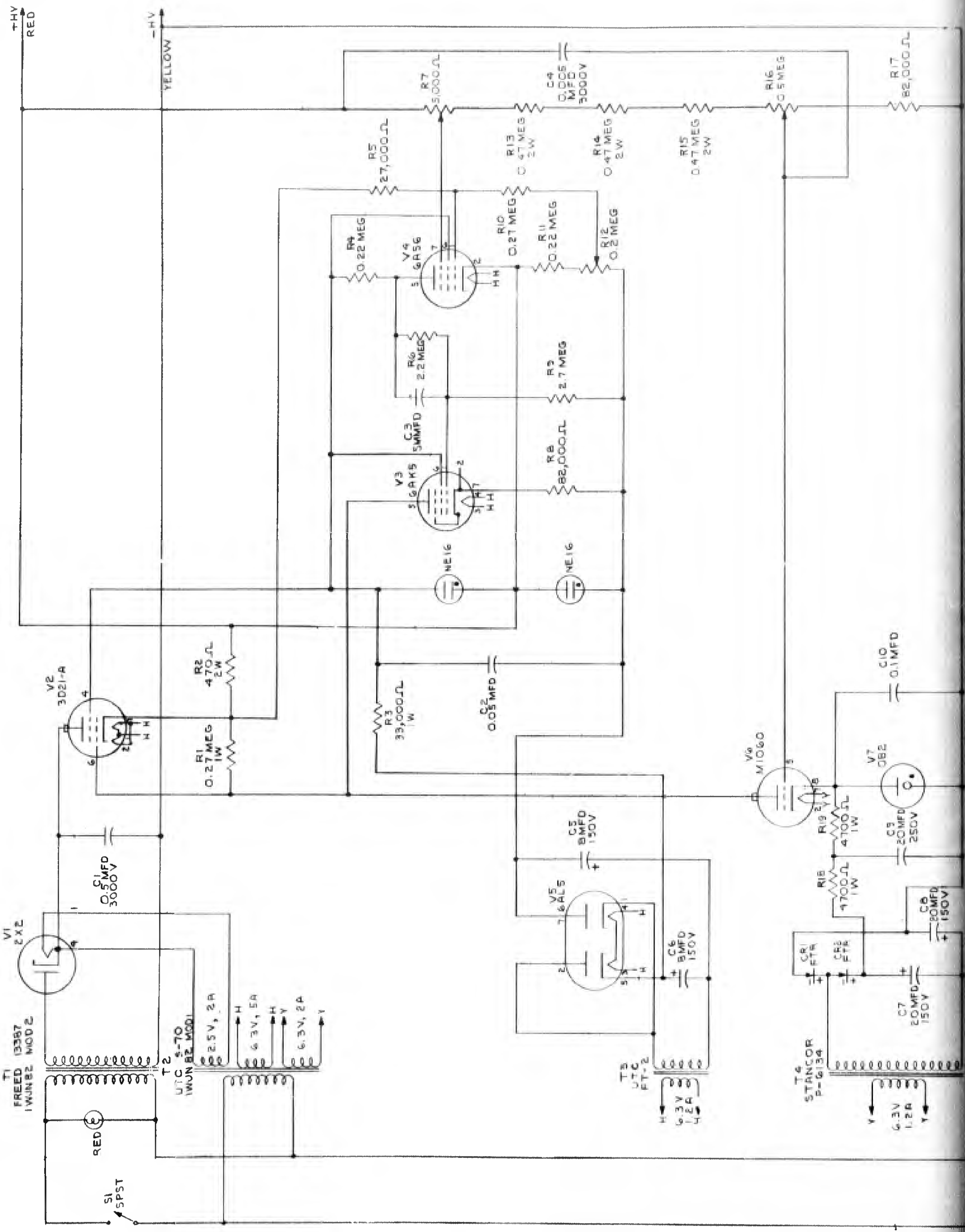
HIGH VOLTAGE SUPPLY
L.S.T. DEMONSTRATION UNIT

SCALE: | DR. D.L.C. 10-13-47 | TR. | CK. | APP. M.J.N.

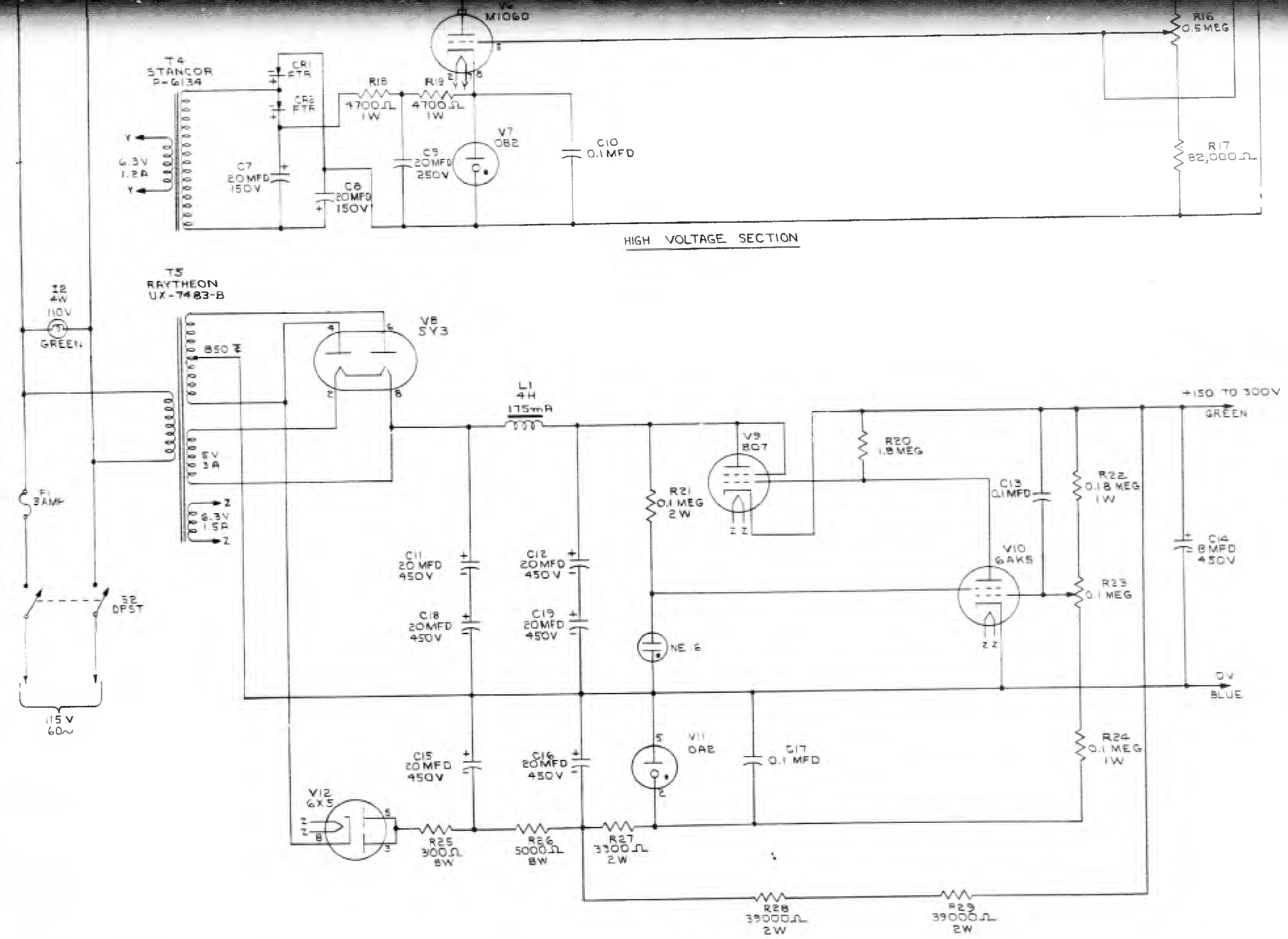
D-31027

1

D-31085



D-31085



LOW VOLTAGE SECTION

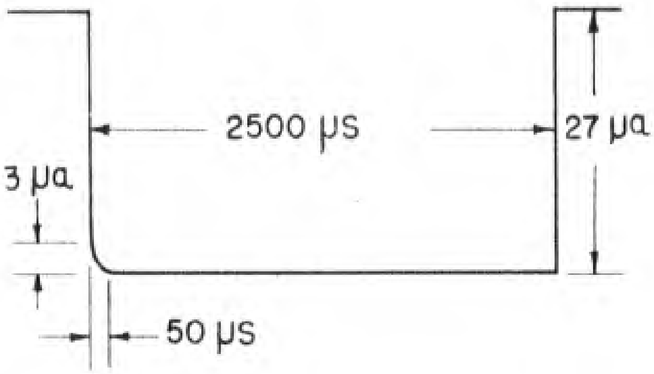
NOTES:
ALL RESISTORS ARE $\frac{1}{2}$W UNLESS OTHERWISE SPECIFIED
ALL CONDENSERS ARE 600V UNLESS OTHERWISE SPECIFIED.
L1 IS STANCOR C-1410
CR1 AND CR2 ARE FTR SELENIUM RECTIFIERS #403D2625 (100ma)

HOLDING GUN POWER SUPPLY

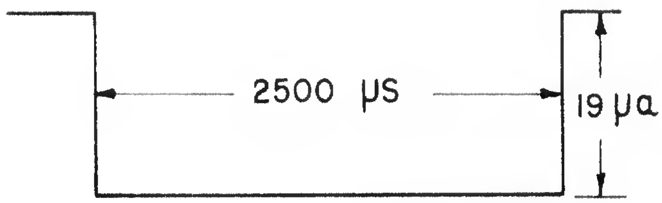
MASSACHUSETTS INSTITUTE OF TECHNOLOGY SERVOMECHANISMS LABORATORY	
6345	D.L.O. 10-19-47
W.J.N.	D-31085

D-31085

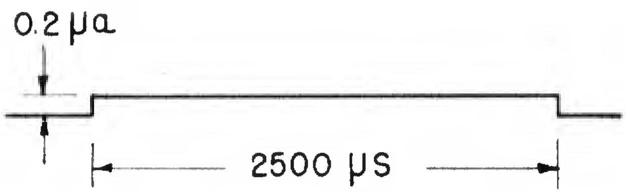
2



3rd ANODE CURRENT



SCREEN CURRENT

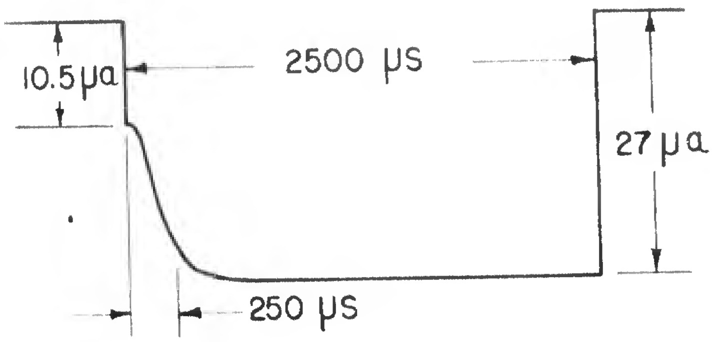


SIGNAL PLATE CURRENT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

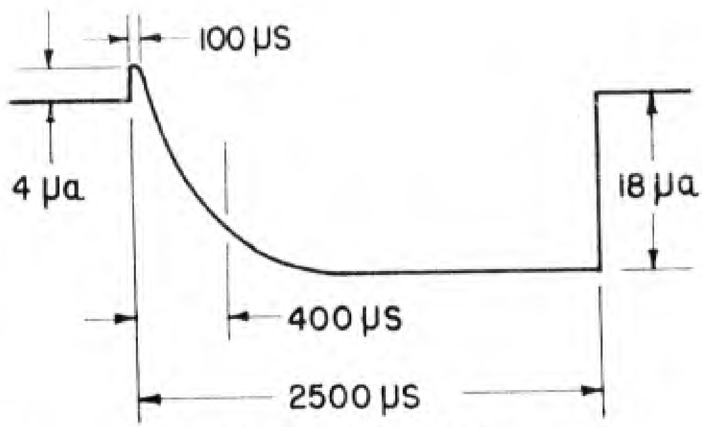
IWJN 104

USED IN 6345 REPORT R-112



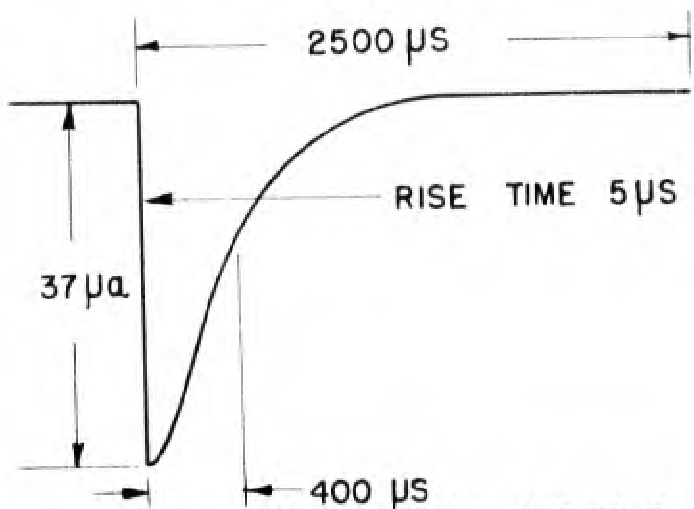
IWJN 105

3rd ANODE CURRENT



SCREEN CURRENT

IWJN 104



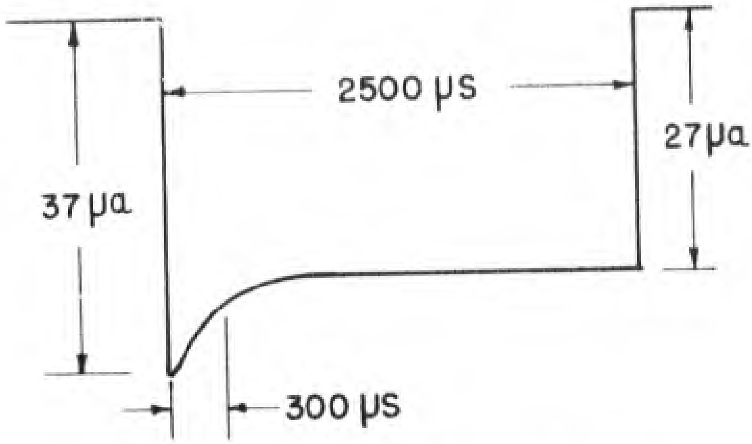
SIGNAL PLATE CURRENT

USED IN 6345 REPORT R-112

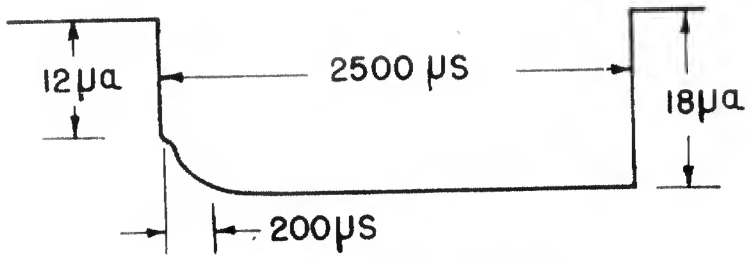
A-31103

IWJN 104

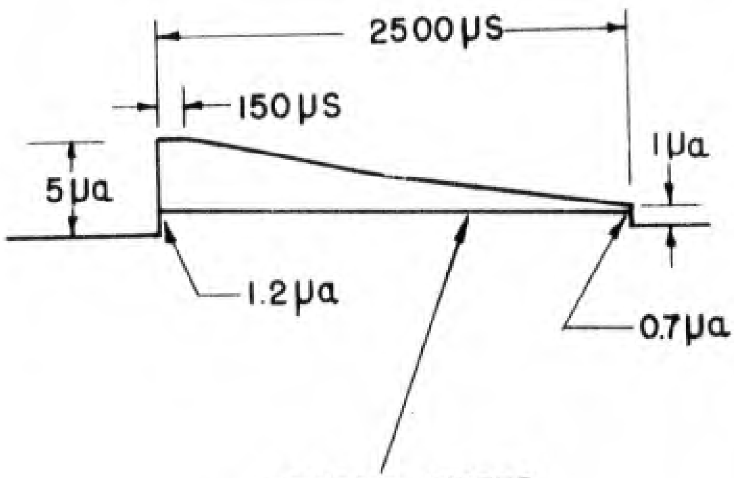
STORAGE TUBE MOD 1
CURRENT WAVEFORMS



3rd ANODE CURRENT



SCREEN CURRENT



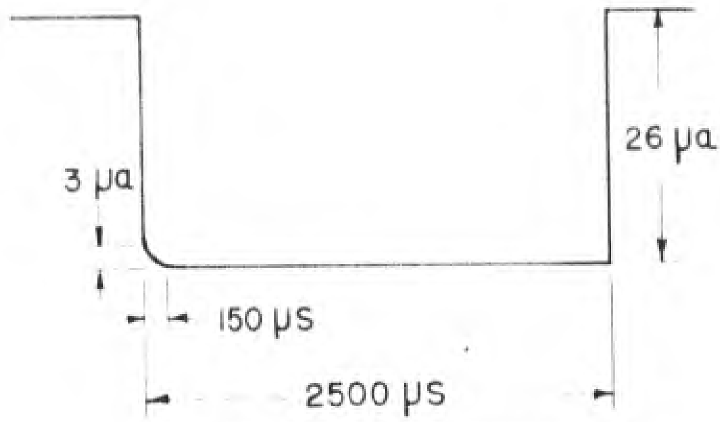
SECOND SWEEP
SIGNAL PLATE CURRENT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

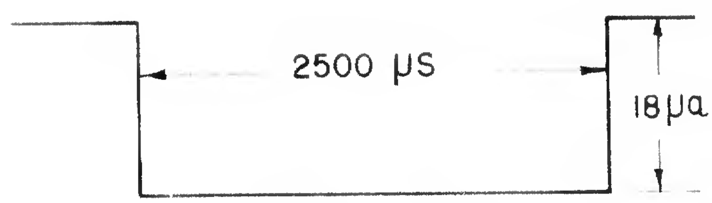
IWJN 105

USED IN 6345 REPORT R-112

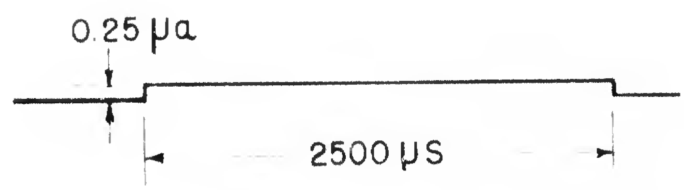
A-31104



3rd ANODE CURRENT



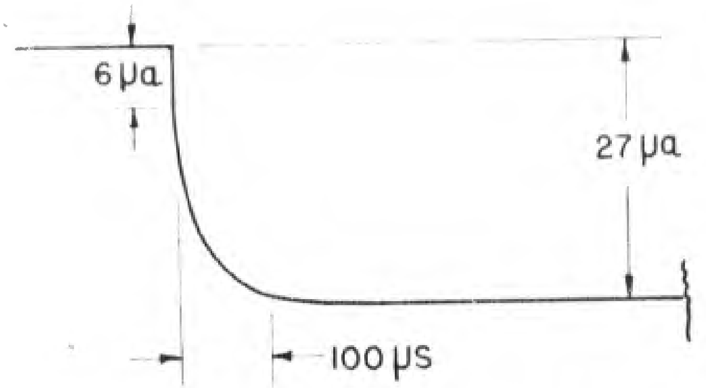
SCREEN CURRENT



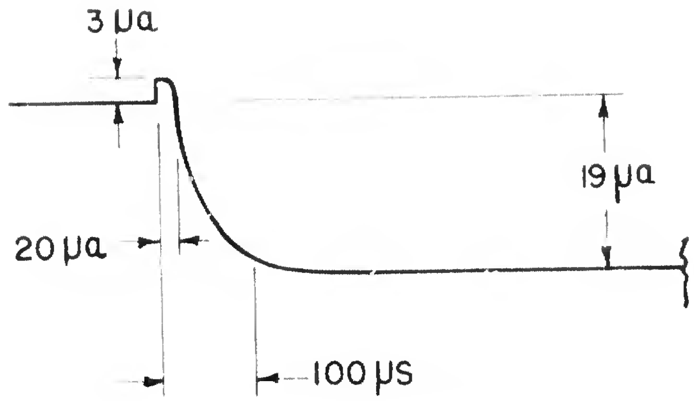
SIGNAL PLATE CURRENT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

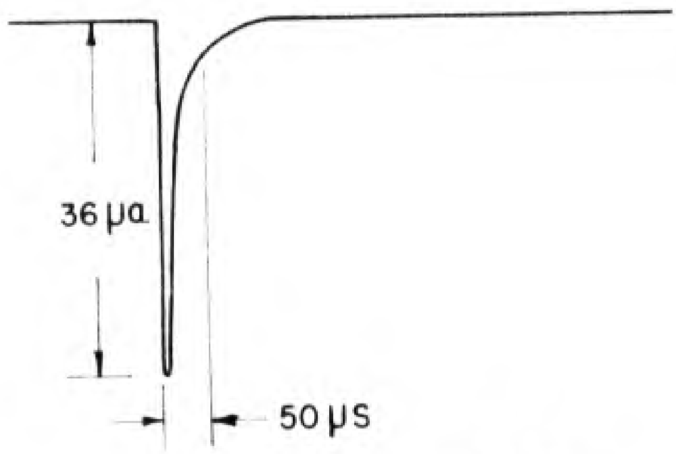
A-31105 USED IN 6345 REPORT R-112



3rd ANODE CURRENT



SCREEN CURRENT



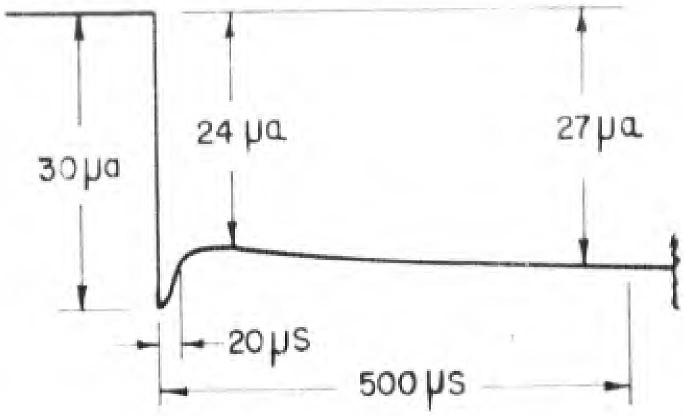
SIGNAL PLATE CURRENT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

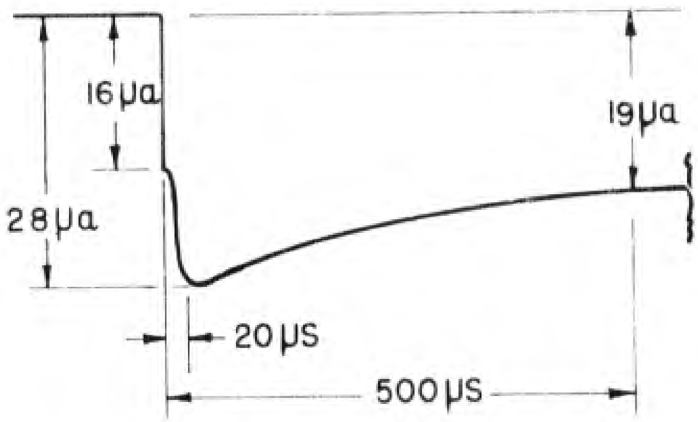
USED IN 6345 REPORT R-112

A-31106

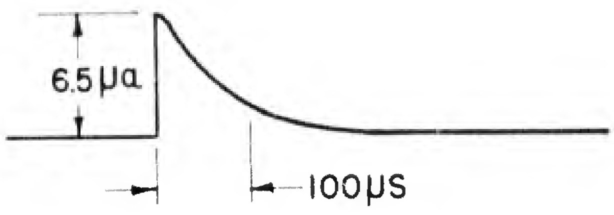
IWJN 106



3rd ANODE CURRENT



SCREEN CURRENT



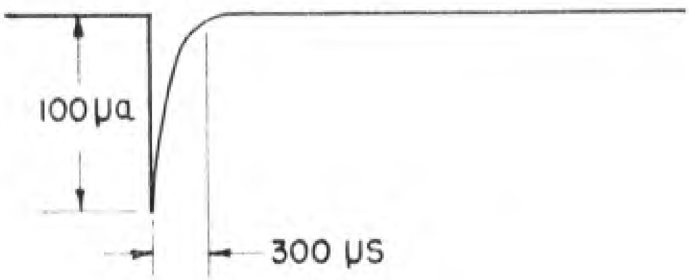
SIGNAL PLATE CURRENT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

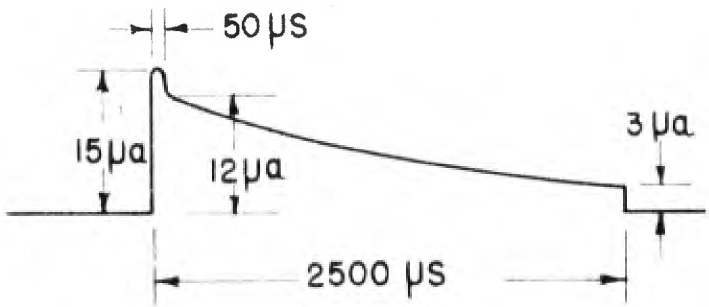
USED IN 6345 REPORT R-112

A-31107

IWJN 107

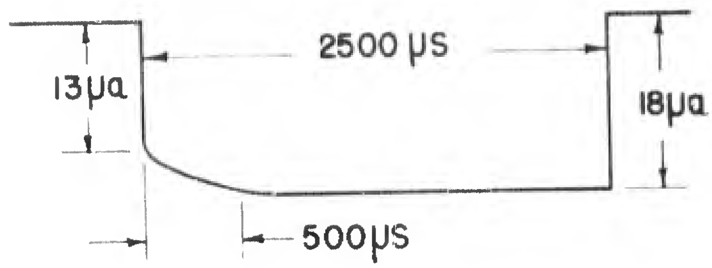


SIGNAL PLATE CURRENT
NEGATIVE CHARGING

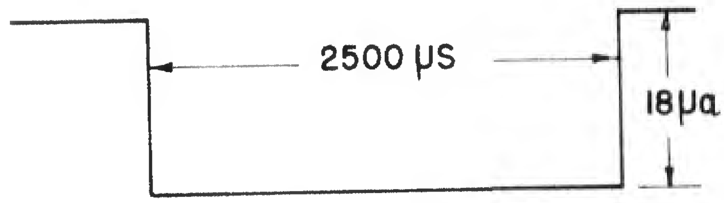


SIGNAL PLATE CURRENT
POSITIVE CHARGING

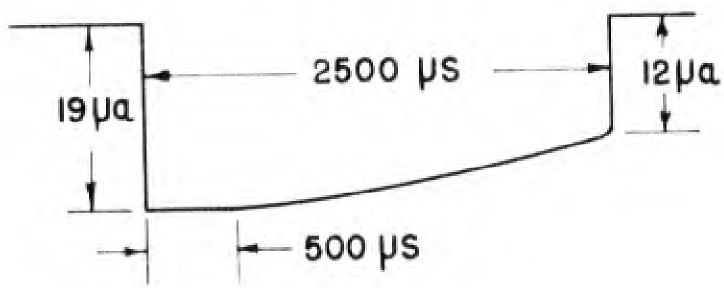
STORAGE TUBE MOD 1
CURRENT WAVEFORMS



SCREEN CURRENT
BEAM DISPLACED TO LEFT



SCREEN CURRENT
BEAM CENTERED

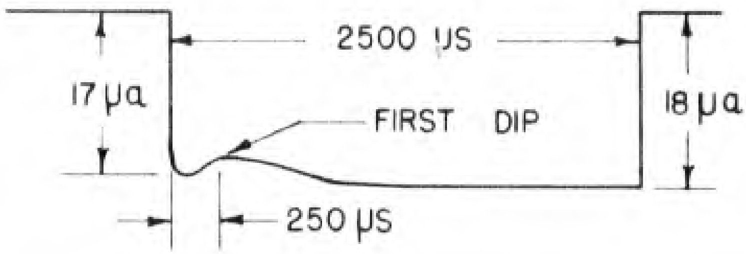


SCREEN CURRENT
BEAM DISPLACED TO RIGHT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

A-31109 USED IN 6345 REPORT R-112

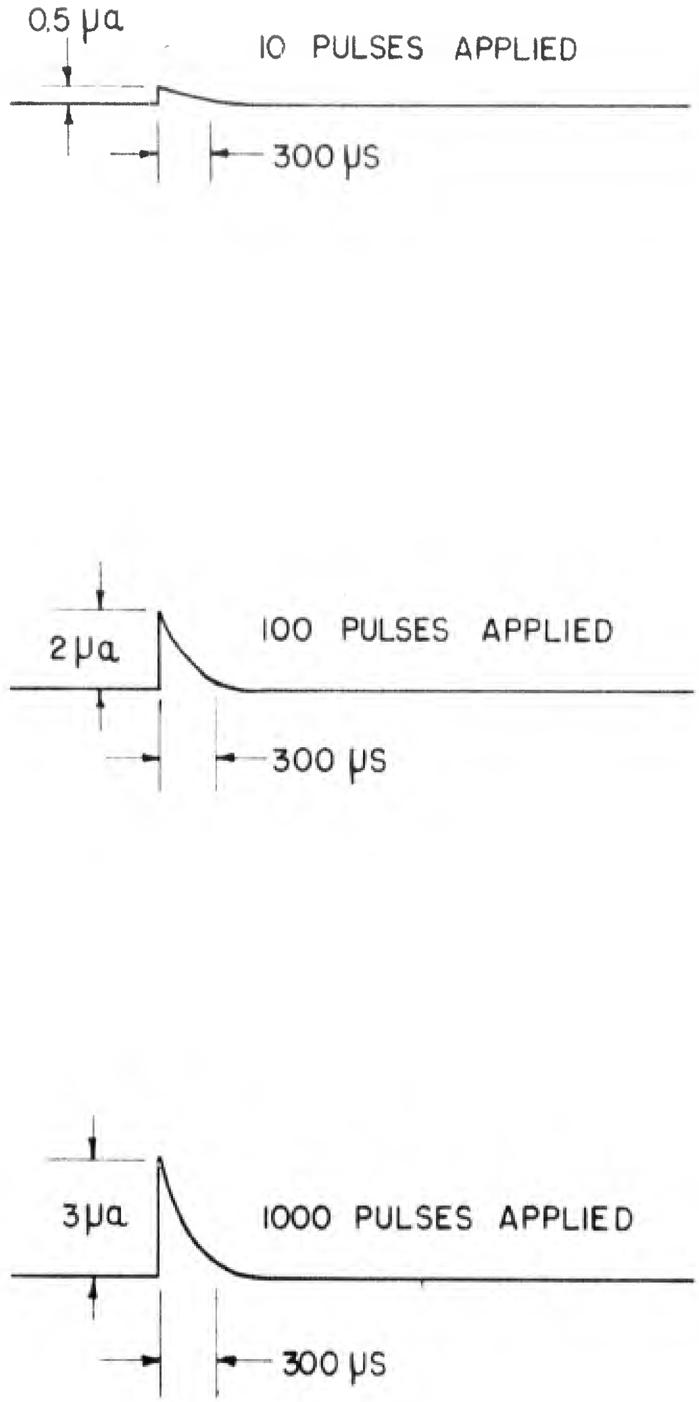
1WJN 108



SCREEN CURRENT
BEAM DISPLACED TO LEFT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

A-3110 USED IN 6345 REPORT R-112

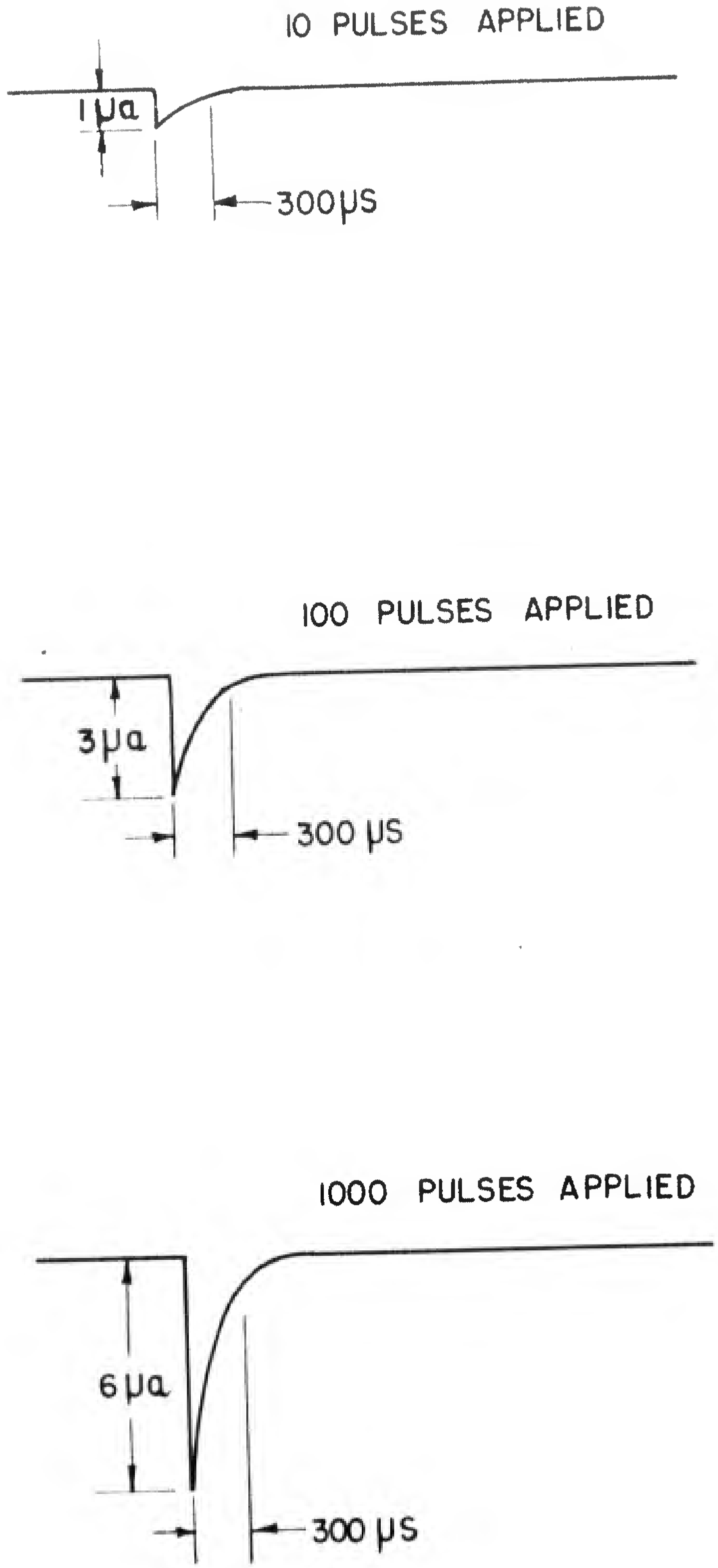


SIGNAL PLATE CURRENT

STORAGE TUBE MOD 1
CURRENT WAVEFORMS

IWJN 109

A-31111 USED IN 6345 REPORT R-112



SIGNAL PLATE CURRENT

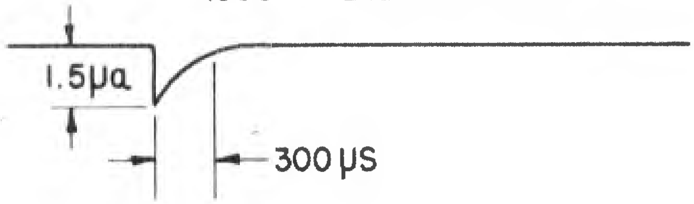
STORAGE TUBE MOD 1
CURRENT WAVEFORMS

IWJN 109

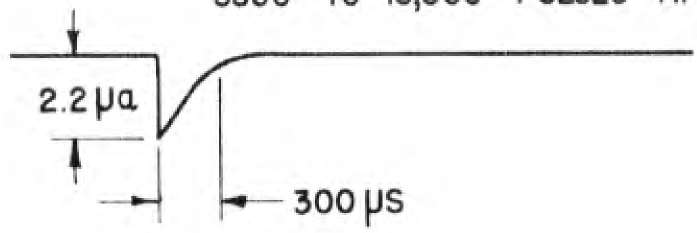
USED IN 6345 REPORT R-112

A-3111

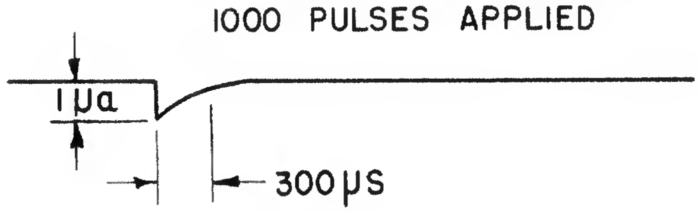
SIGNAL PLATE AT + 50 VOLTS
1000 PULSES APPLIED



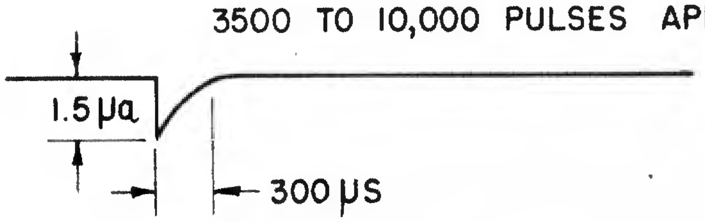
SIGNAL PLATE AT + 50 VOLTS
3500 TO 10,000 PULSES APPLIED



SIGNAL PLATE AT GROUND
1000 PULSES APPLIED



SIGNAL PLATE AT GROUND
3500 TO 10,000 PULSES APPLIED

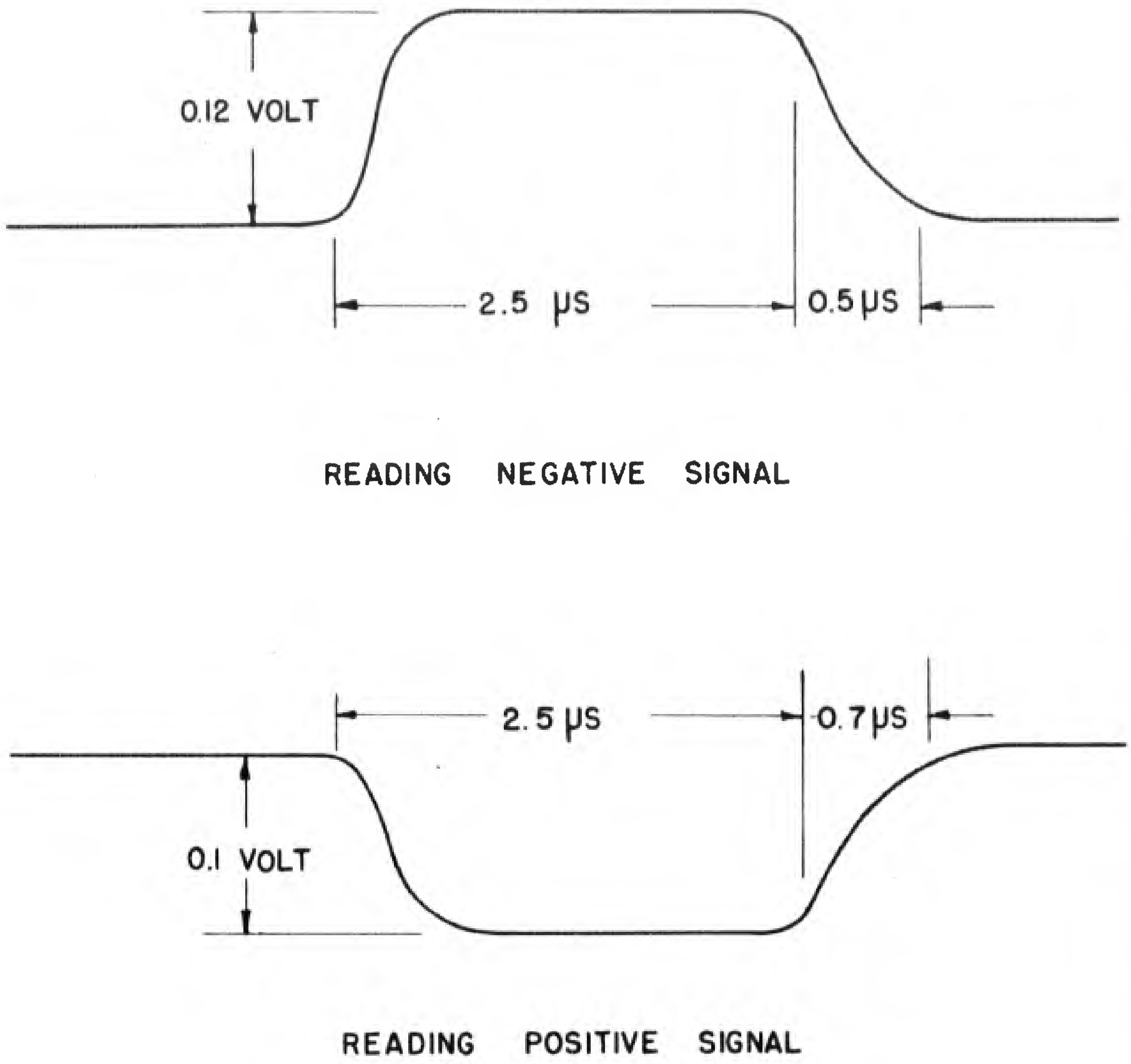


STORAGE TUBE MOD 1
CURRENT WAVEFORMS

IWJN 110

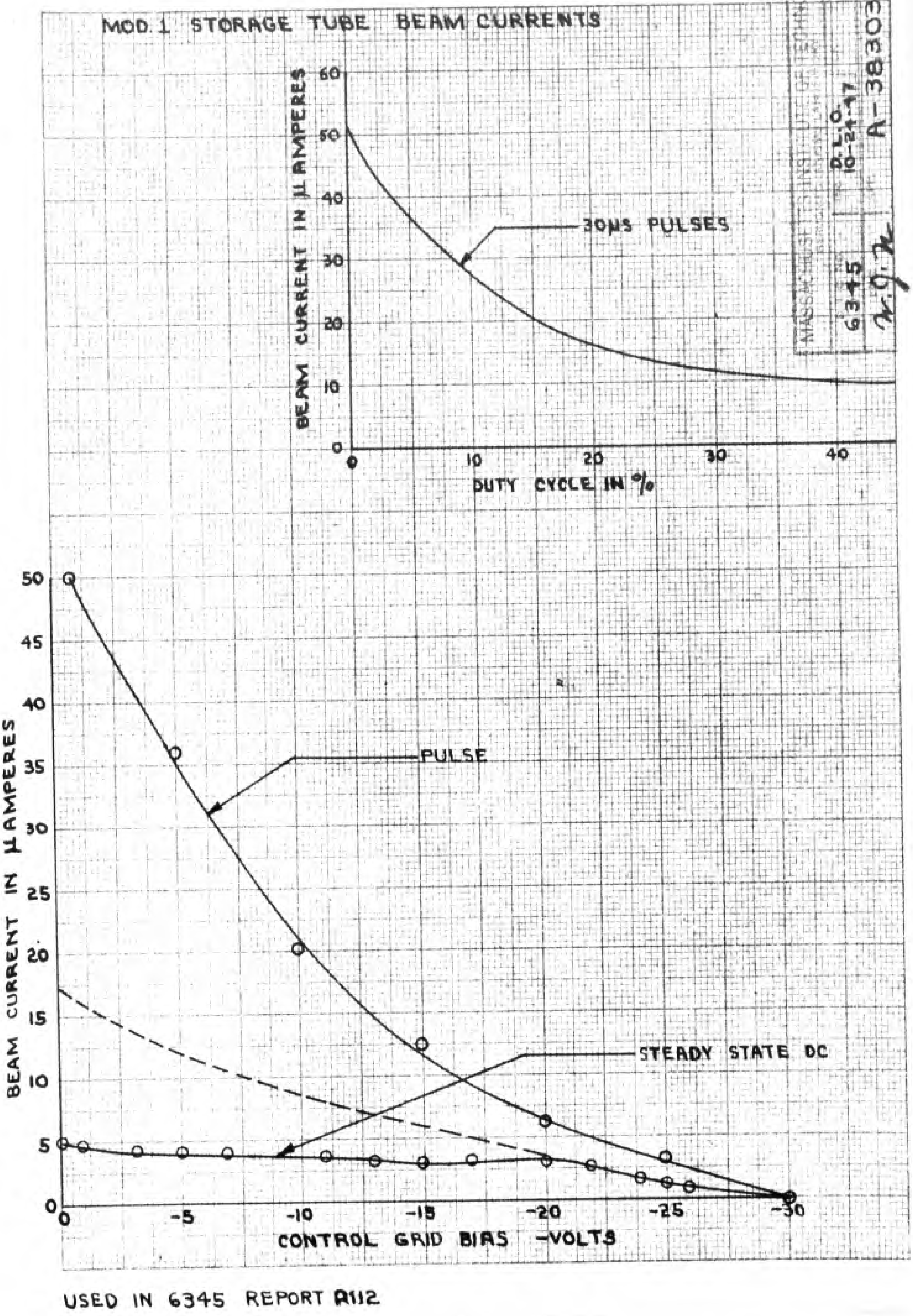
USED IN 6345 REPORT R-112

A-31113



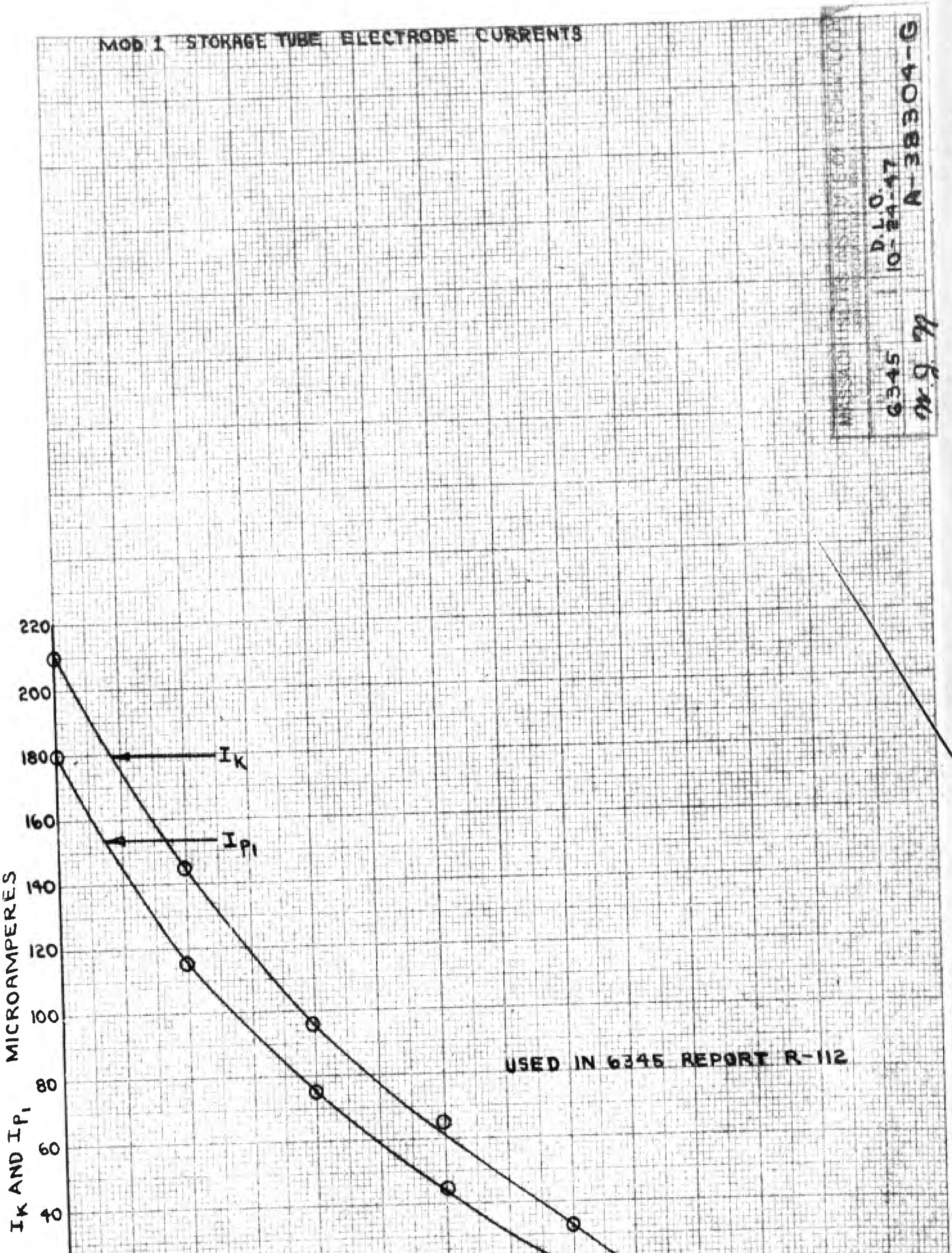
STORAGE TUBE MOD 15
OUTPUT WAVEFORMS

A-31187



USED IN 6345 REPORT R112

FORM IT TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.

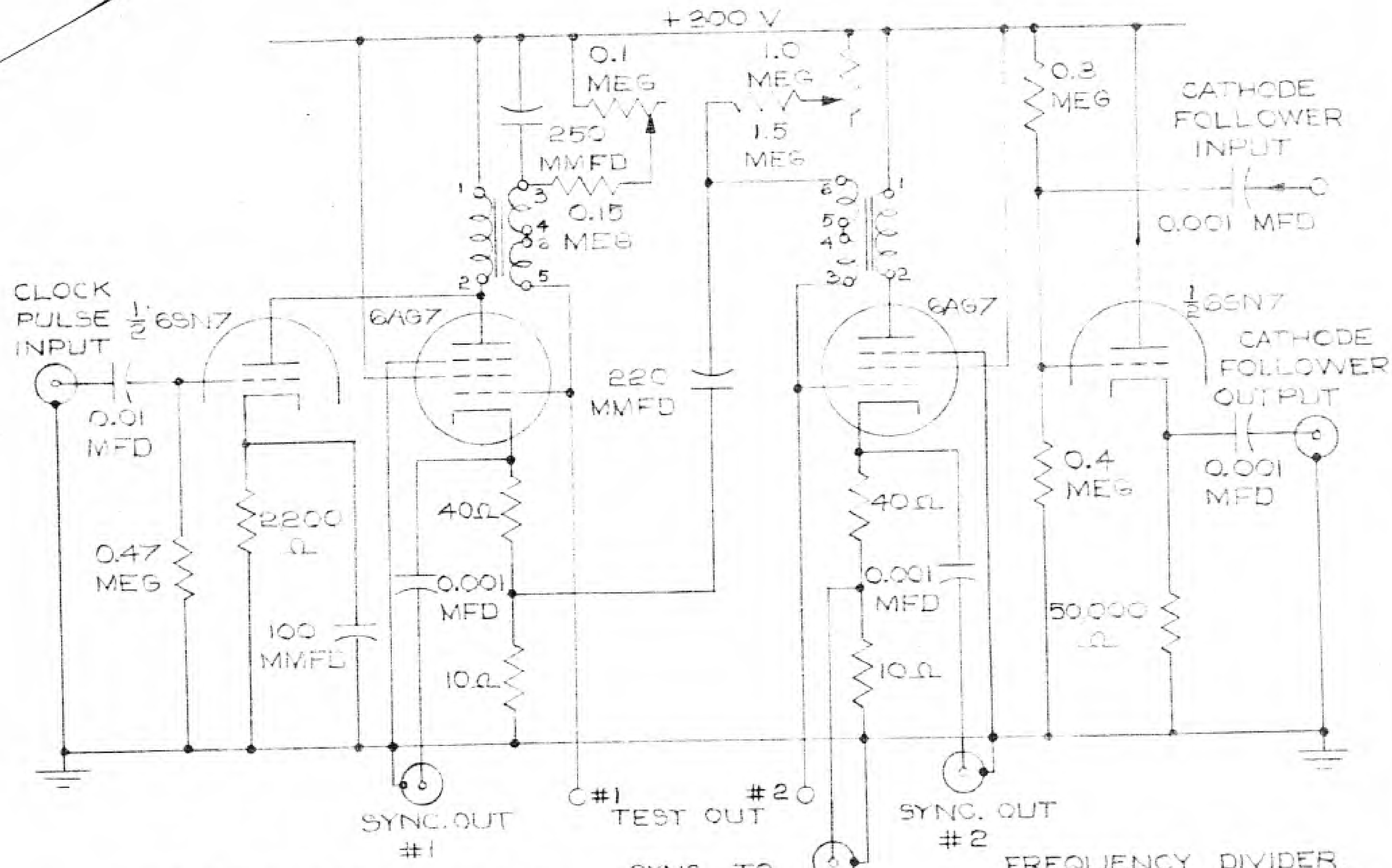


MASSACHUSETTS INSTITUTE OF TECHNOLOGY
6345 D.L.O. 10-24-47 A-38304-G
M.J. M.

TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.
FORM I T

A-38304-G

A-3305C



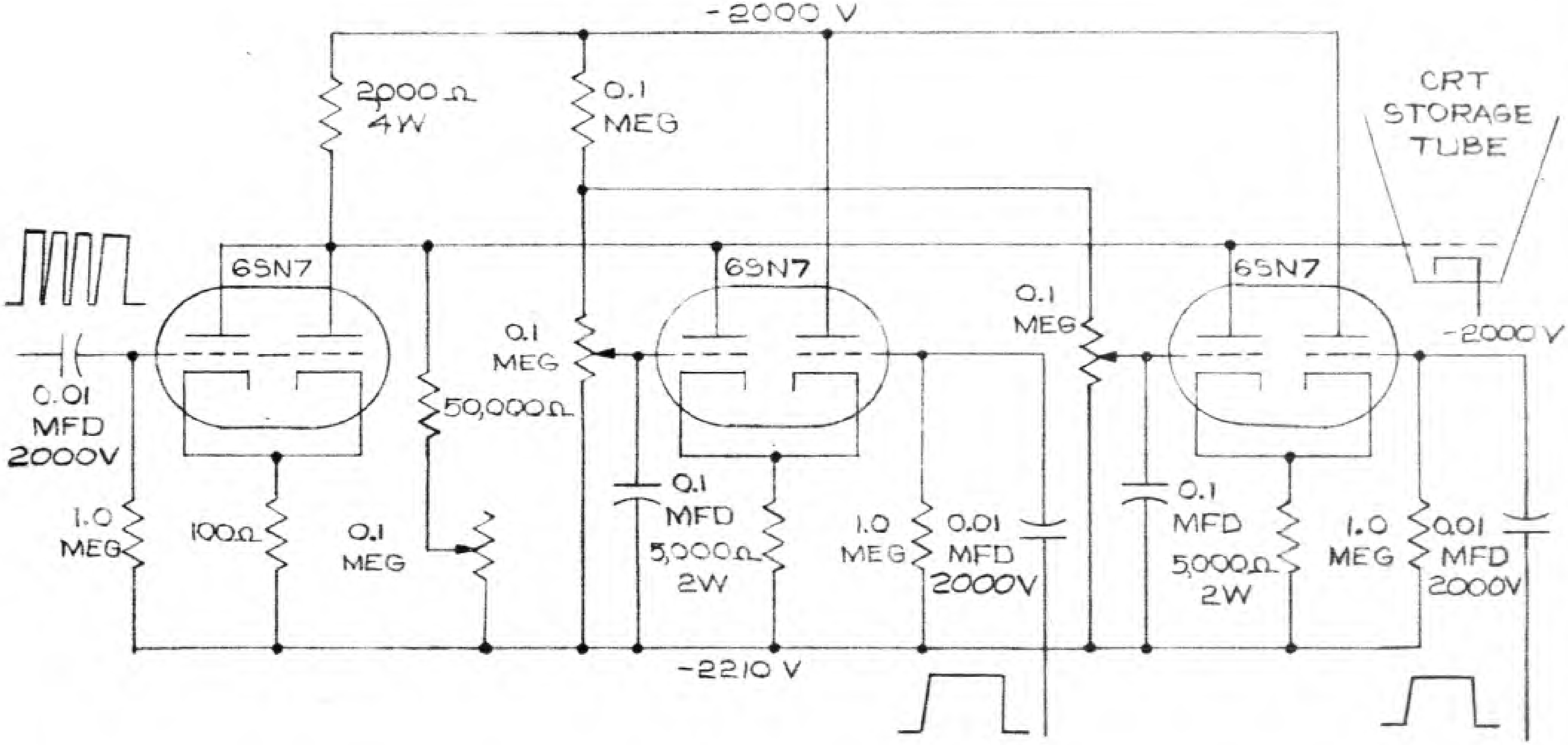
FREQUENCY DIVIDER

NOTE: TRANSFORMERS ARE WESTINGHOUSE 132AW.

6345

RVW
11-12-47

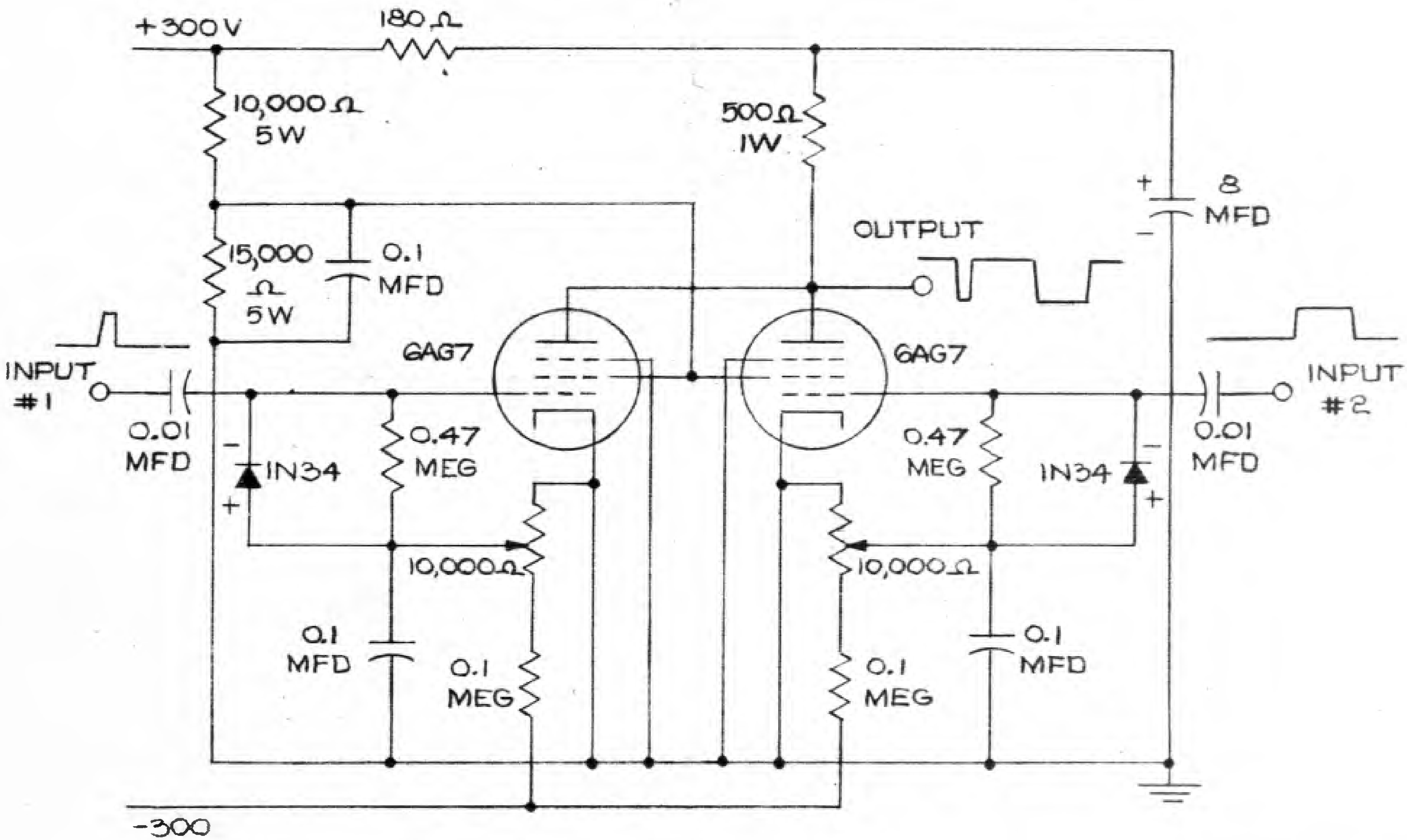
A-39051



STORAGE TUBE INTENSITY CONTROL

6345 RYW 11-11-47
M. J. N.
A-39051

A-39053



STORAGE TUBE INTENSITY
GATE MIXER

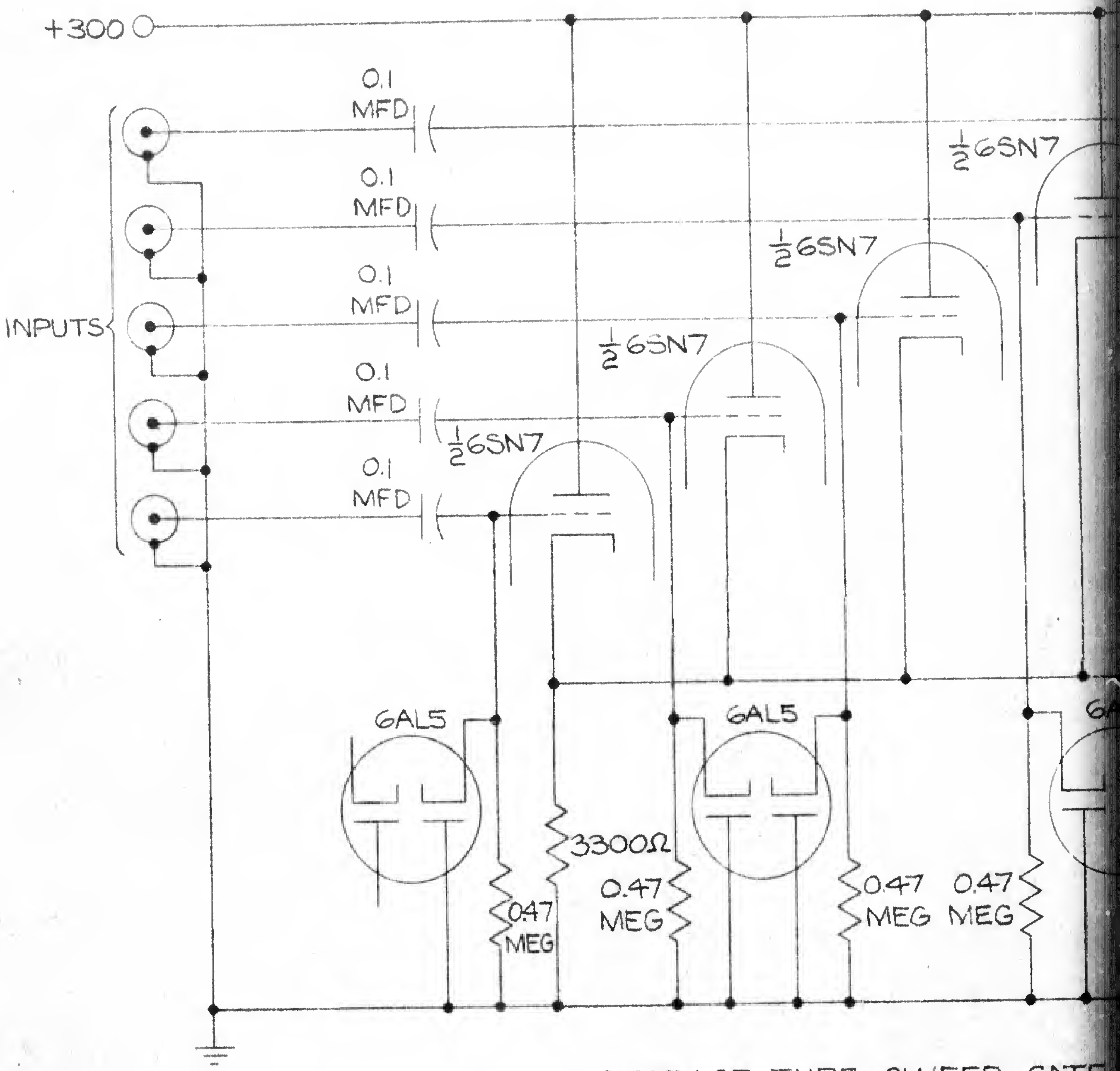
6345 RVW 11-11-47

M.J.N.

A-39053

B-39054-2

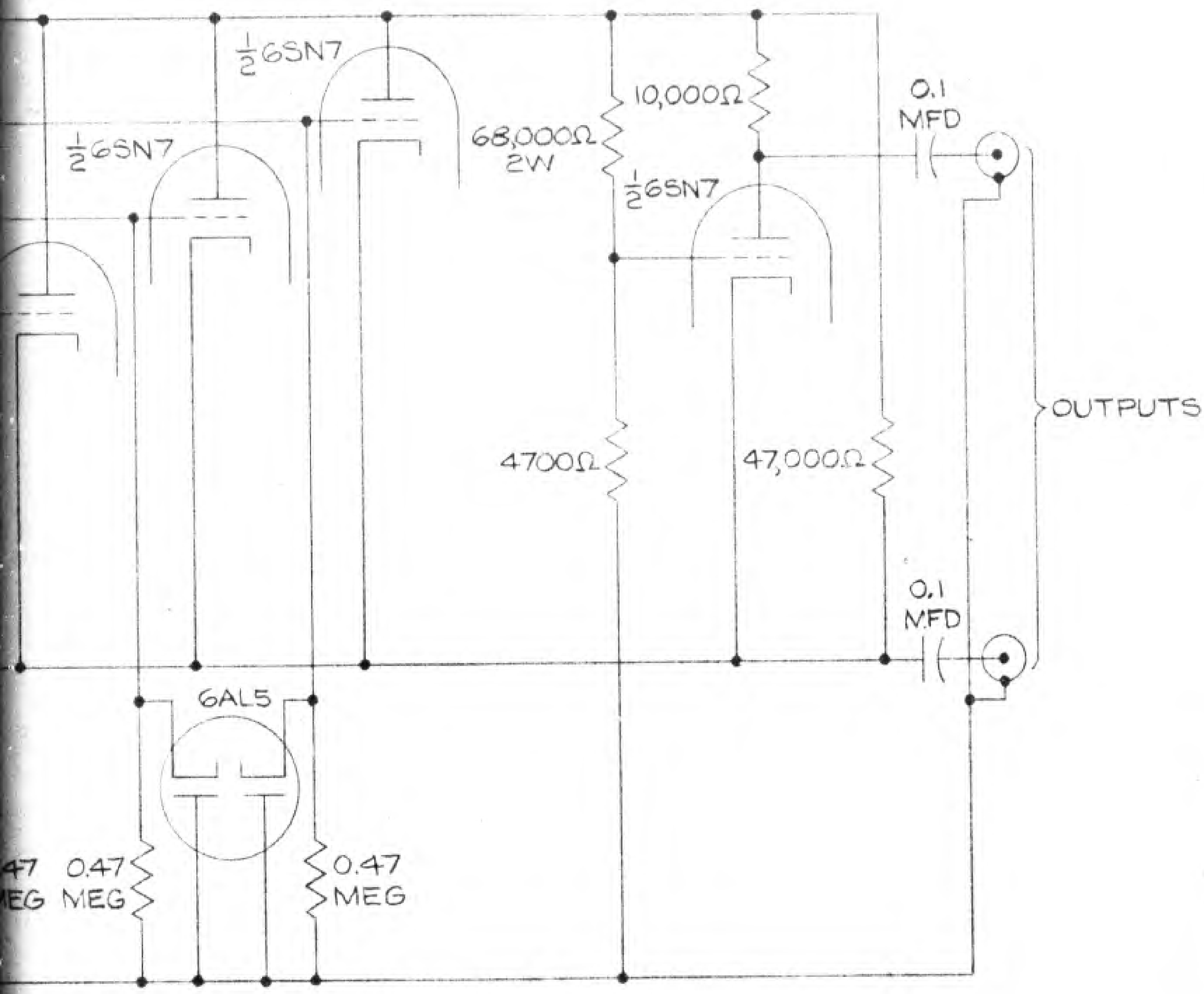
1



STORAGE TUBE SWEEP GATE

USED IN 6345 REPOR

2o



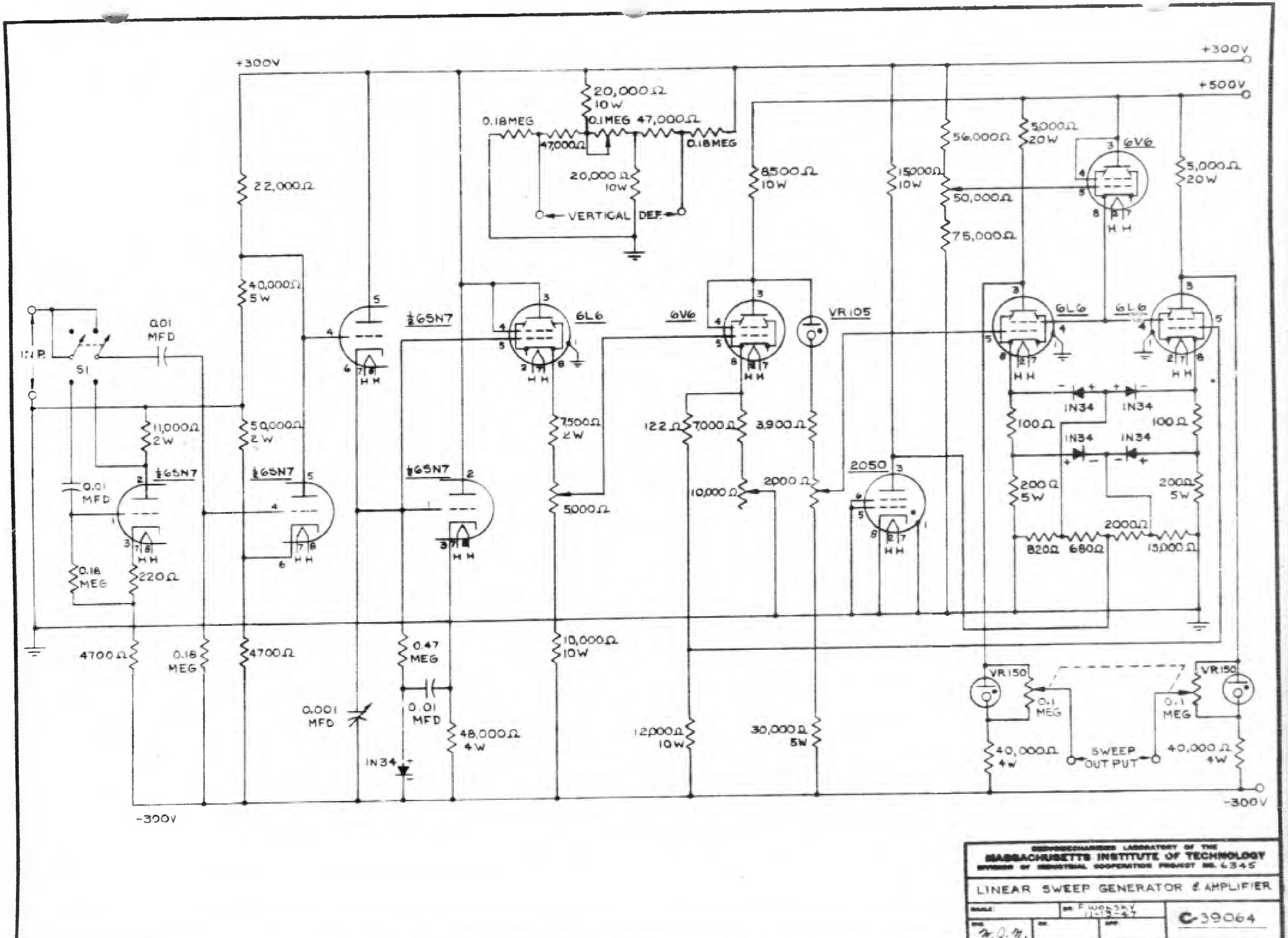
SWEEP GATE MIXER

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SERVOMECHANISMS LABORATORY

D.I.C. NO. 6345	DR. TL 2/3/47	CK SHR
ENG. SHR	APP.	B-39054-2

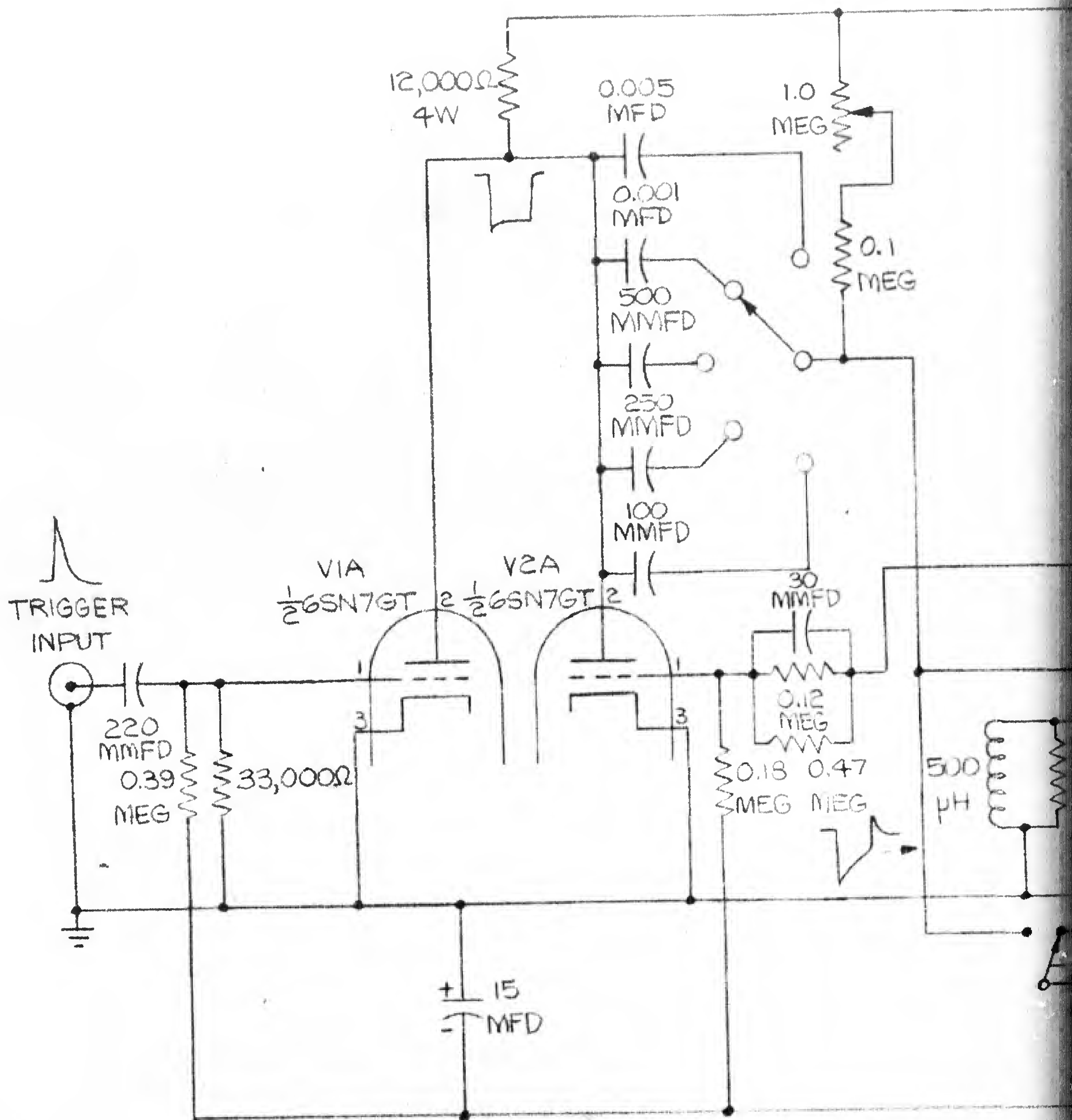
6345 REPORT R-112

C-39064

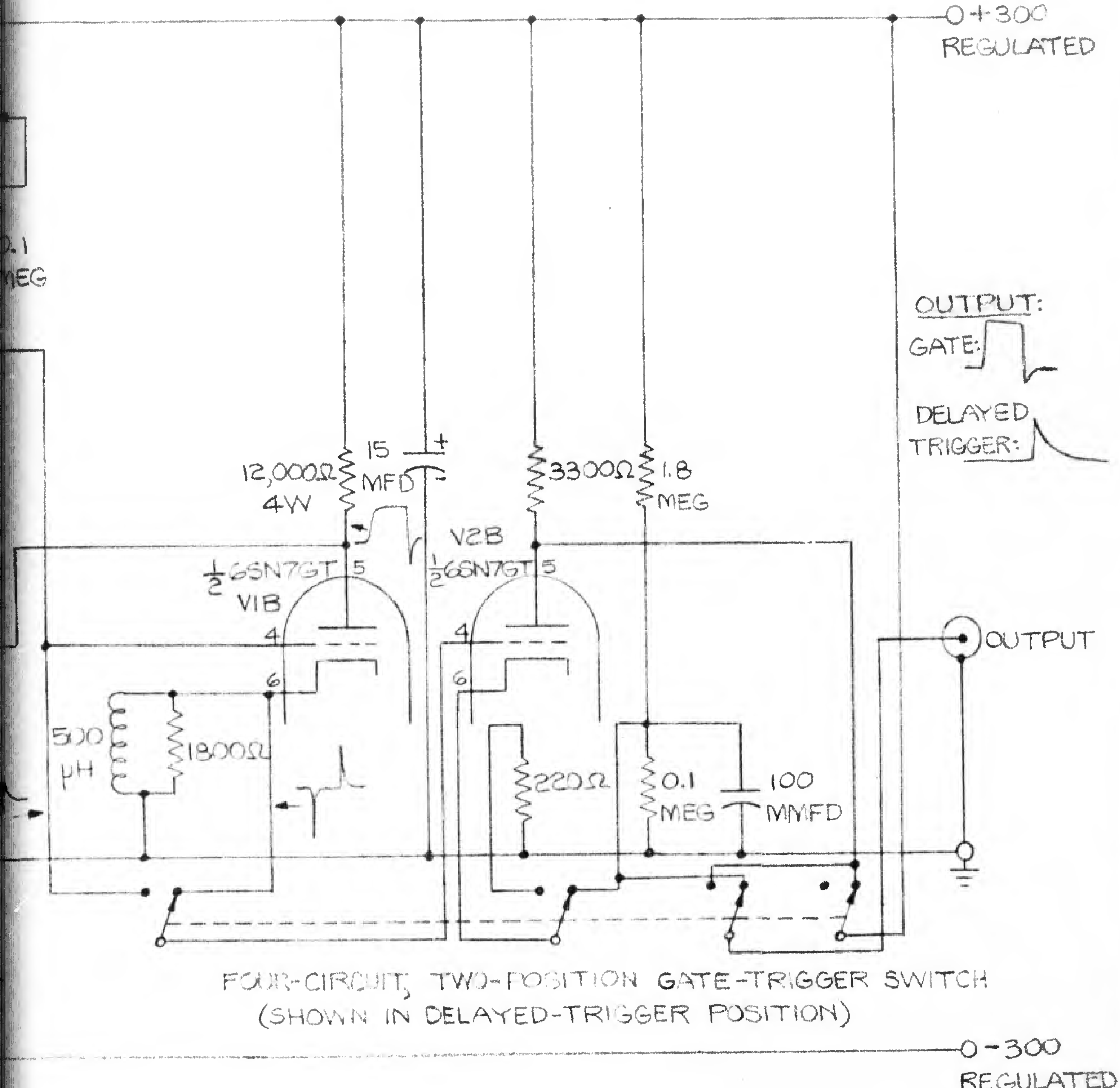

+300V
+500V
-300V
INP.
S1
0.01 MFD
11,000Ω 2W
½6SN7
0.18 MEG
220Ω
4700Ω
22,000Ω
40,000Ω 5W
50,000Ω 2W
0.001 MFD
IN34
0.47 MEG
0.01 MFD
48,000Ω 4W
6L6
7500Ω 2W
5000Ω
10,000Ω 10W
0.18MEG
47,000Ω
20,000Ω 10W
0.1MEG 47,000Ω
VERTICAL DEF.
6V6
8500Ω 10W
VR105
122Ω
7000Ω
3,900Ω
10,000Ω
2000Ω
12,000Ω 10W
30,000Ω 5W
15000Ω 10W
2050
56,000Ω
50,000Ω
75,000Ω
5000Ω 20W
5,000Ω 20W
6L6
100Ω
200Ω 5W
820Ω
680Ω
2000Ω
15,000Ω
VR150
0.1 MEG
40,000Ω 4W
SWEEP OUT PUT
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
PROJECT NO. 6345
LINEAR SWEEP GENERATOR & AMPLIFIER
F. WOLSKY 11-13-47
C-39064

B-39081-2

1


12,000Ω
4W
0.005
MFD
1.0
MEG
0.001
MFD
0.1
MEG
500
MMFD
250
MMFD
100
MMFD
V1A
½6SN7GT
V2A
½6SN7GT
30
MMFD
TRIGGER
INPUT
220
MMFD
0.39
MEG
33,000Ω
0.12
MEG
0.18
MEG
0.47
MEG
500
μH
15
MFD

2



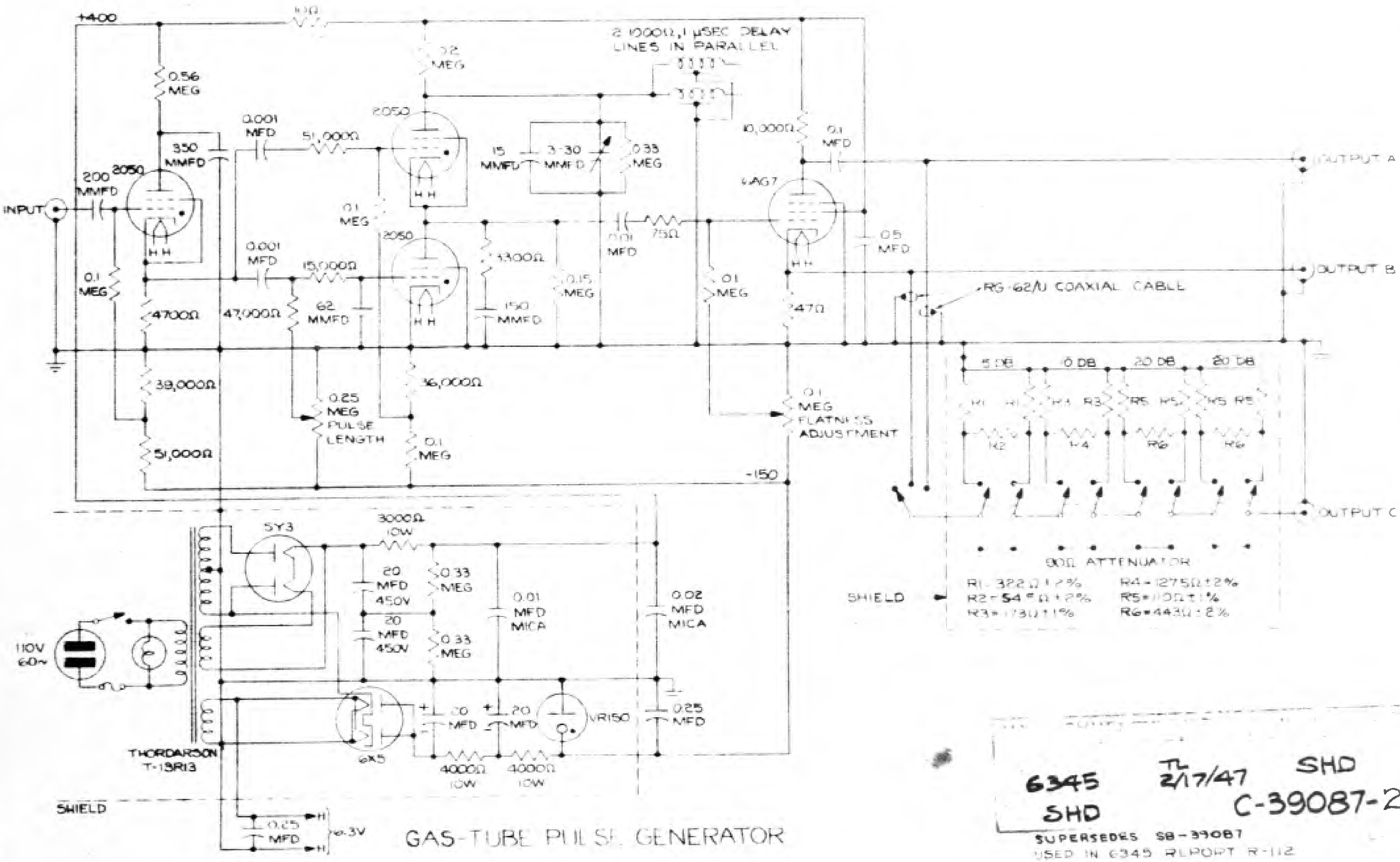
GATE GENERATOR OR DELAY BOX

P.C.G.
9/30/46

6345 B-39081-2

USED IN 6345 REPORTS R-112 & R-120

C-39087-2



GAS-TUBE PULSE GENERATOR

6345 SHD

TL 2/17/47

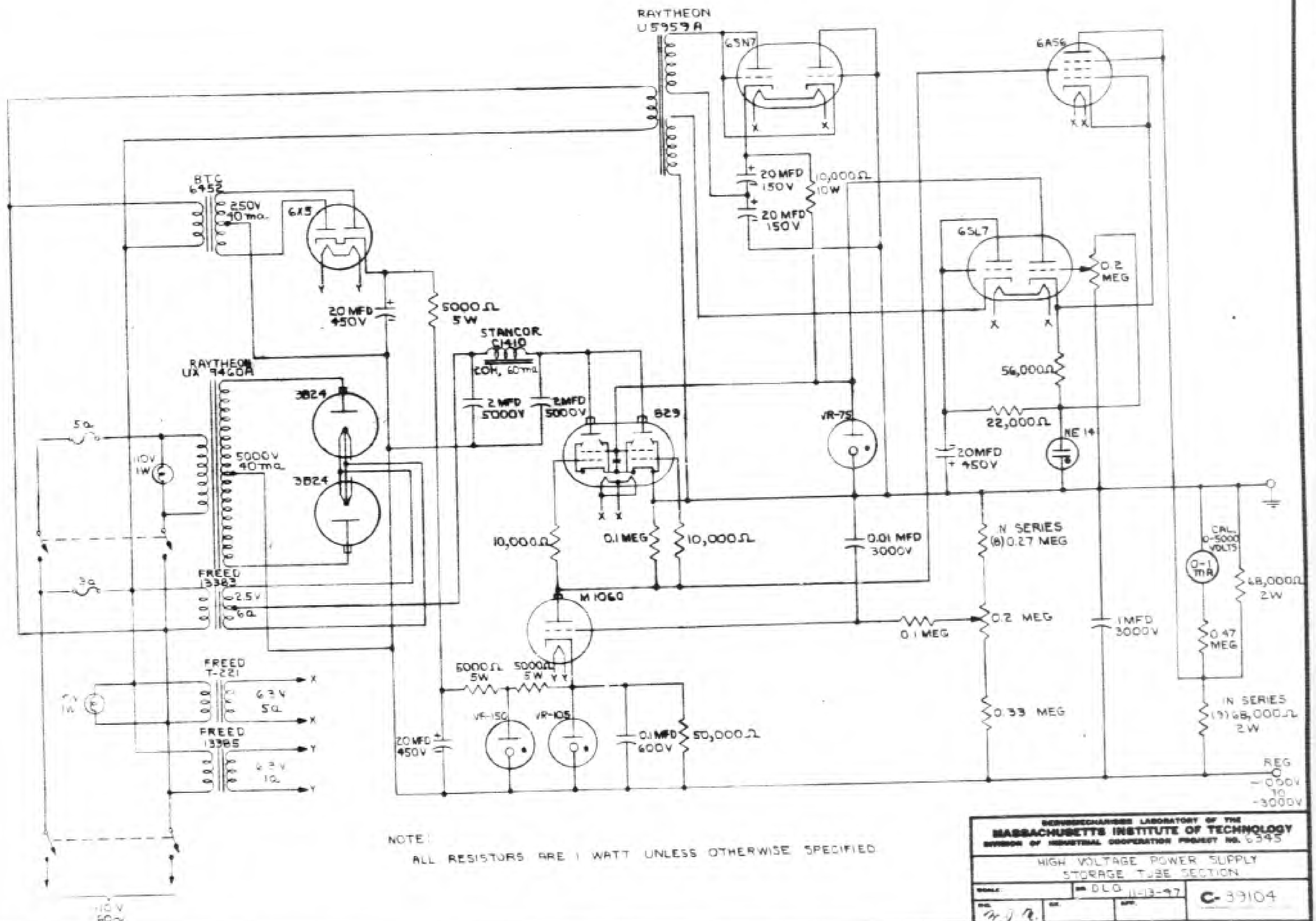
SHD

C-39087-2

SUPERSEDES SB-39087

USED IN 6345 REPORT R-112

C-39104



NOTE:
ALL RESISTORS ARE 1 WATT UNLESS OTHERWISE SPECIFIED

SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

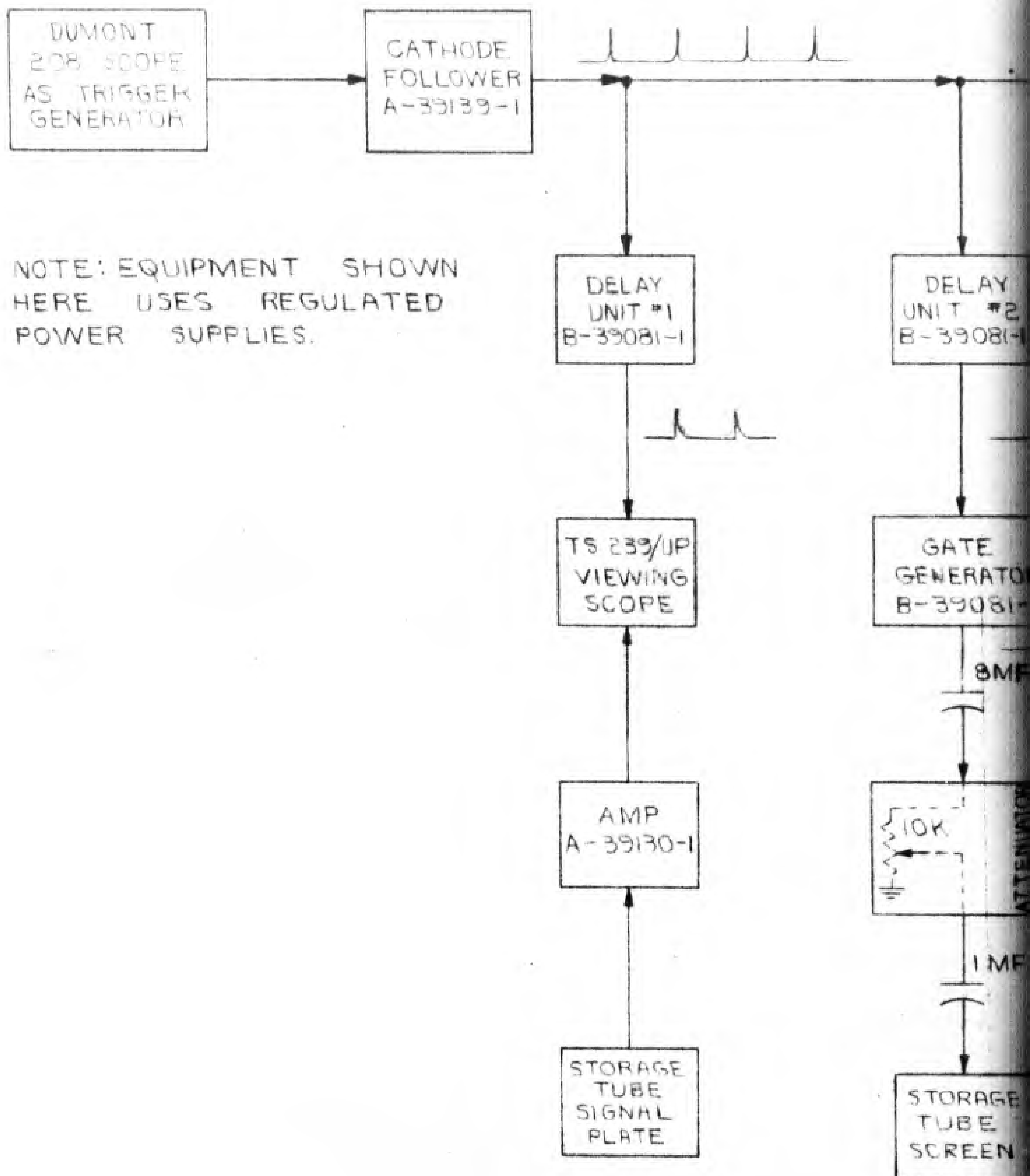
HIGH VOLTAGE POWER SUPPLY
STORAGE TUBE SECTION

DR. DLQ 11-13-47

C-39104

B-39132-C

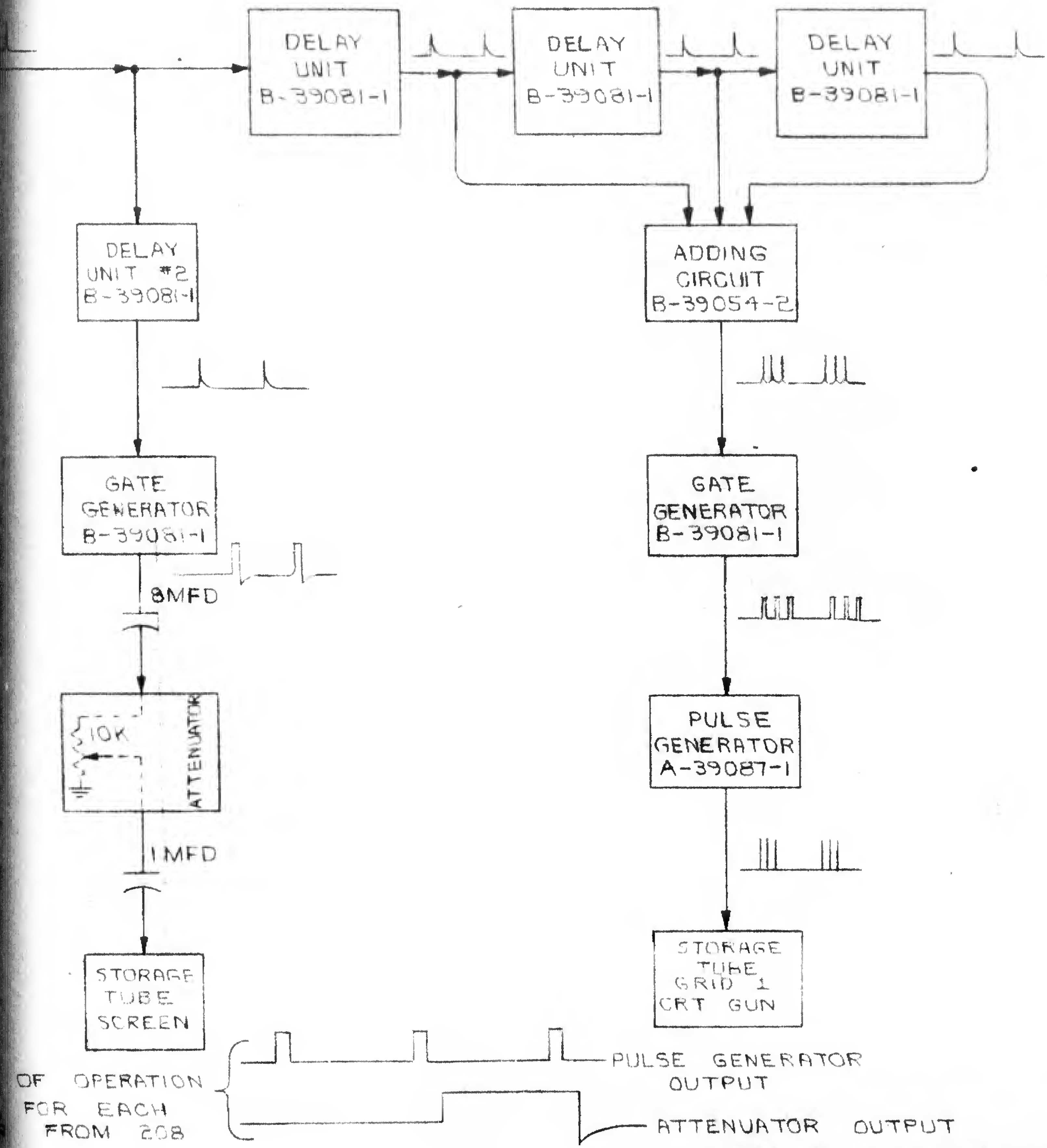
1



CYCLE OF OPERATION
NOTE: 1 CYCLE FOR EACH TRIGGER FROM 208

BLOCK DIAGRAM OF STORAGE T
FOR AUTOMATIC SWITCH

2

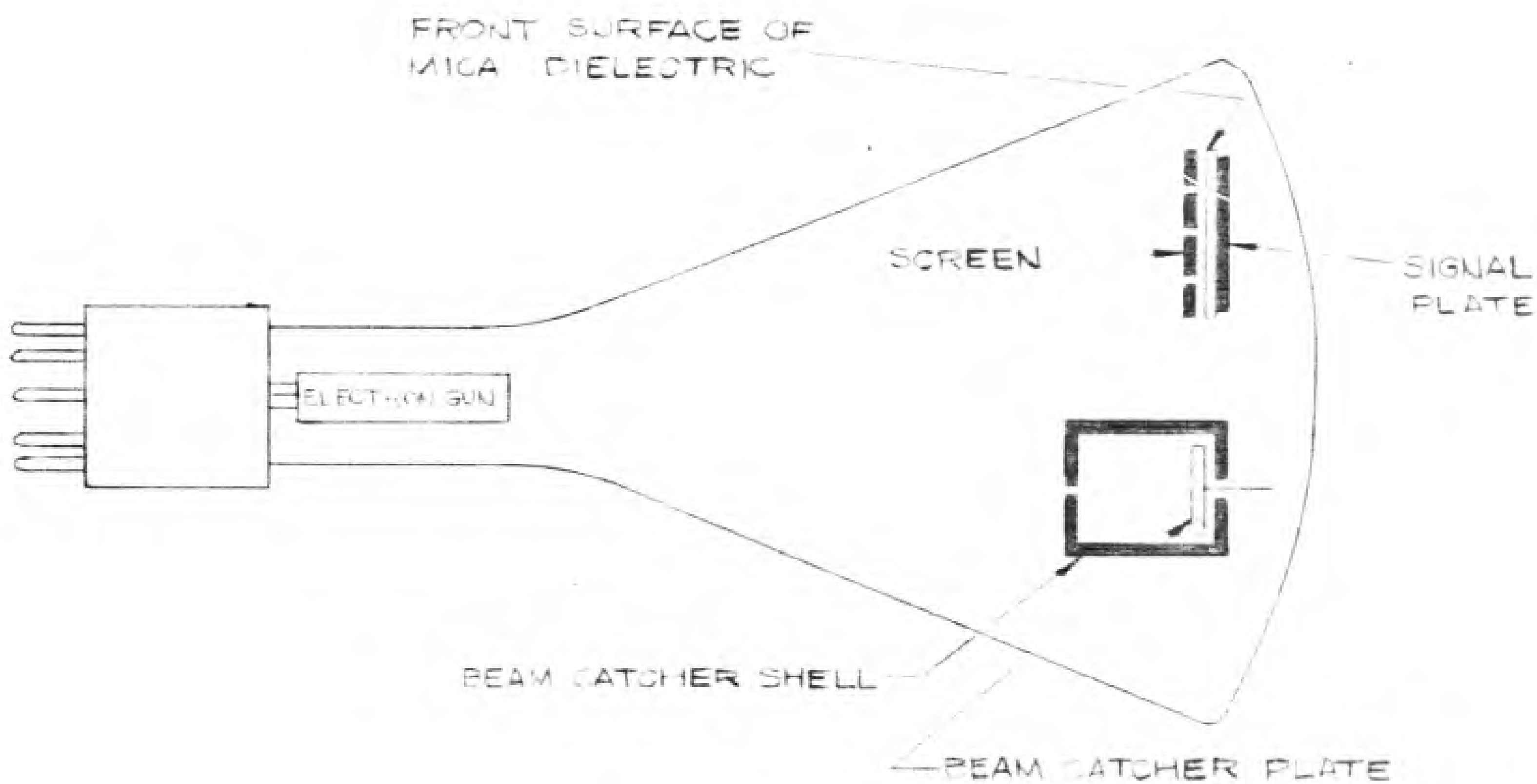


STORAGE TUBE TEST EQUIPMENT
IC SWITCHING OF SCREEN.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SERVOMECHANISMS LABORATORY

D.I.C. NO. 6345	DR. D.L.O. 1-28-46	CK TL 2/4/47
ENG. SHW	APP.	B-39132-2

A-39147-1



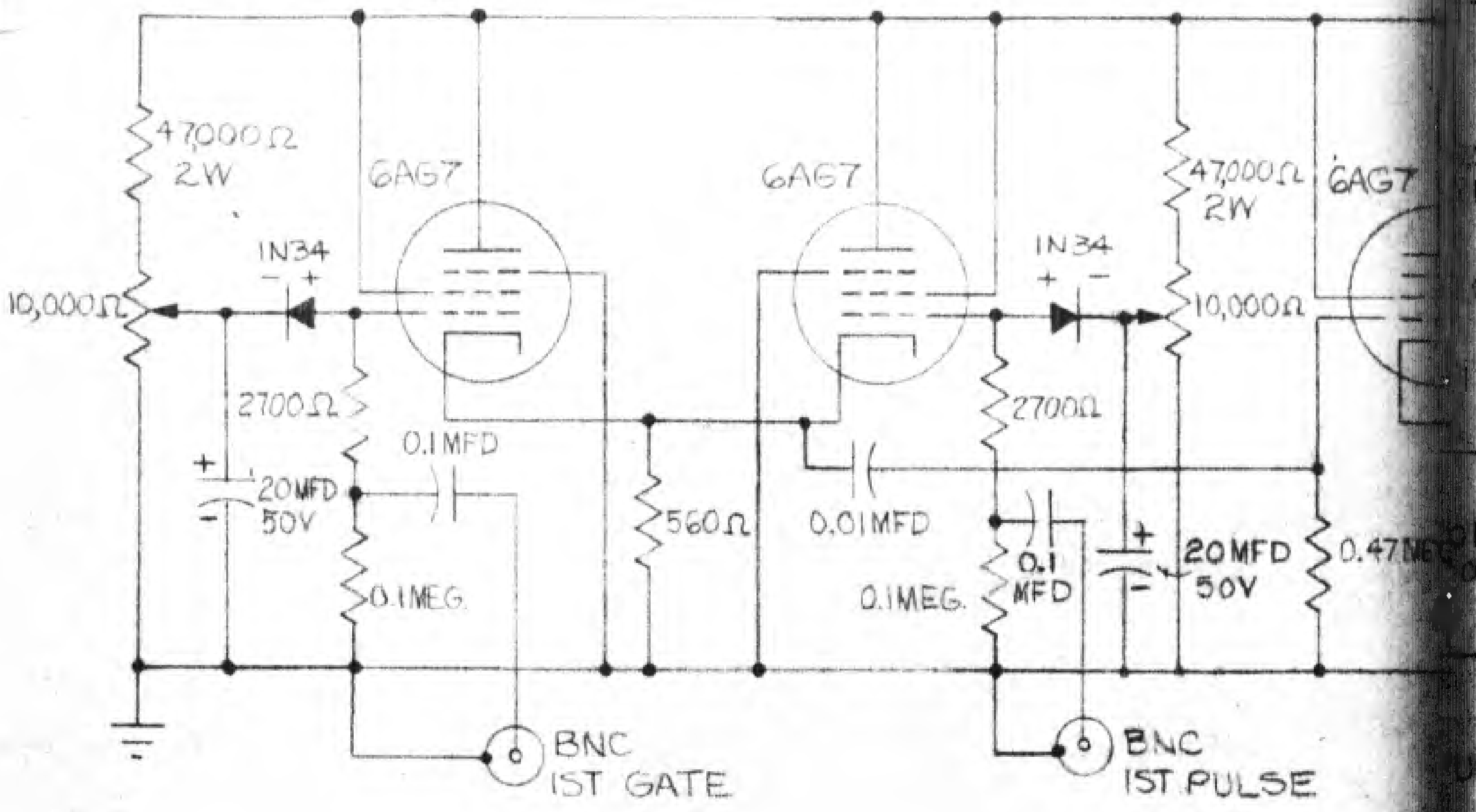
TERMINOLOGY FOR MODEL 1 STORAGE TUBE

USED IN 6345 REPORT R-112

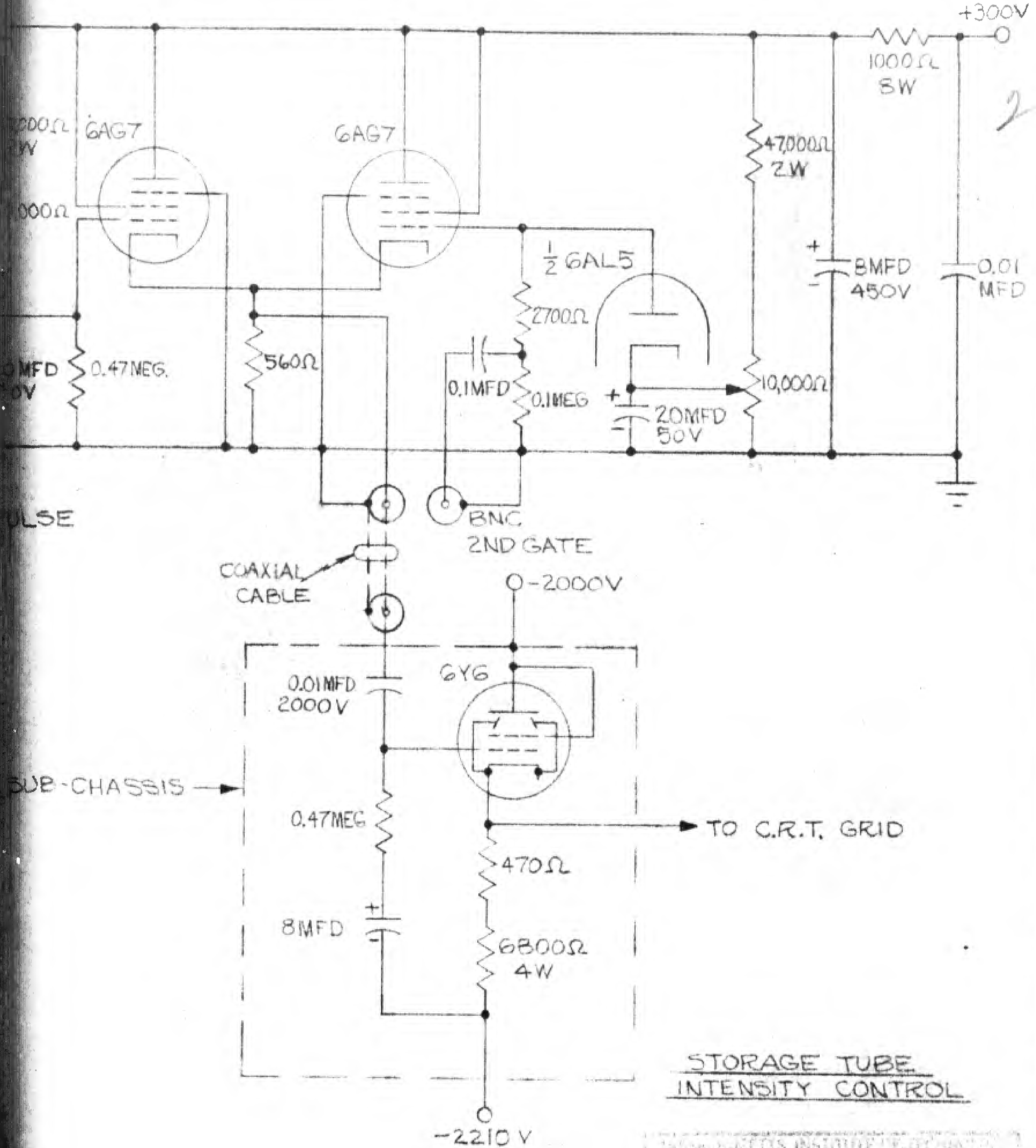
MASSACHUSETTS INSTITUTE OF TECHNOLOGY SERVOMECHANISMS LABORATORY		
D.I.C. NO. 6345	DR. CTS 1/28/47	CK. TL 1/28/47
ENG. SAB	APP.	A-39147-1

B-39179

1



SUB-CHASS

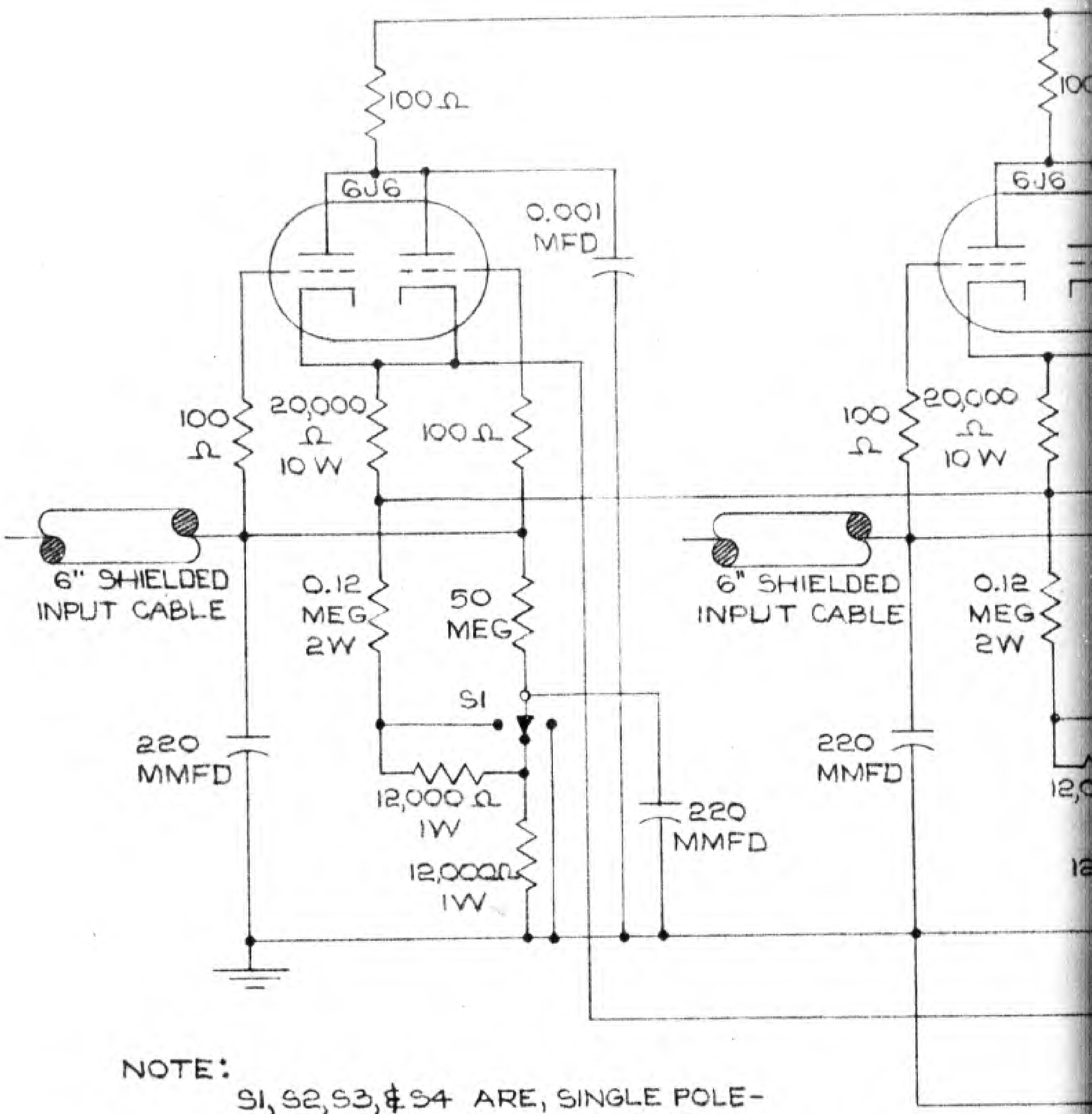


STORAGE TUBE
INTENSITY CONTROL

6345	MC HUGH 11-13-47
M.G.W.	B-39179

B-39180

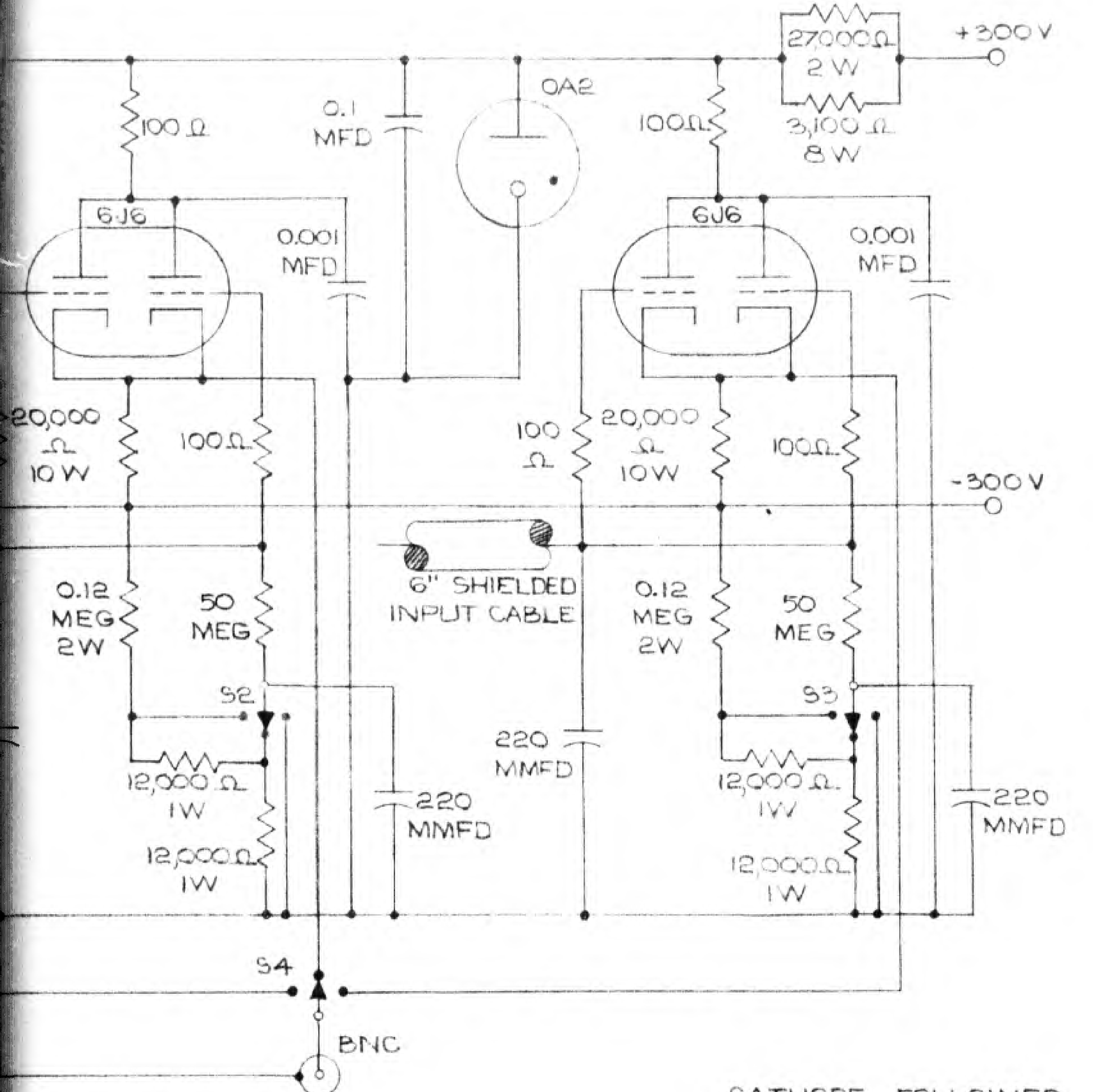
1



NOTE:

S1, S2, S3, & S4 ARE, SINGLE POLE-
THREE POSITION, SWITCHES.
ALL HEATERS FROM 6.3V D.C. SUPPLY.

2

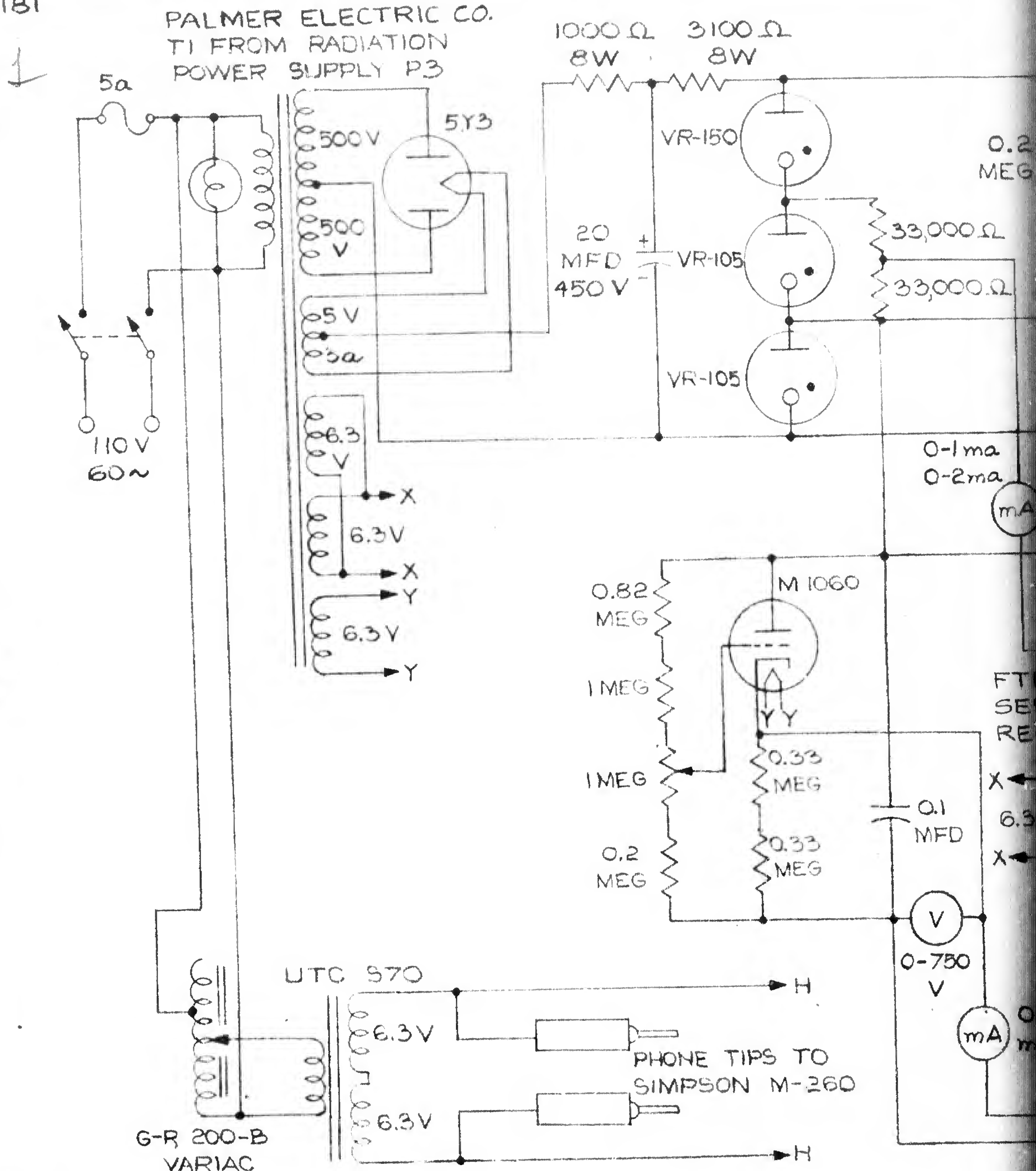


CATHODE FOLLOWER

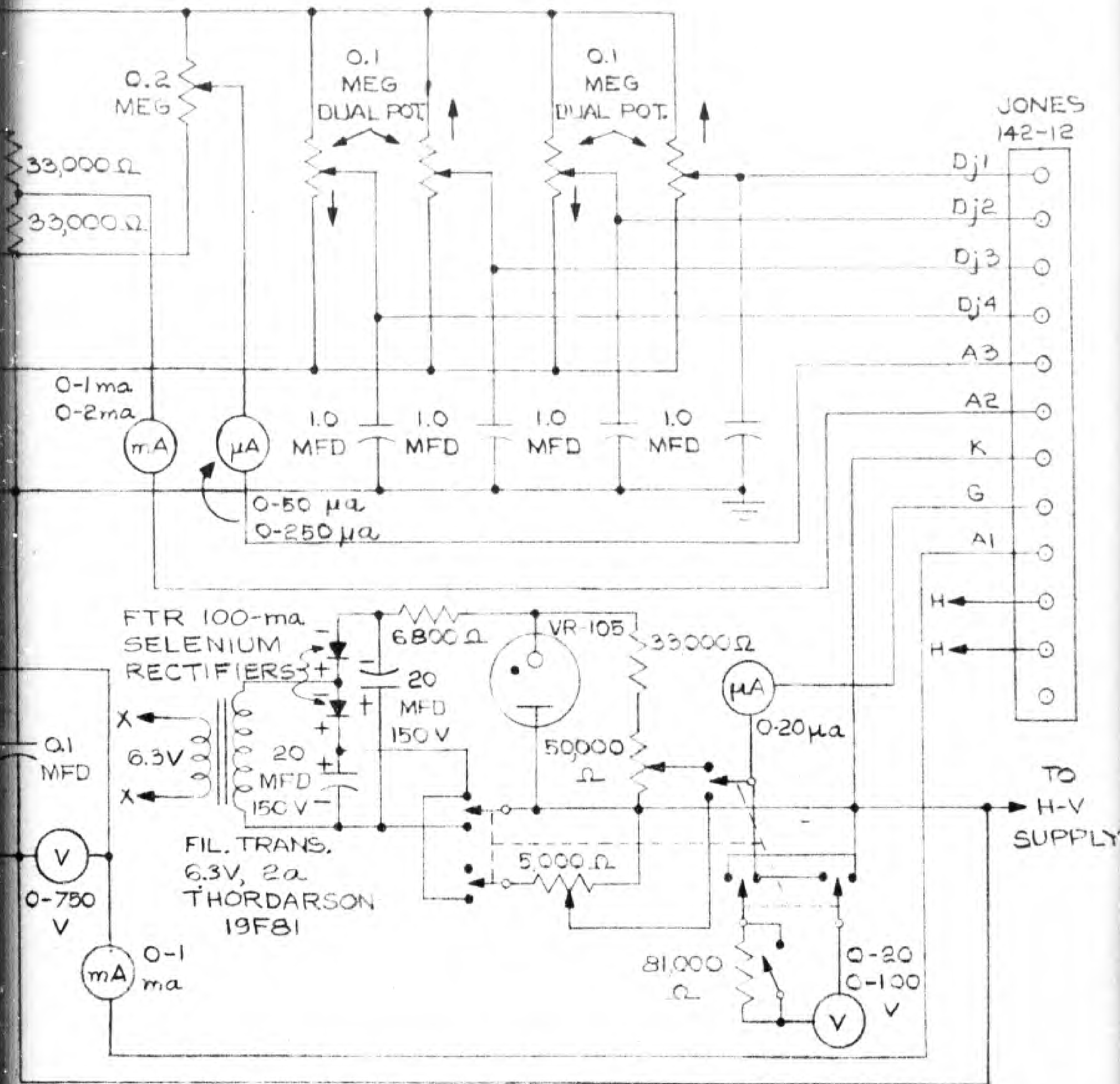
6345 RVW 11-13-47

B-39180

B-39181



NOTE:
THIS UNIT IS PORTABLE, FOR OPERATION
WHILE C.R.T. IS ON PUMPS.
CHASSIS IS GROUNDED.



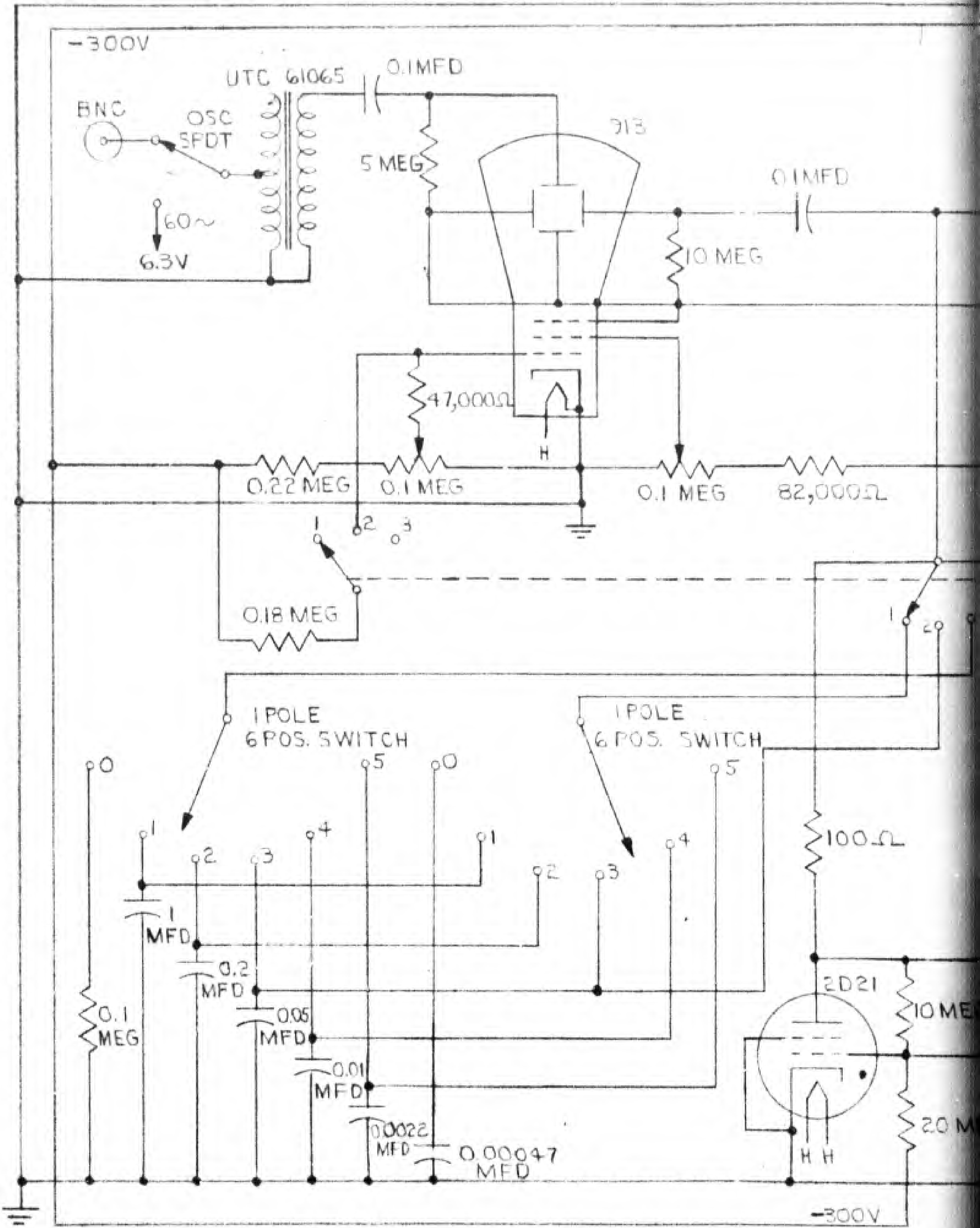
CRT OPERATION CIRCUIT

ERATION

6345 RVW 11-13-47
B-39181

B-39184

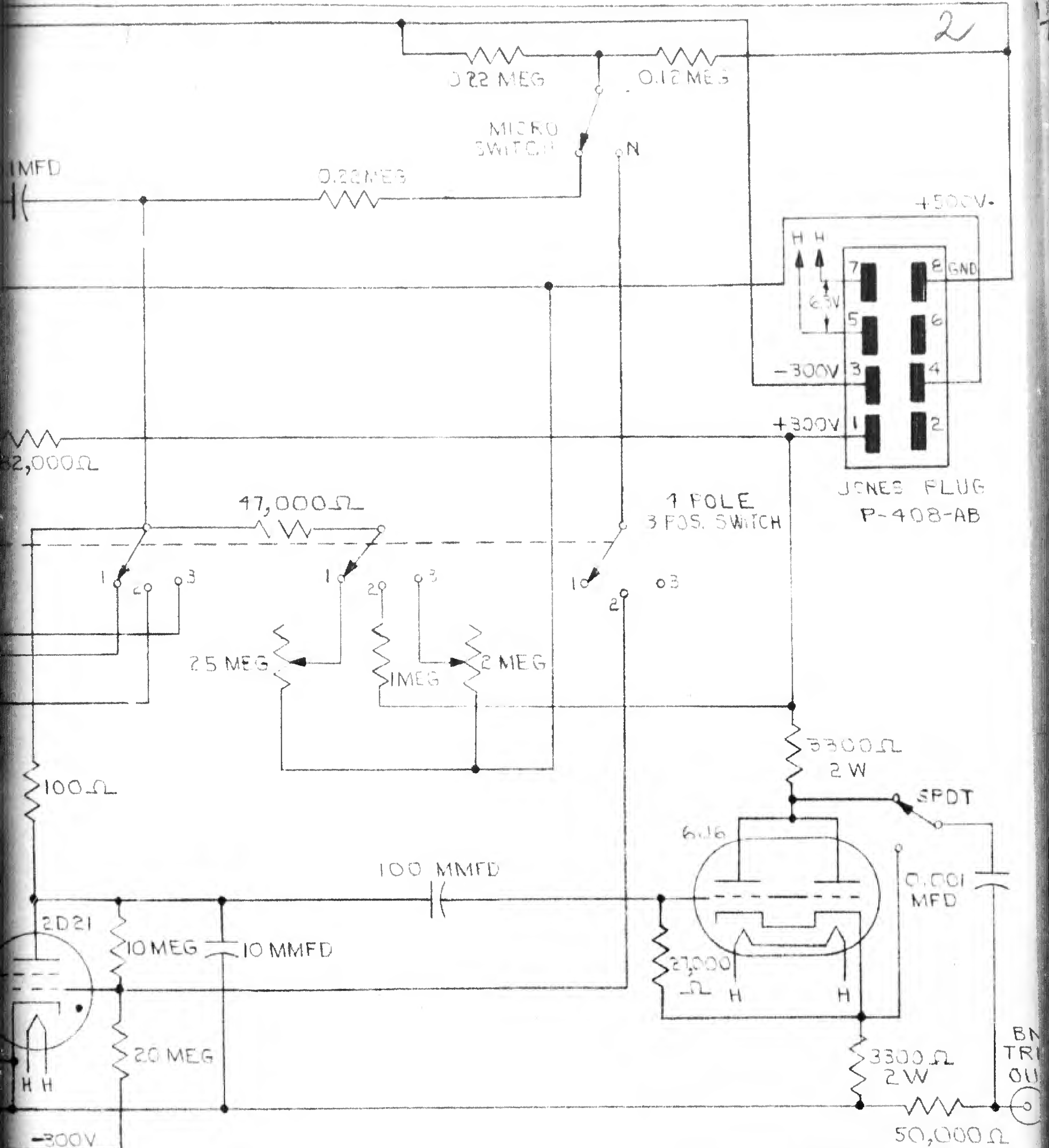
1



TRIGGER GENERAT

USED IN 6345 REPORT

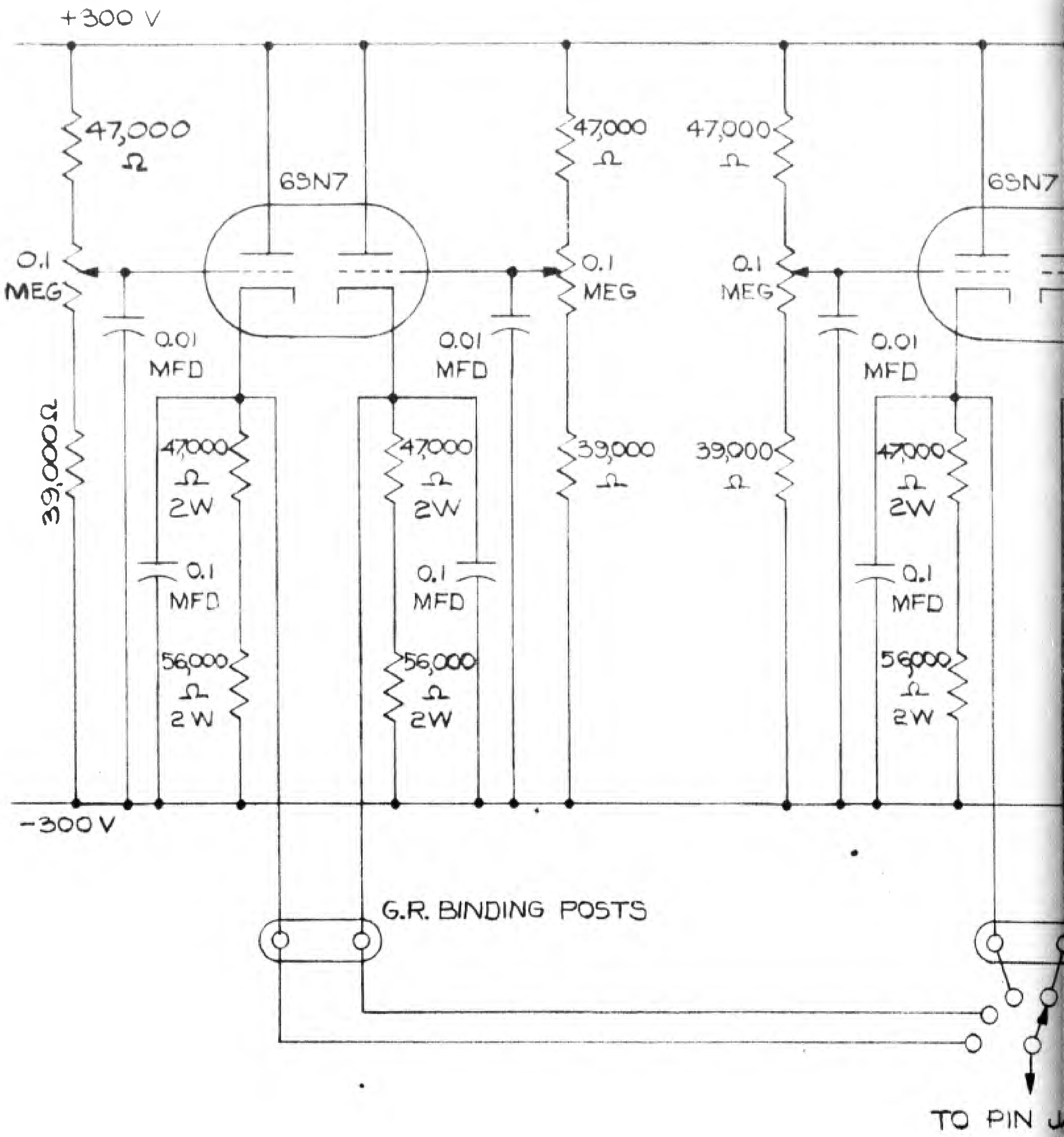
2



MASSACHUSETTS INSTITUTE OF TECHNOLOG

ER GENERATOR

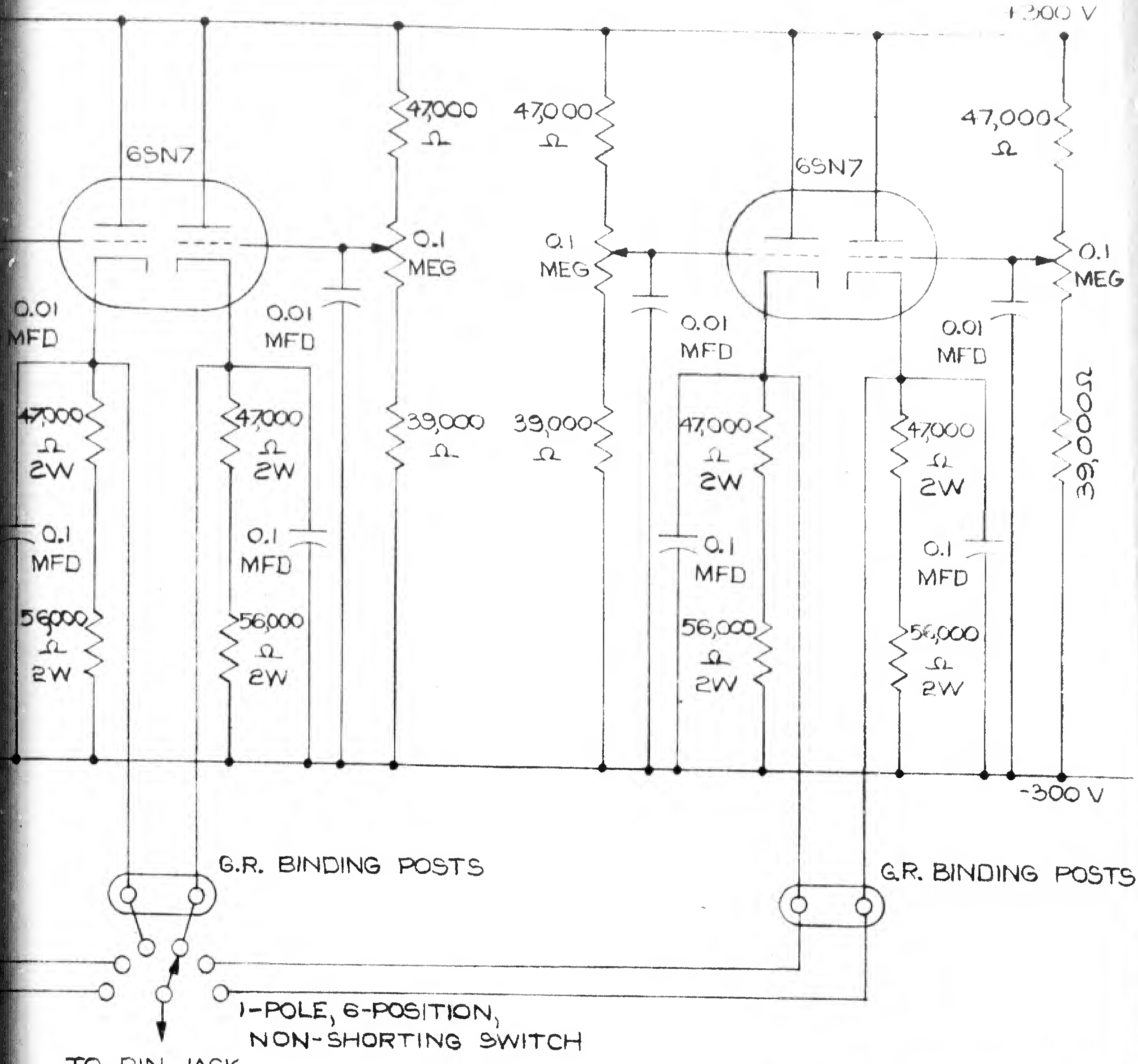
1



ALL RESISTORS ARE 1-WATT ±10%
UNLESS OTHERWISE SPECIFIED.

NOTE:
OF FR
AVAILA
POSIT

2



NOTE: ADJUSTABLE VOLTAGES OF FROM +150V TO −150V ARE AVAILABLE AT EACH SWITCH POSITION.

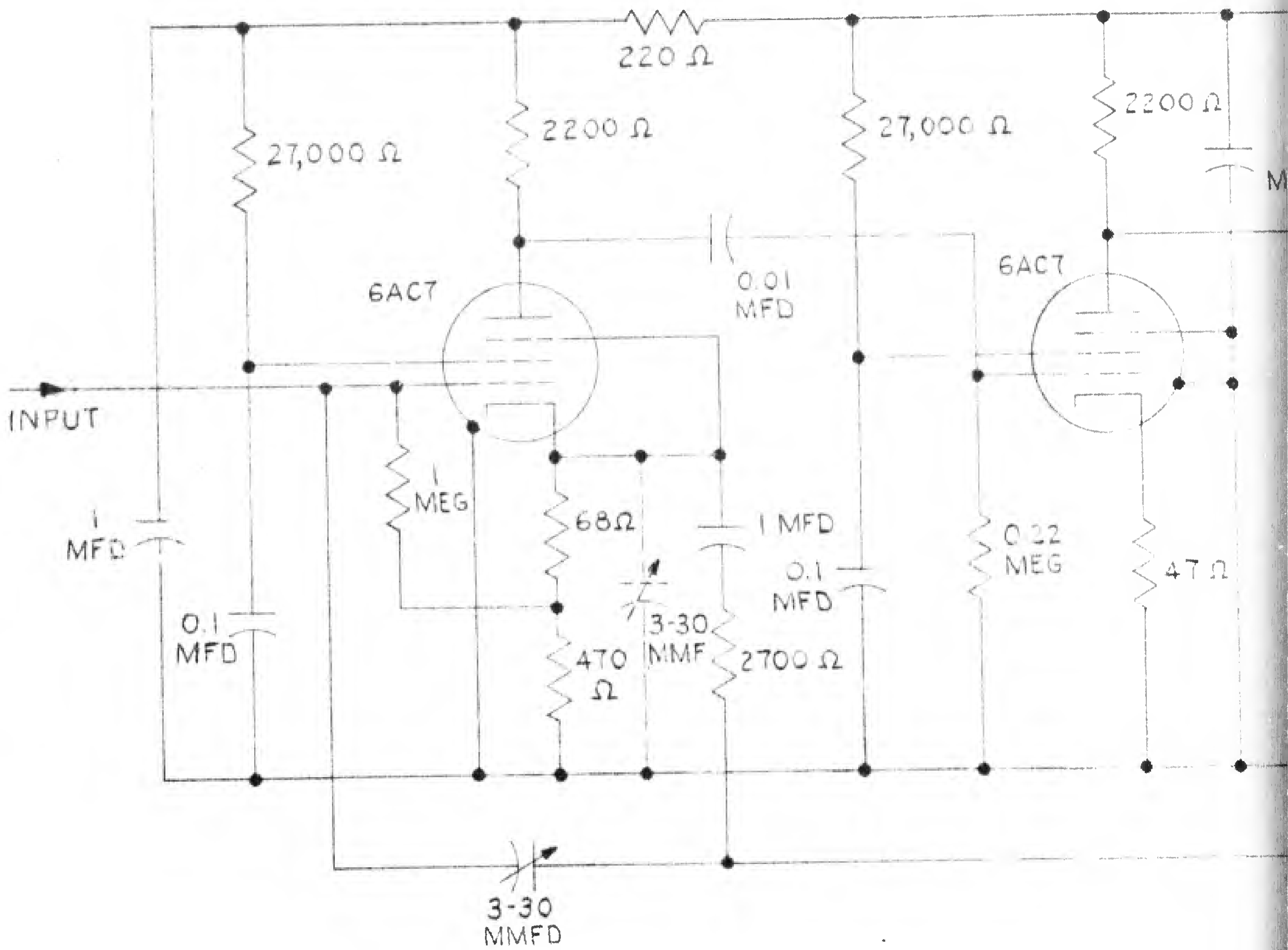
VOLTAGE SOURCE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6345	RYW 11-11-47	
ENG. J.J.M.		B-39187

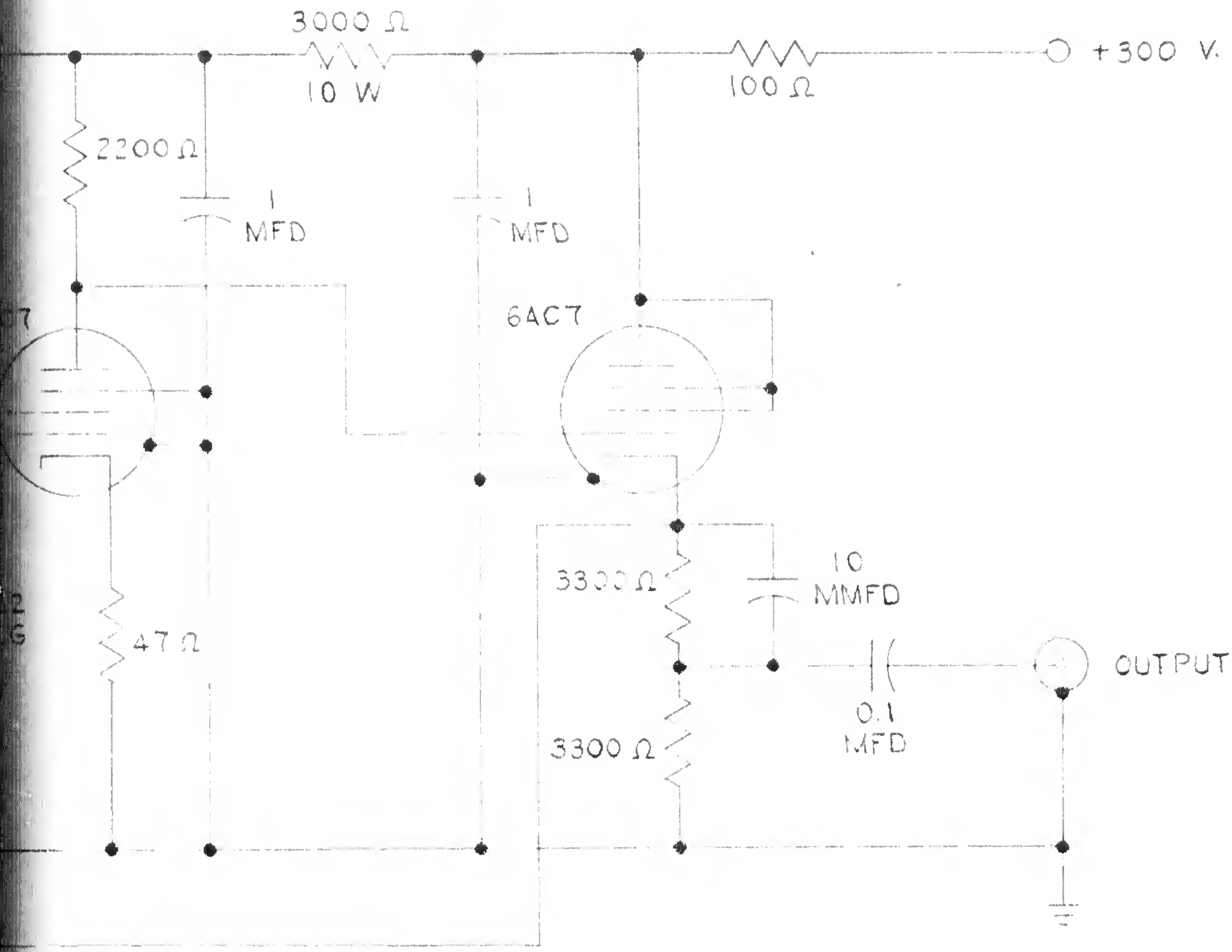
3-31193

1



"ALBANENE" NO. 100L K&E CO. N.Y.
REG. U.S. PAT. OFF.

2

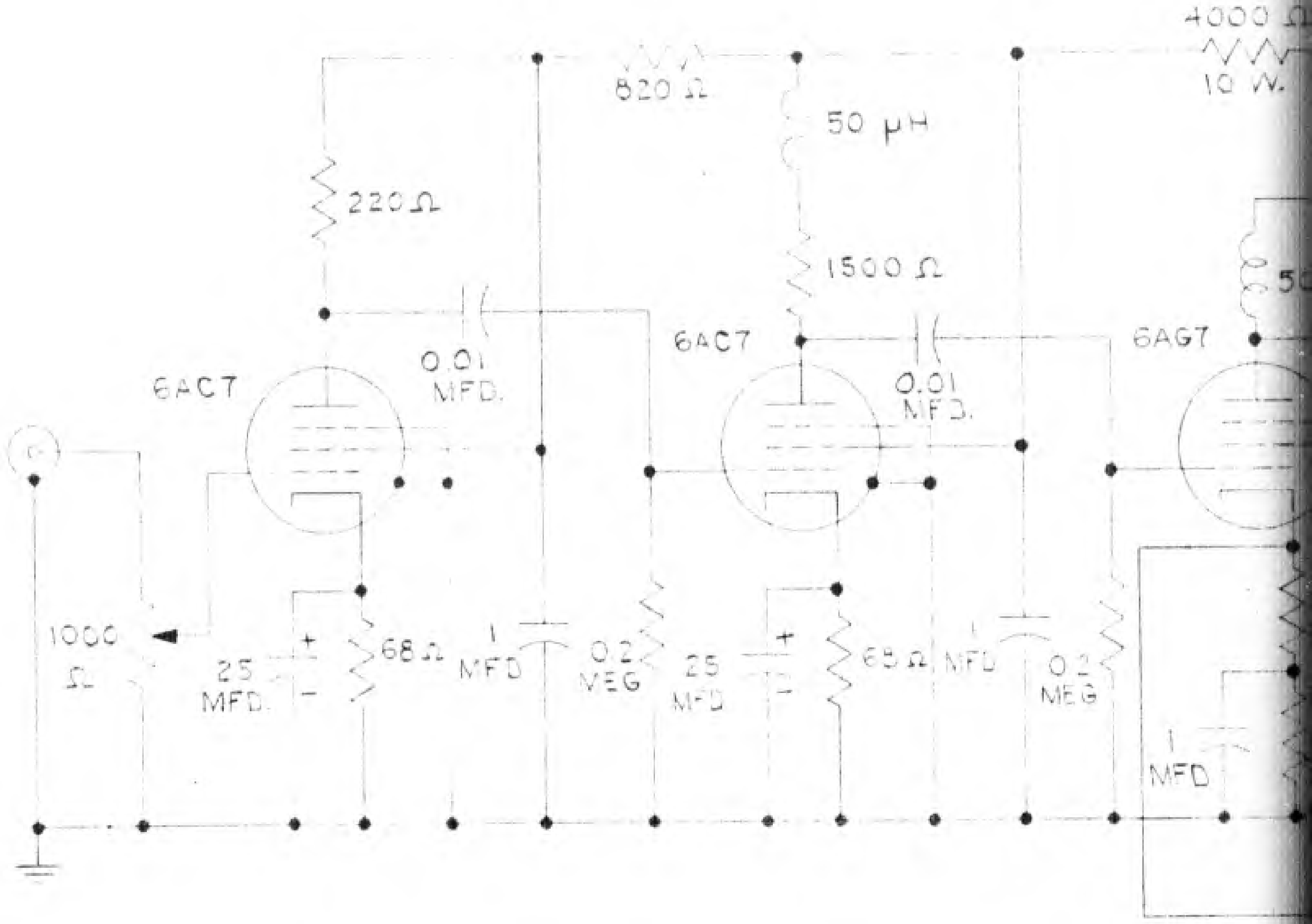


SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

NEGATIVE-CAPACITY AMPLIFIER

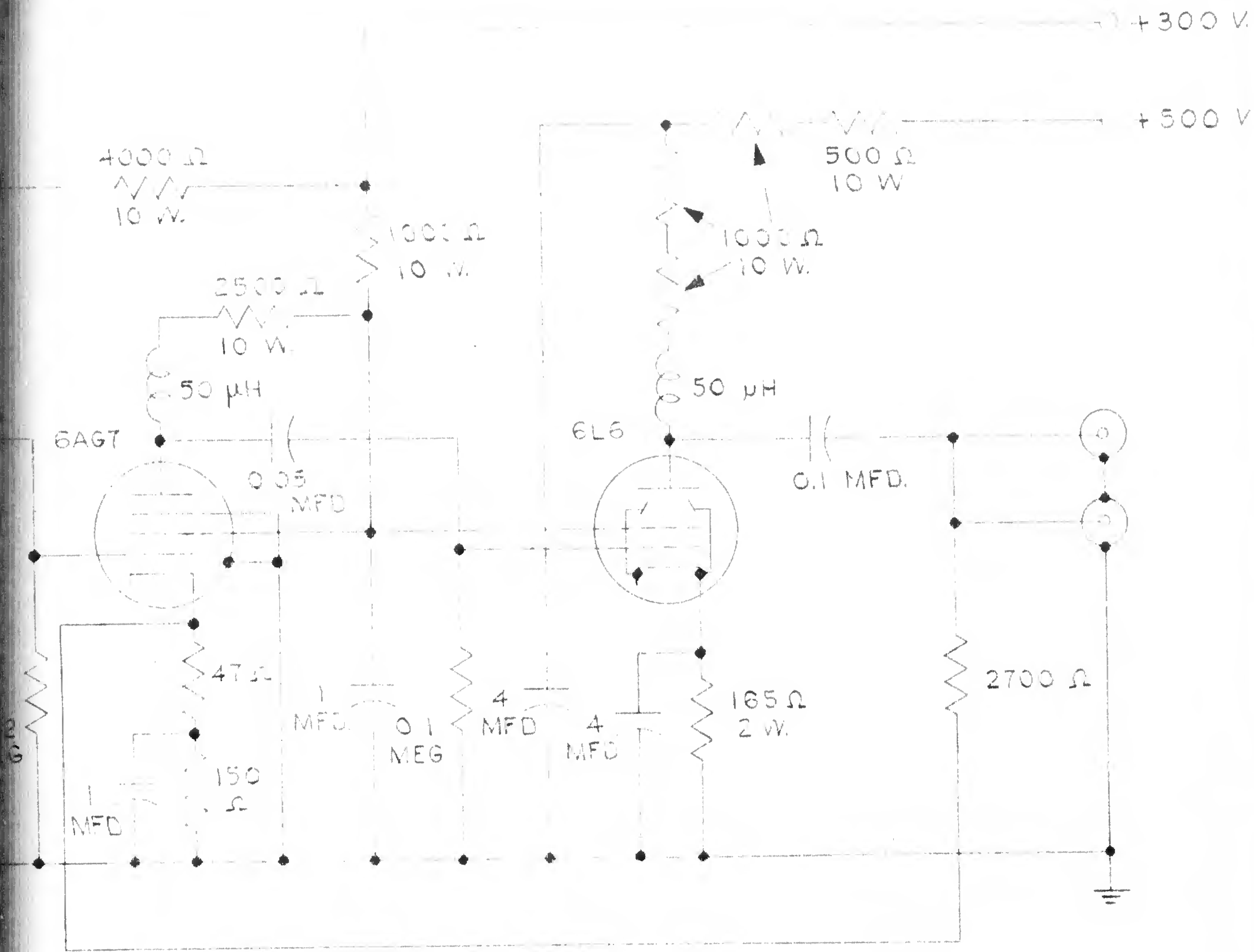
SCALE:	DR. RJG 11-13-47		B- 31193
ENG.	CK.	APP.	

1



"ALBANENE" NO.100L K&E CO. N.Y.
REG. U.S. PAT. OFF.

2



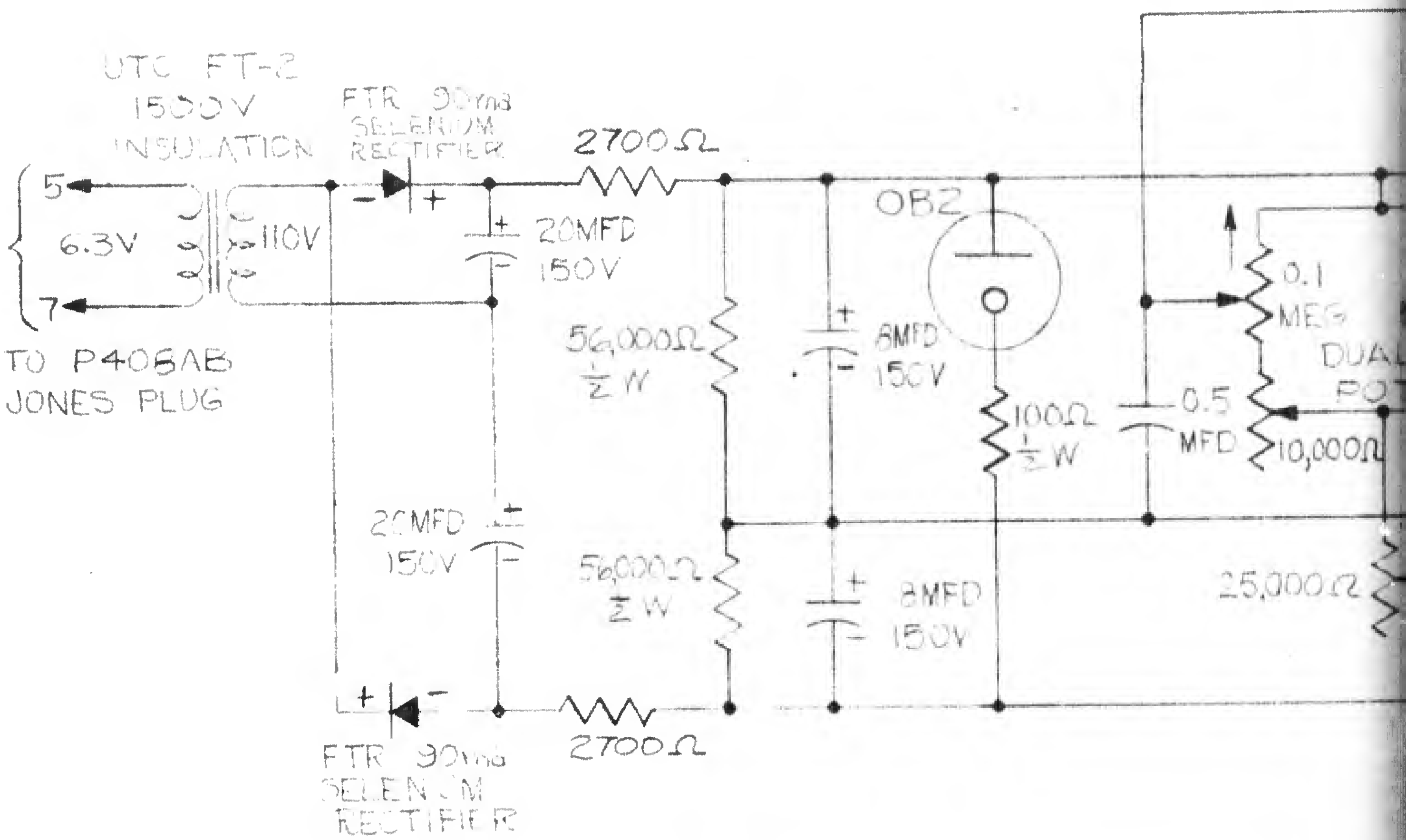
SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

VIDEO AMPLIFIER

SCALE:	DR. RJG 11-12-47		B-31194
ENG.	CK.	APP.	

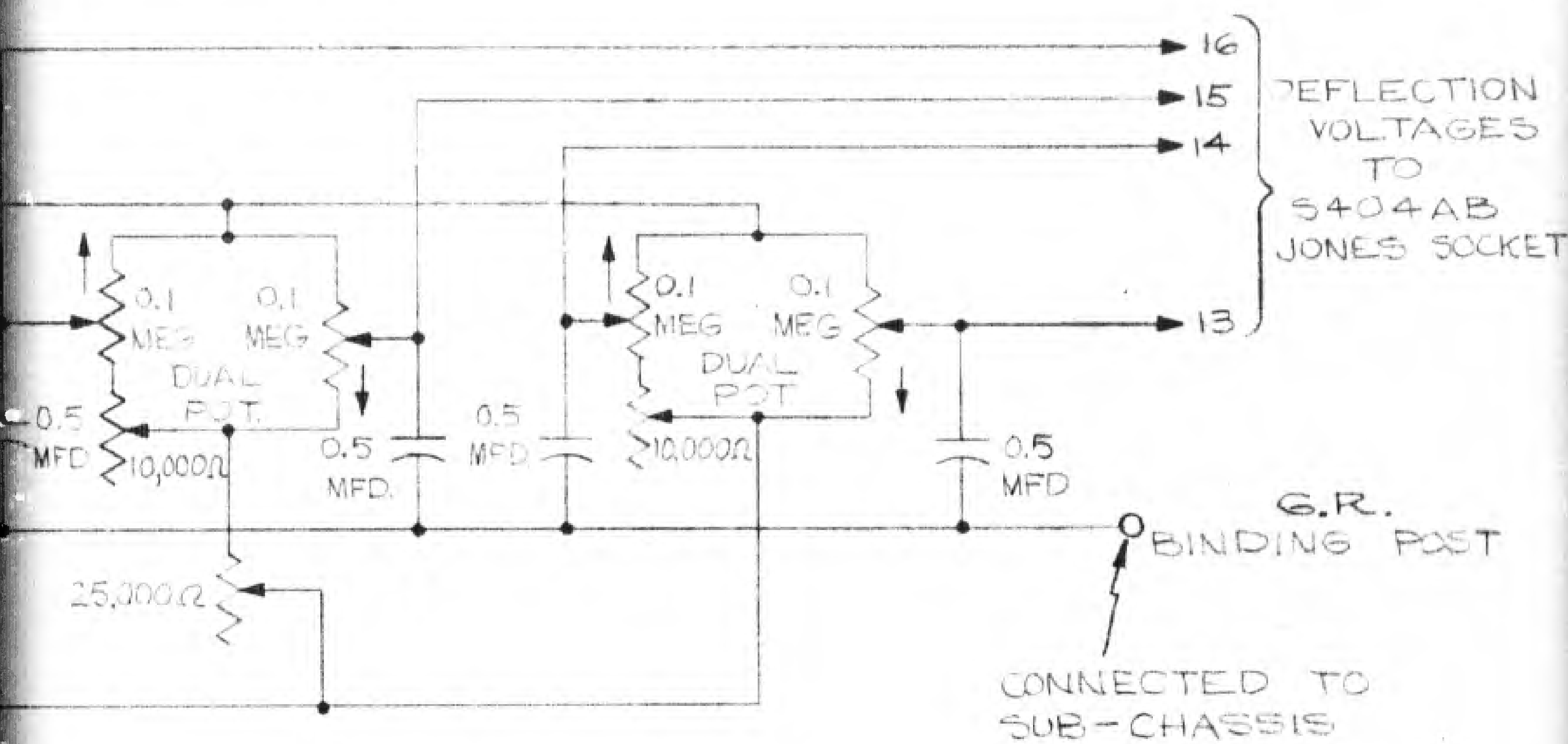
B-31195

1



NOTE: ALL COMPONENTS EXCEPT UTC FT-2
ARE MOUNTED ON SUB-CHASSIS.
UTC FT-2 IS MOUNTED ON STANDOFFS
ON MAIN CHASSIS.

2

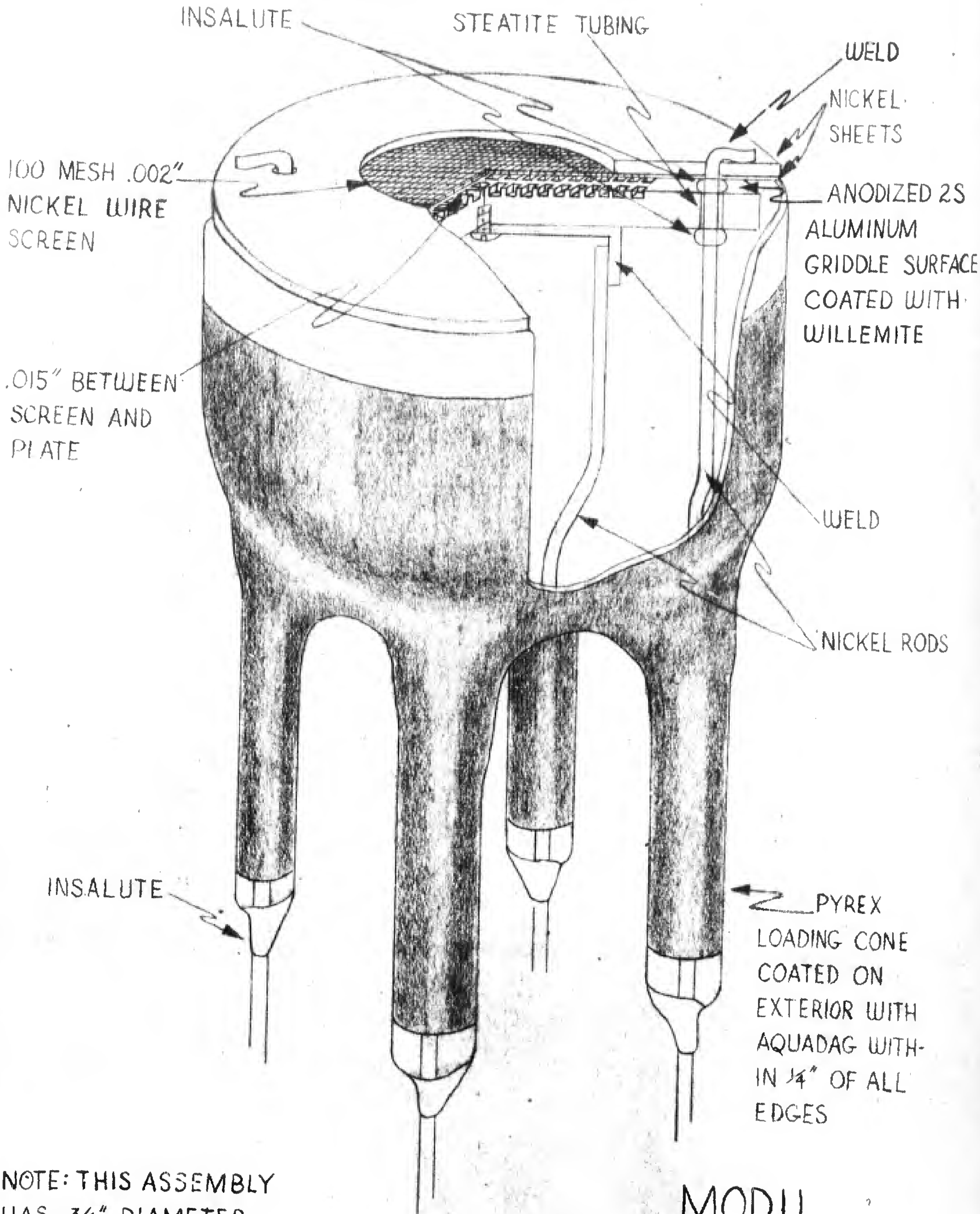


DEFLECTION CIRCUIT

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LABORATORY

6345	J. McHugh 11/13/47
M.G.M.	B-31195

USED IN 6345 MEMO M-159

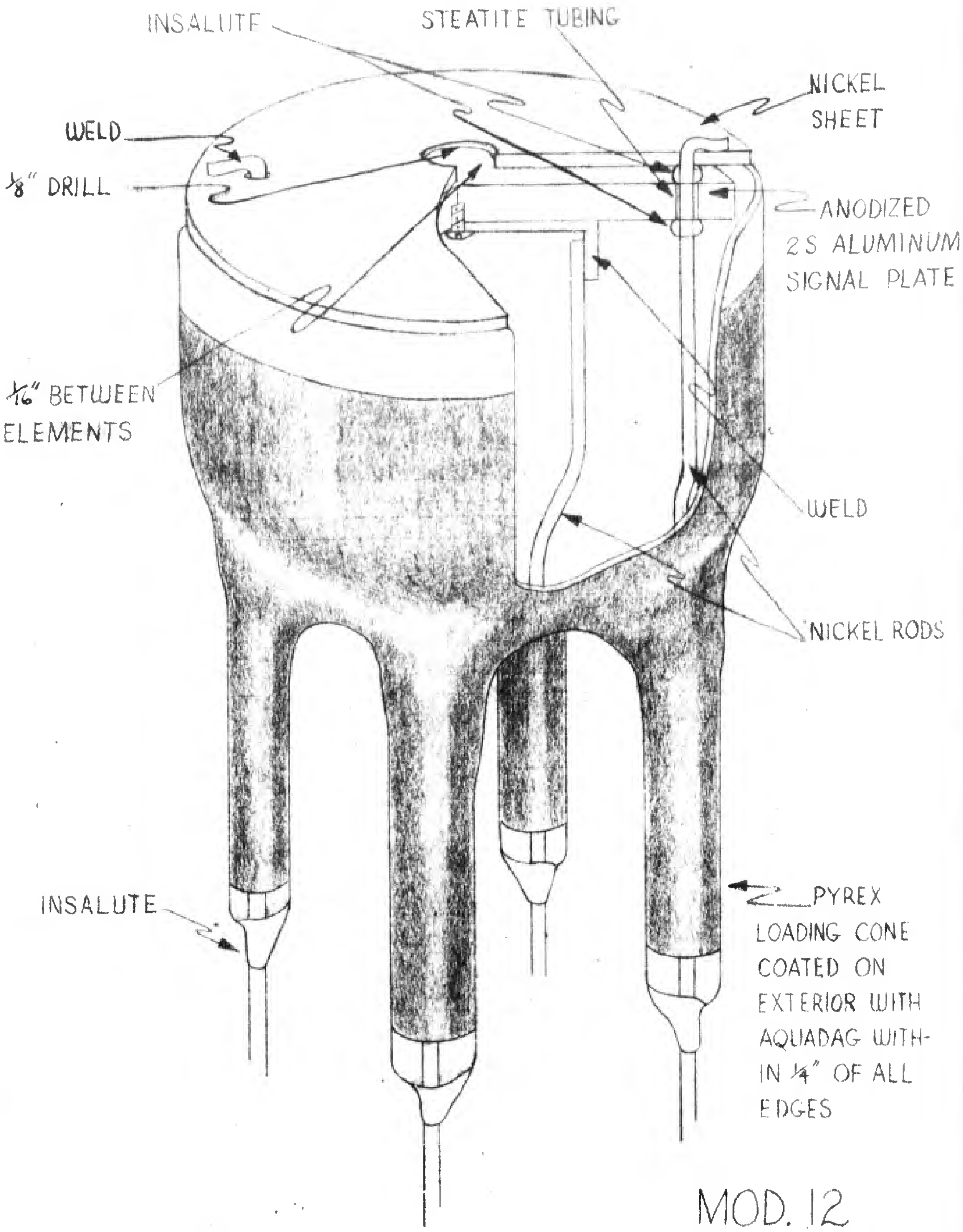


NOTE: THIS ASSEMBLY HAS 3/4" DIAMETER STORAGE AREA

MOD.II ASSEMBLY

A-31196

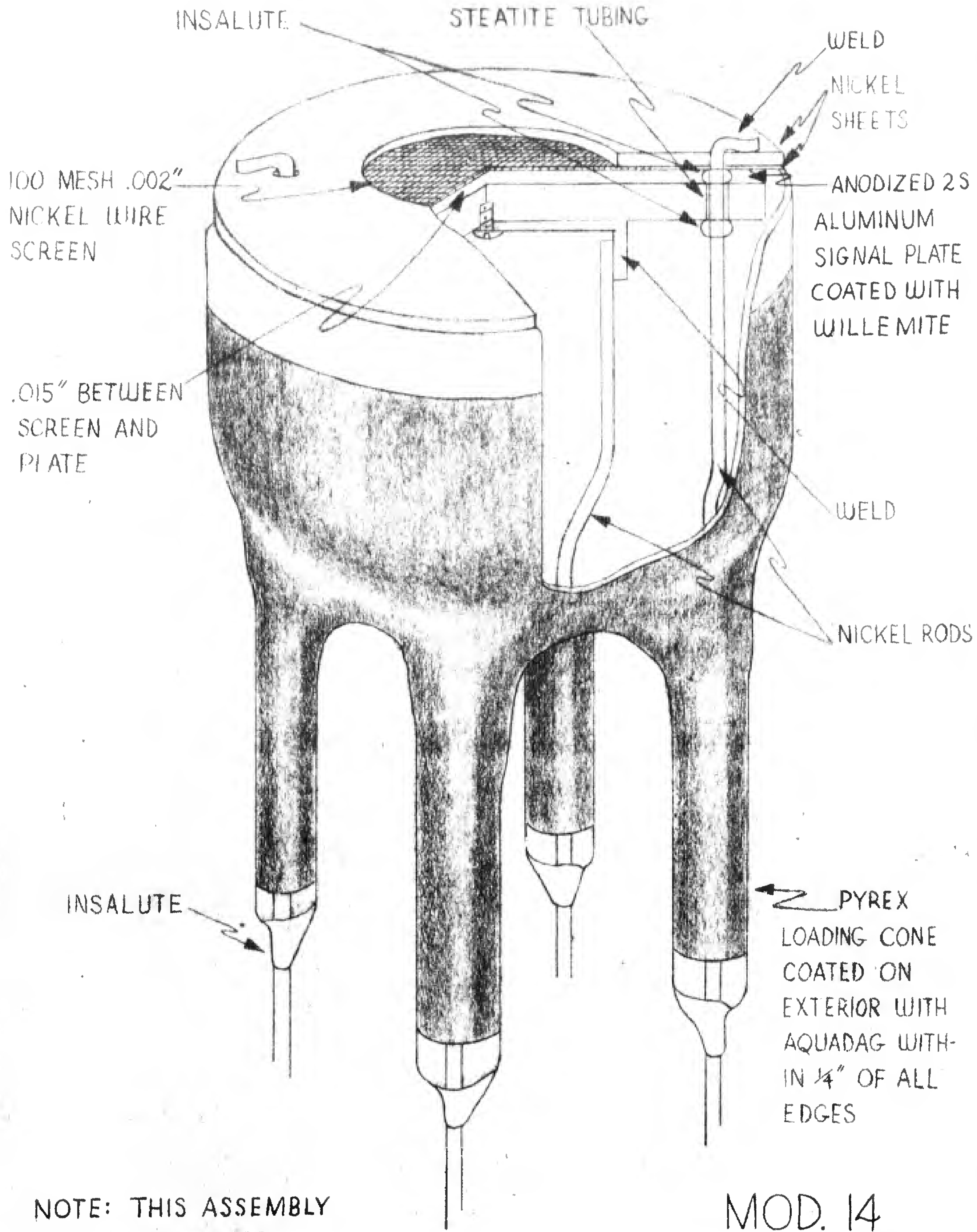
A-31196



A-31197 USED IN 6345 MEMO M-159

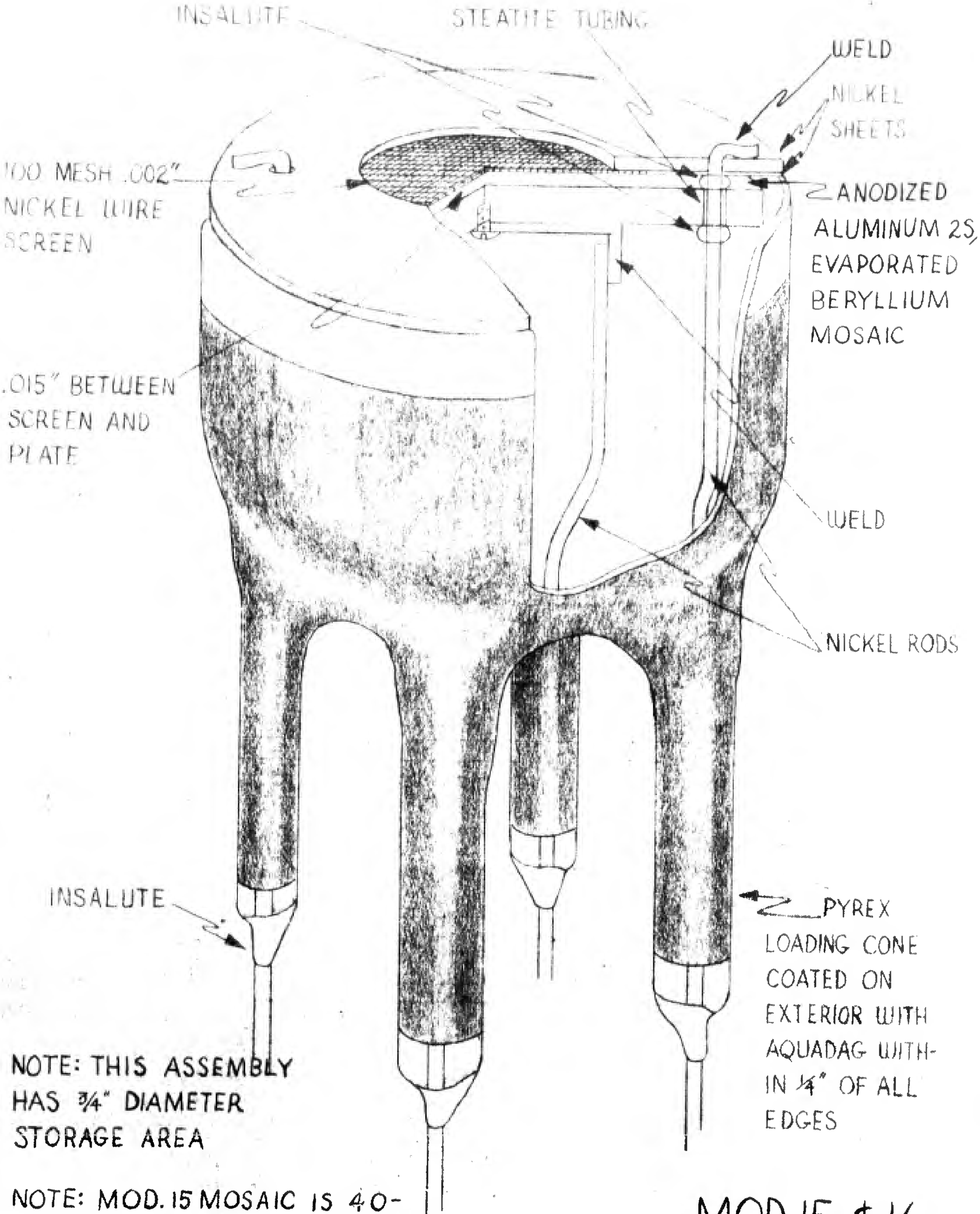
MOD. 12
STORAGE TUBE
ASSEMBLY
A-31197

A-31198 USED IN 6345 MEMO - M-159



NOTE: THIS ASSEMBLY HAS 3/4" DIAMETER STORAGE AREA

MOD. 14
ASSEMBLY
A-31198



NOTE: THIS ASSEMBLY HAS 3/4" DIAMETER STORAGE AREA

NOTE: MOD. 15 MOSAIC IS 40-MESH EVAPORATED BERYLLIUM
MOD. 16 MOSAIC IS 100-MESH EVAPORATED BERYLLIUM

MOD. 15 & 16 ASSEMBLY

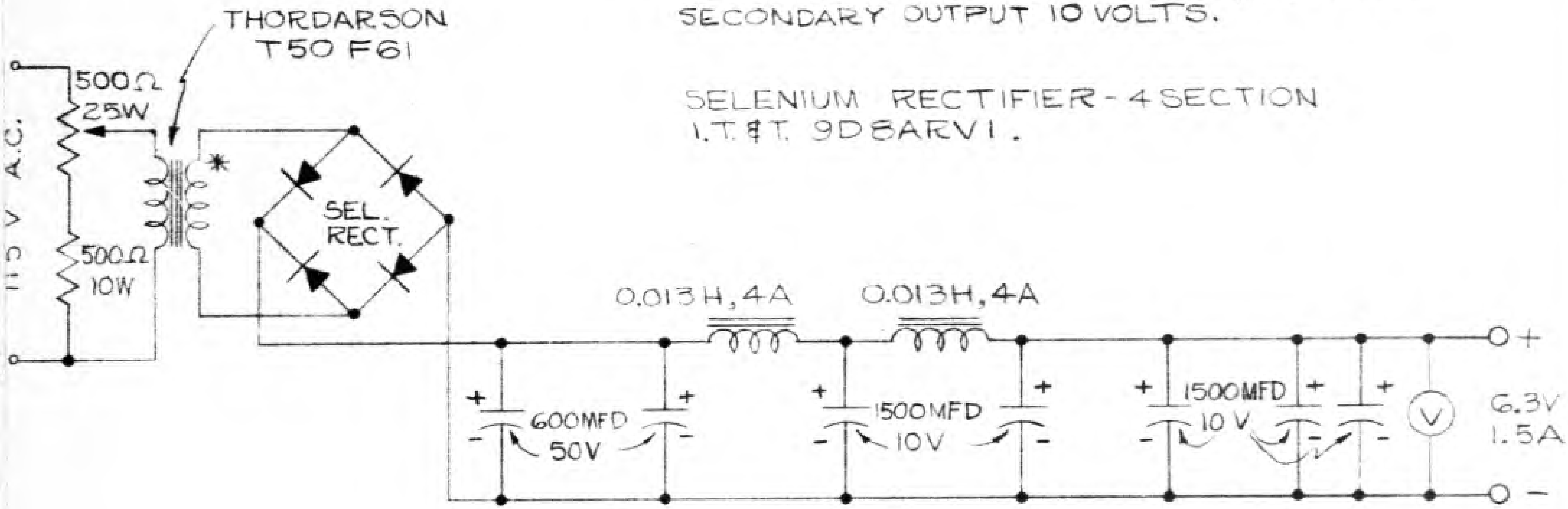
A-31199

A-31199 USED IN 6345 MEMO. M-159

A-39243

* FILAMENT TRANSFORMER SECONDARY REWOUND WITH #20 FORMEX, 89 TURNS. SECONDARY OUTPUT 10 VOLTS.

SELENIUM RECTIFIER - 4 SECTION I.T.&T. 9D8ARV1.



D-C HEATER SUPPLY

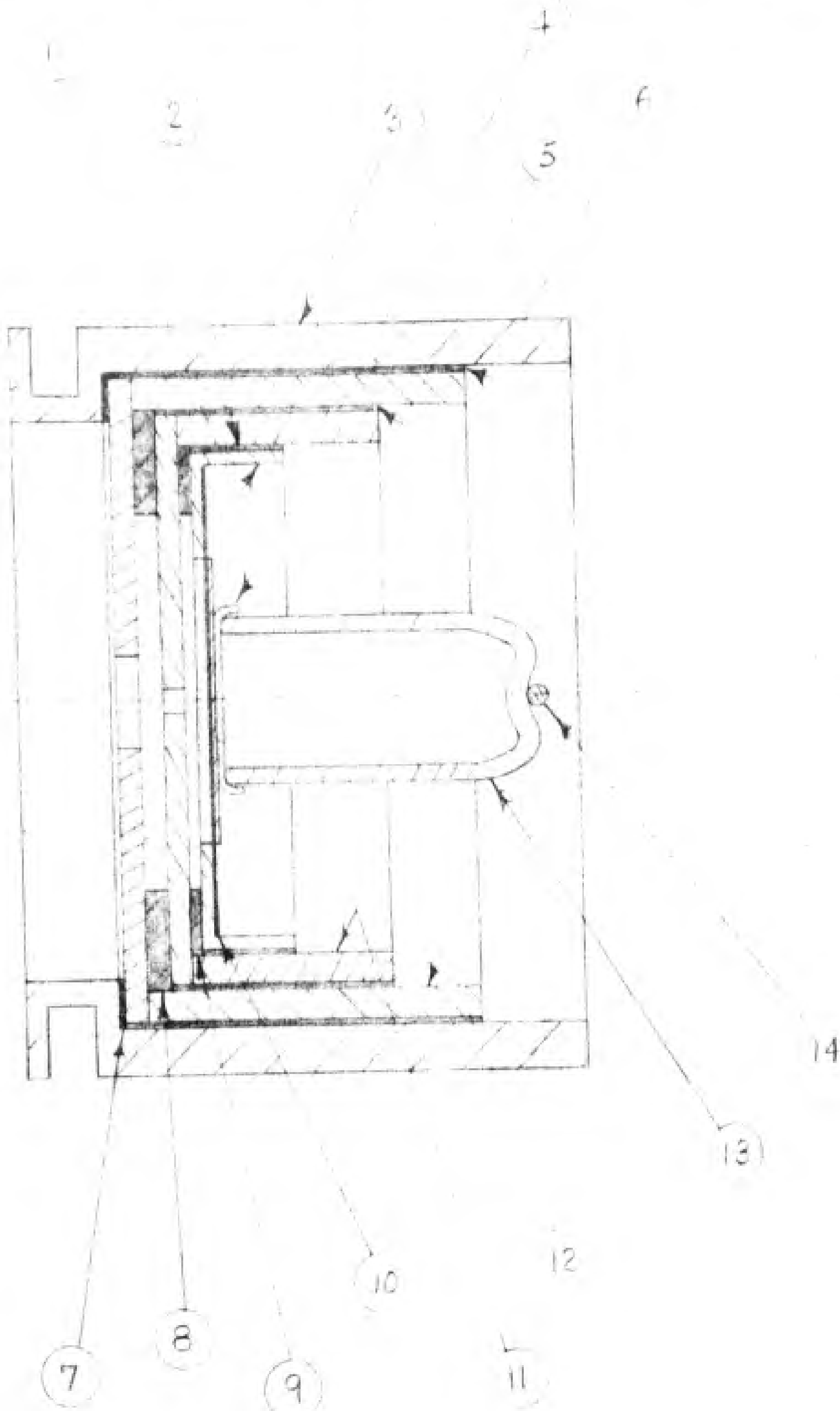
6345 J. McHugh 11/12/47

Mr. J. M.

A-39243

B- 39266	TOLERANCES NOT OTHERWISE SPECIFIED:
WO-	DECIMAL ± .005 FRACTIONAL ± 1/64

1



P			
N			
M			
L			
K			
J			
H			
	WAS	APP.	DATE

"ALBANENE" NO. 195L K&E CO. N.Y.
REG. U.S. PAT. OFF.

2

ITEM	MATERIAL - DESCRIPTION	PART NO.	QUAN.
14	1/16 TUNGSTEN WIRE 2 1/4 LONG		
13	GLASS LOADING CONE	SA-39264	1
12	SHIELD GRID ELECTRODE	SA-39120	1
11	SCREEN GRID ELECTRODE	SA-39121	1
10	DIELECTRIC PLATE	SA-39265	1
9	INSULATOR	SA-39261	1
8	INSULATOR	SA-39260	1
7	INSULATOR	SA-39258	1
6	INSULATOR	SA-39257	1
5	INSULATOR	SA-39259	1
4	CONE SEAT	SA-39263	1
3	THIRD ANODE ELECTRODE	SA-39119	1
2	INSULATOR	SA-39262	1
1	GUARD RING ELECTRODE	SA-39122	1

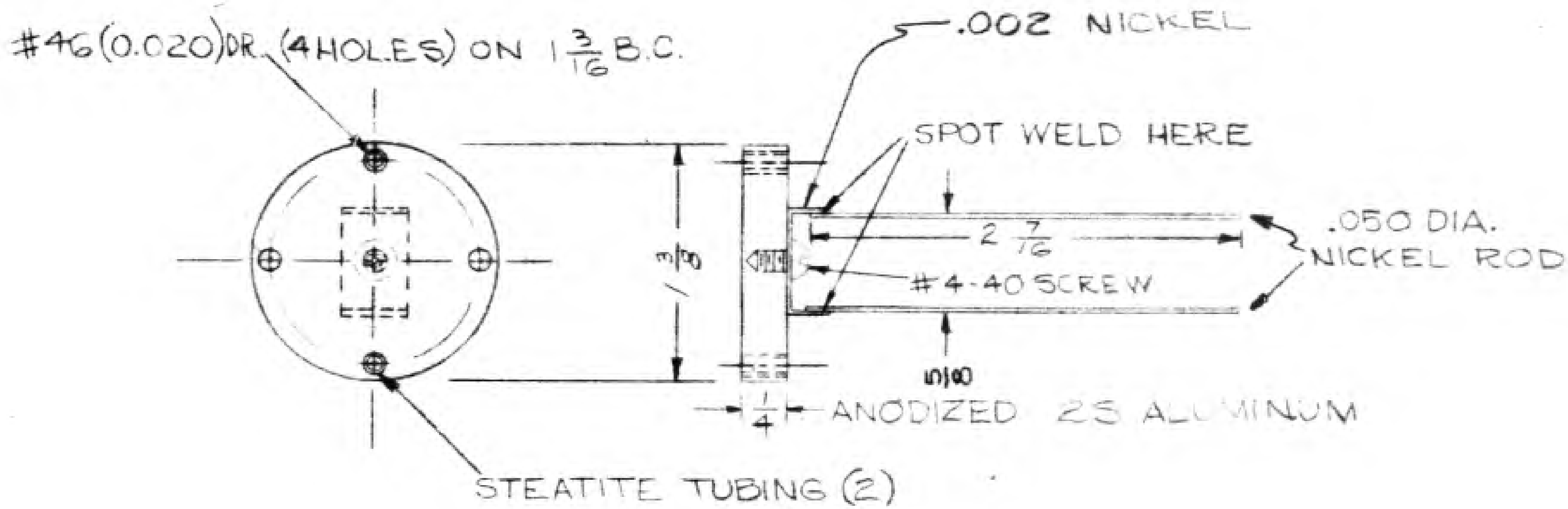
	DATE			WAS	APP.	DATE
			G			
			F			
			E			
			D			
			C			
			B			
			A			

SERVOMECHANISMS LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345

STORAGE TUBE MOD 5 ELECTRODE

SCALE: 2 : 1	DR. McNEILL 5-20-47		B-39266
TR.	CK. HHS 6-28-47	APP.	

A-39367



MOD. 12 STORAGE TUBE
SIGNAL PLATE ASS'Y.

6345
J. McHugh 11/12/47
M. J. M.
A-39367

Memorandum M-130

Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

To: Director, Special Devices Center

From: Jay W. Forrester

Subject: Storage Tube Program, Project Whirlwind, Extracts from M-102 dated Sept. 15, 1947.

See Drawing List on last page

Date: November 5, 1947

This memorandum is in response to a request for information on the present status of Project Whirlwind Storage Tube research.

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 changes 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 commercial 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.

Drawing List Instructions - Put Figure Numbers on Prints

Figure 1	Drawing A 30892
Figure 2	Drawing A 30885
Figure 3	Drawing A 30886
Figure 4	Drawing A 30887
Figure 5	Photograph FB 169
Figure 6	Photograph FB 193
Figure 7	Drawing B 30888
Figure 8	Drawing B 30889
Figure 9	Photograph FB 197
Figure 10	Photograph FB 198
Figure 11	Photograph FB 194
Figure 12	Photograph FB 112
Figure 13	Photograph FB 172
Figure 14	Photograph FB 103
Figure 15	Photograph FB 154
Figure 16	Photograph FB 166
Figure 17	Photograph FB 134
Figure 18	Photograph FB 132
Figure 19	Drawing A 30893

A-30892 USED IN 345 MEMO M-102

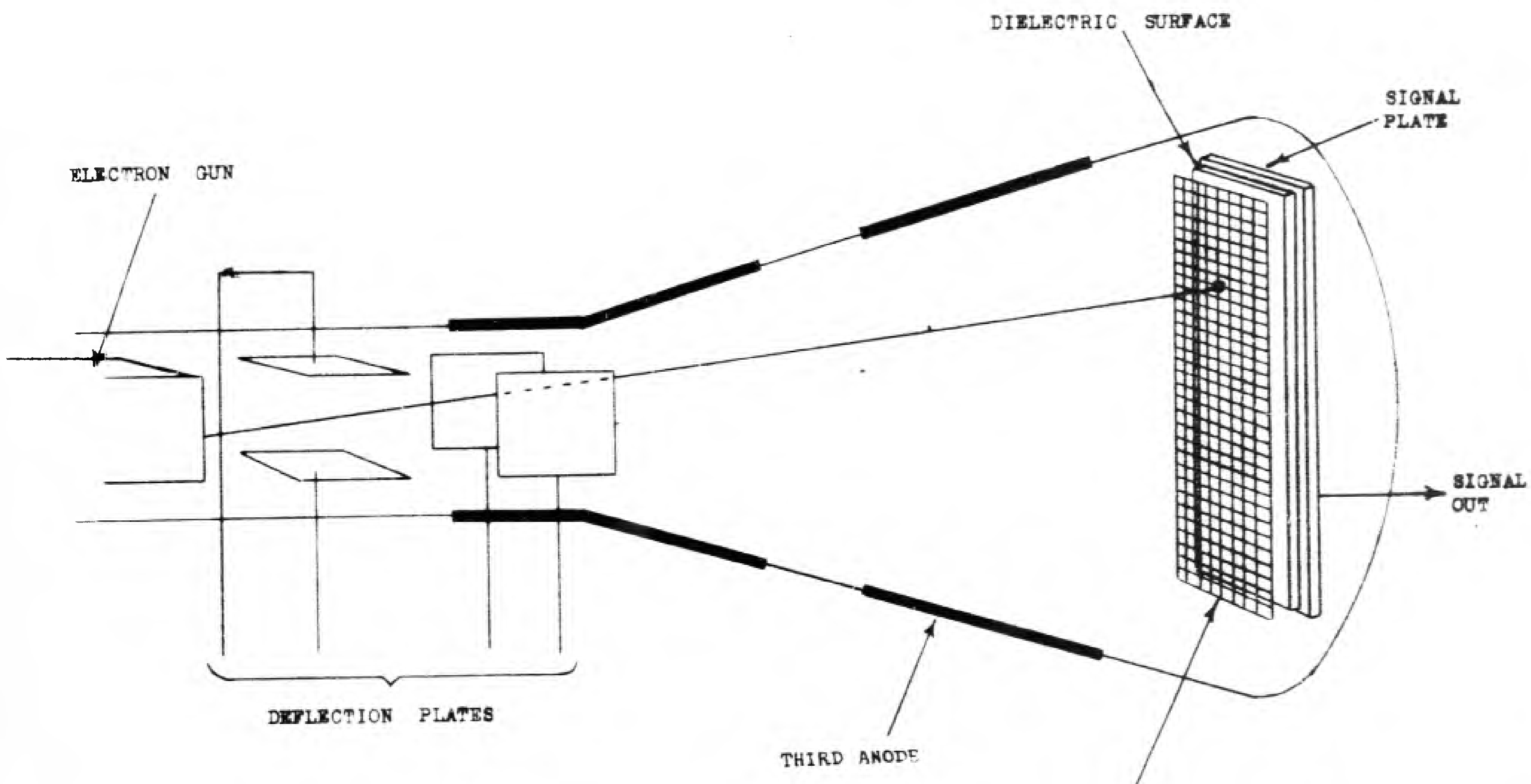


FIG. 1

ELECTROSTATIC STORAGE TUBE

A-30885 USED IN 6345 MEMO M-102

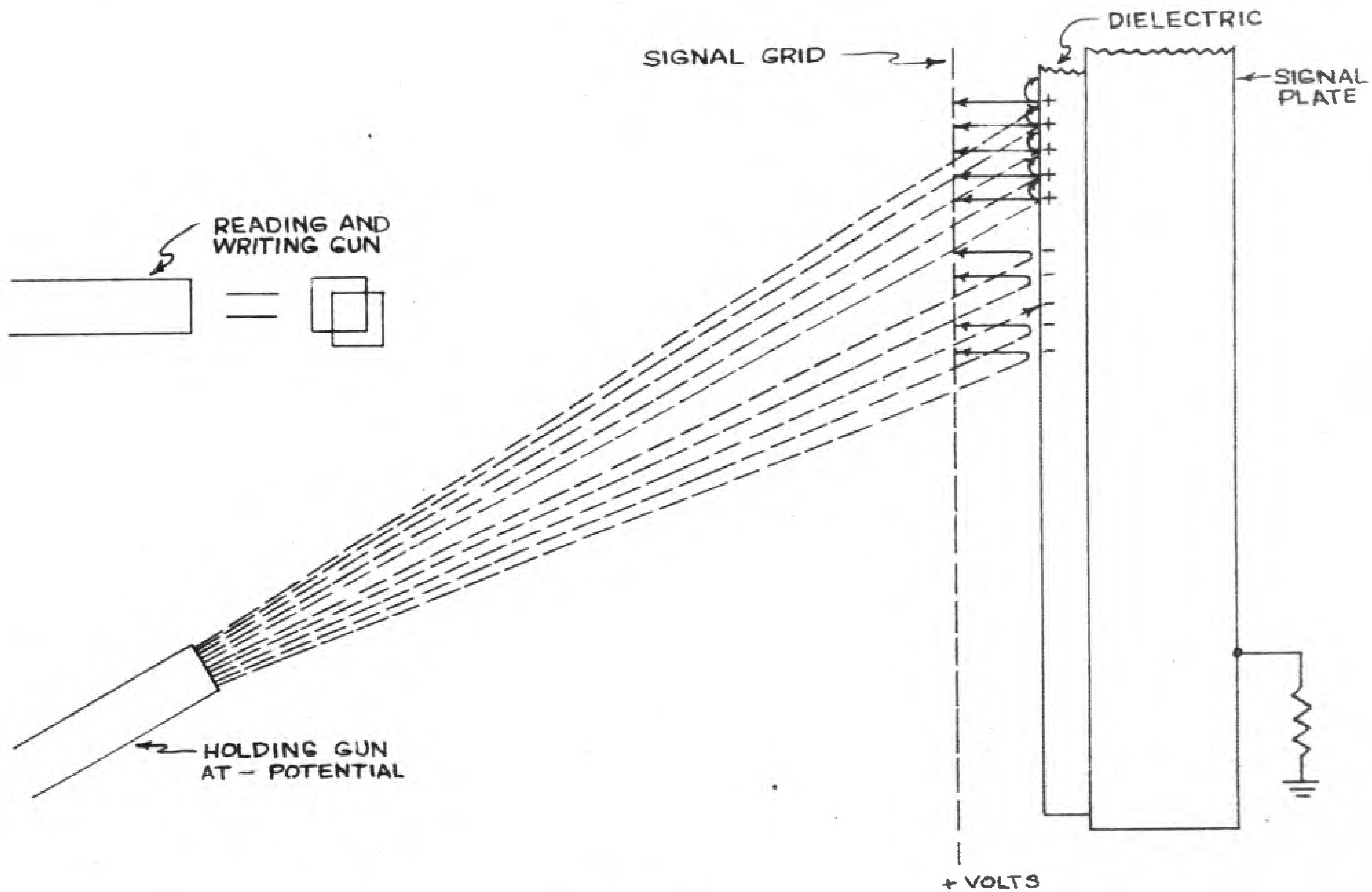


FIGURE 2

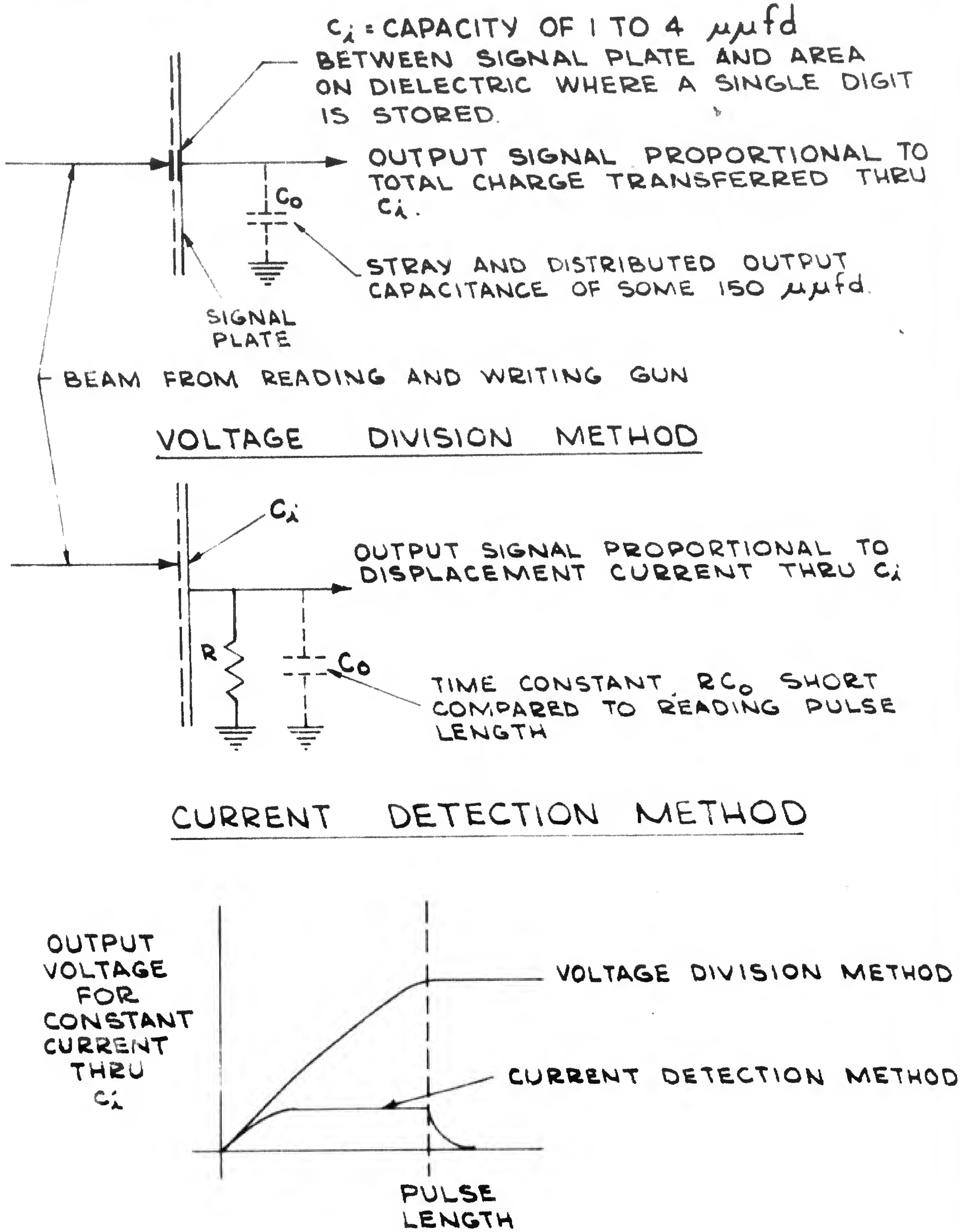
A-30886 USED IN 6345 MEMO M-102

COMPARISON OF PRESENT STORAGE TUBE RESEARCH RESULTS WITH FINAL OBJECTIVES

CHARACTERISTIC	FINAL WHIRLWIND STORAGE TUBE	PRESENT M.I.T. RESEARCH RESULTS	
1. PARALLEL DIGIT STORAGE	YES	YES	
2. SIGNAL LEVEL a. VOLTAGE DIVISION b. CURRENT METHOD	 0.100 VOLTS MIN. .050 VOLTS MIN.	 0.200 VOLTS 0.100 VOLTS	
3. WRITING SPEED	1 TO 2 MICRO SEC.	50 MICRO SEC.	
4. READING SPEED	1 TO 2 MICRO SEC.	1 TO 2 MICRO SEC.	
5. STORAGE TIME	PERMANENT	PERMANENT	
6. RELIABILITY	EXCELLENT	GOOD	
7. CHECKING SIGNAL	YES	NOT TRIED	
8. RESOLUTION, DIGITS PER INCH FOR COMPUTER USE	10	5	
9. STORAGE CAPACITY	1024 DIGITS	16 (SMALL TARGET)	
10. BOTH + & - SIGNALS	YES	YES	
11. PICTORIAL DEFINITION	PERHAPS	NO	
12. MUST GUN POTENTIAL BE SWITCHED.	NO	NO	

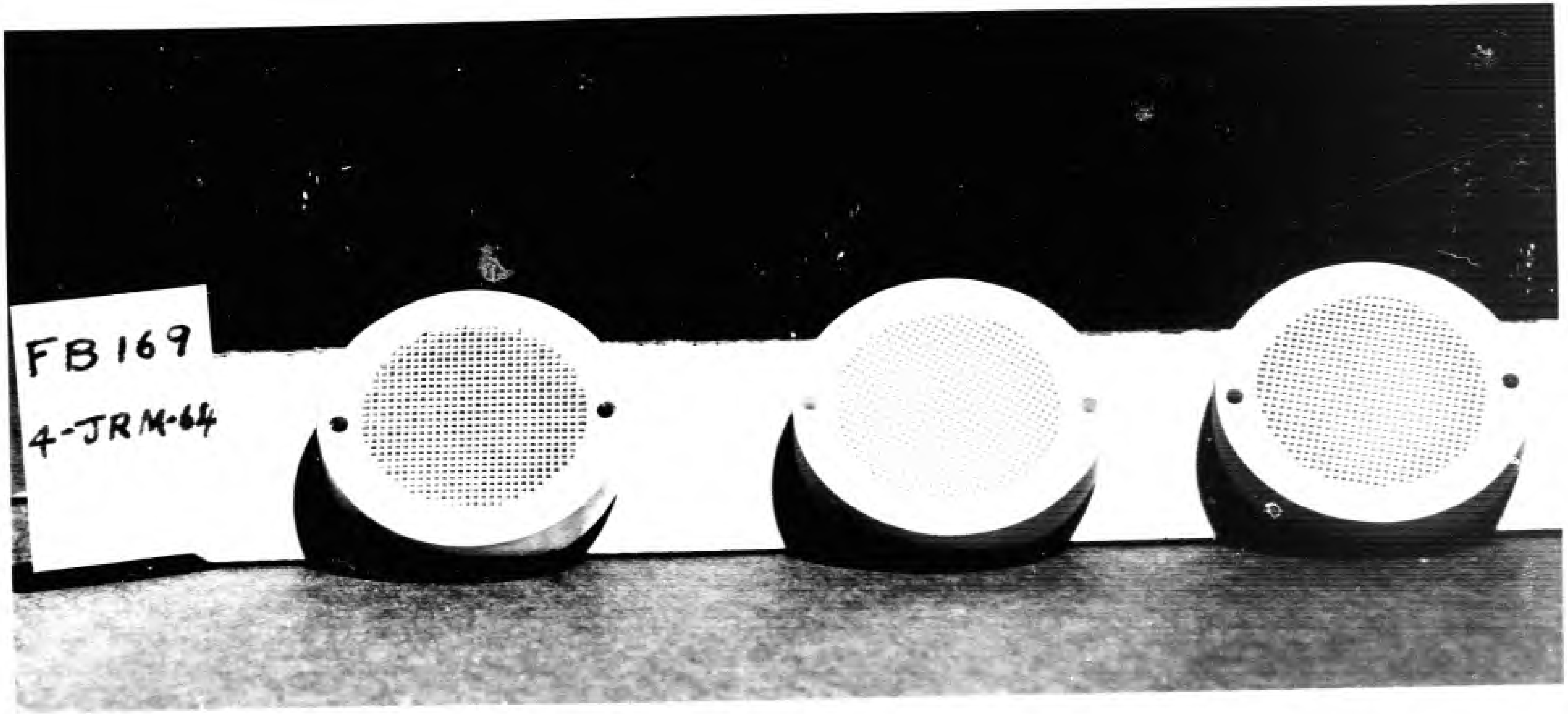
FIG-3

A-30887 USED IN 6345 MEMO M-102



SIGNAL LEVEL DETECTION

FIG. 4


FB169
4-JRM-64


8 SHD 13
FB 193

B-30886 USED IN 6345 MEMO M-102

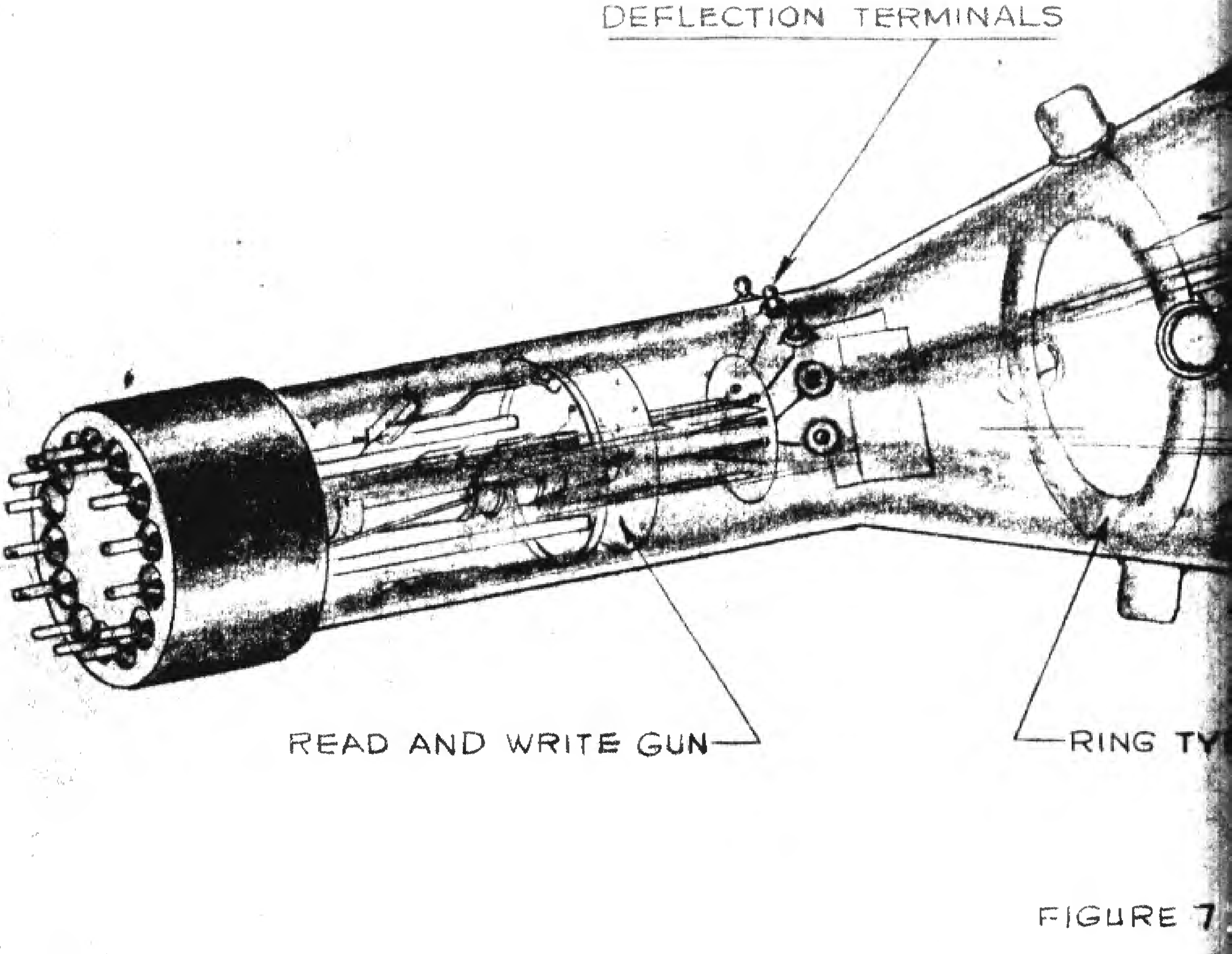


FIGURE 7

POSSIBLE FINAL STORAGE

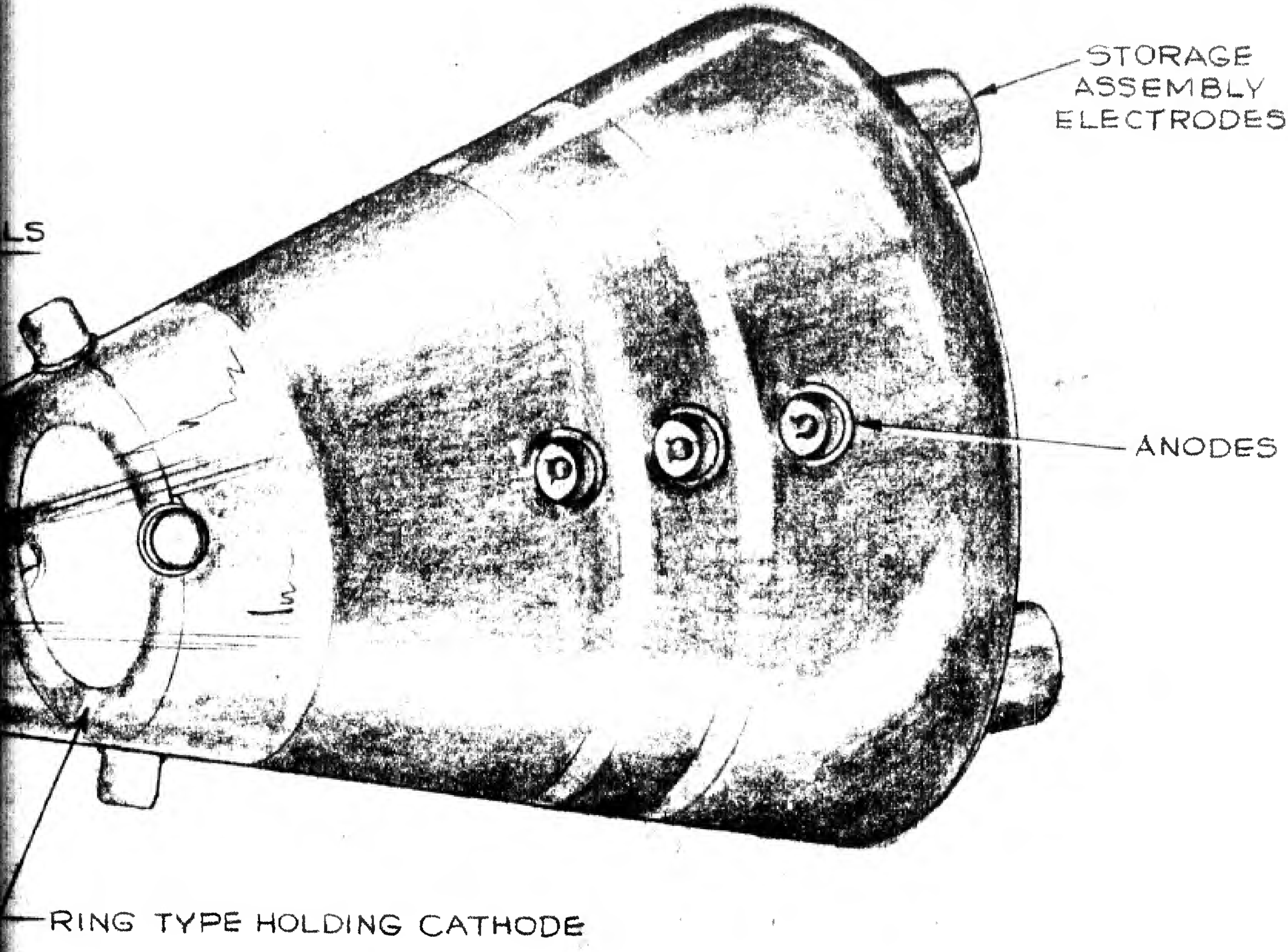
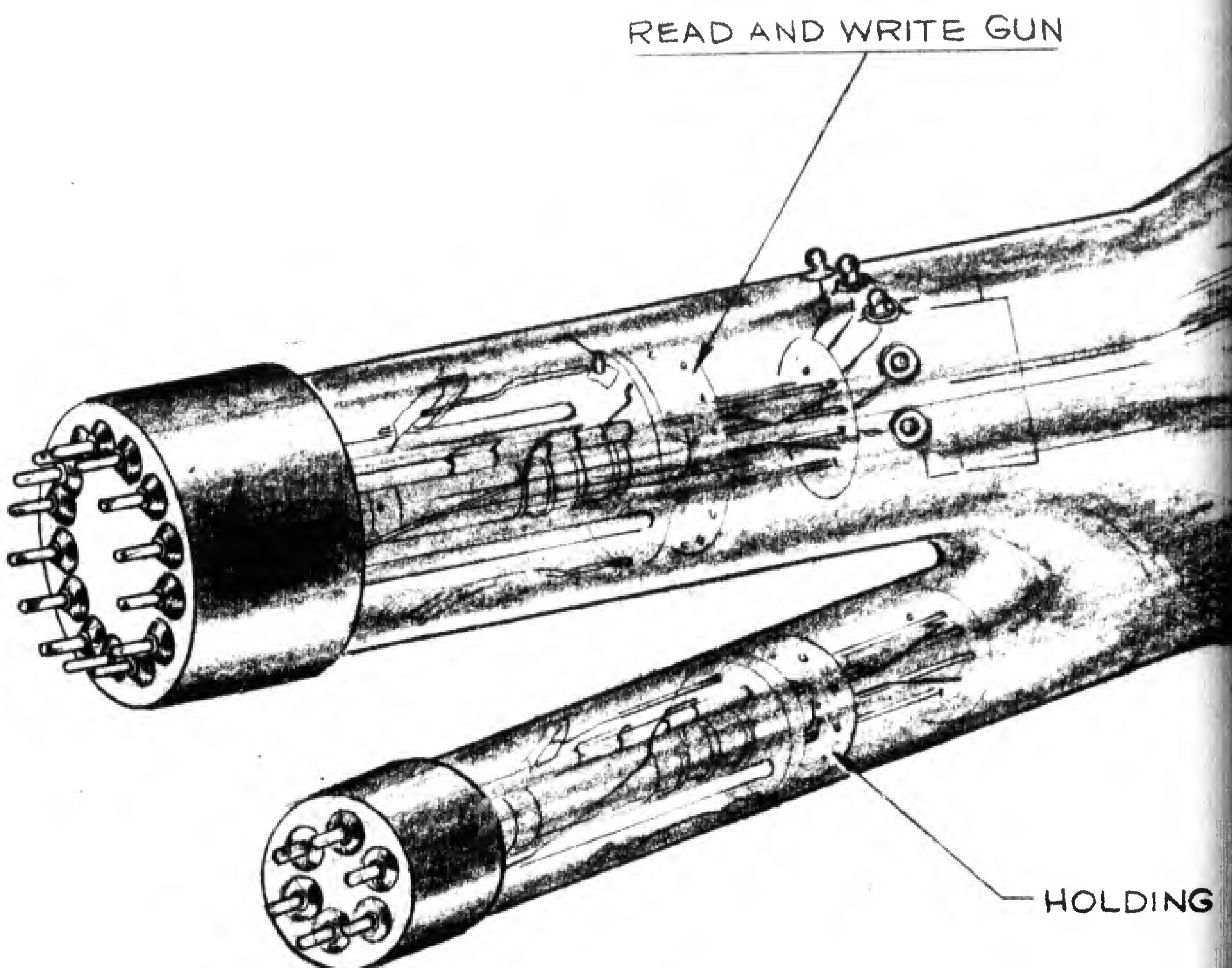


FIGURE 7

STORAGE TUBE DESIGN

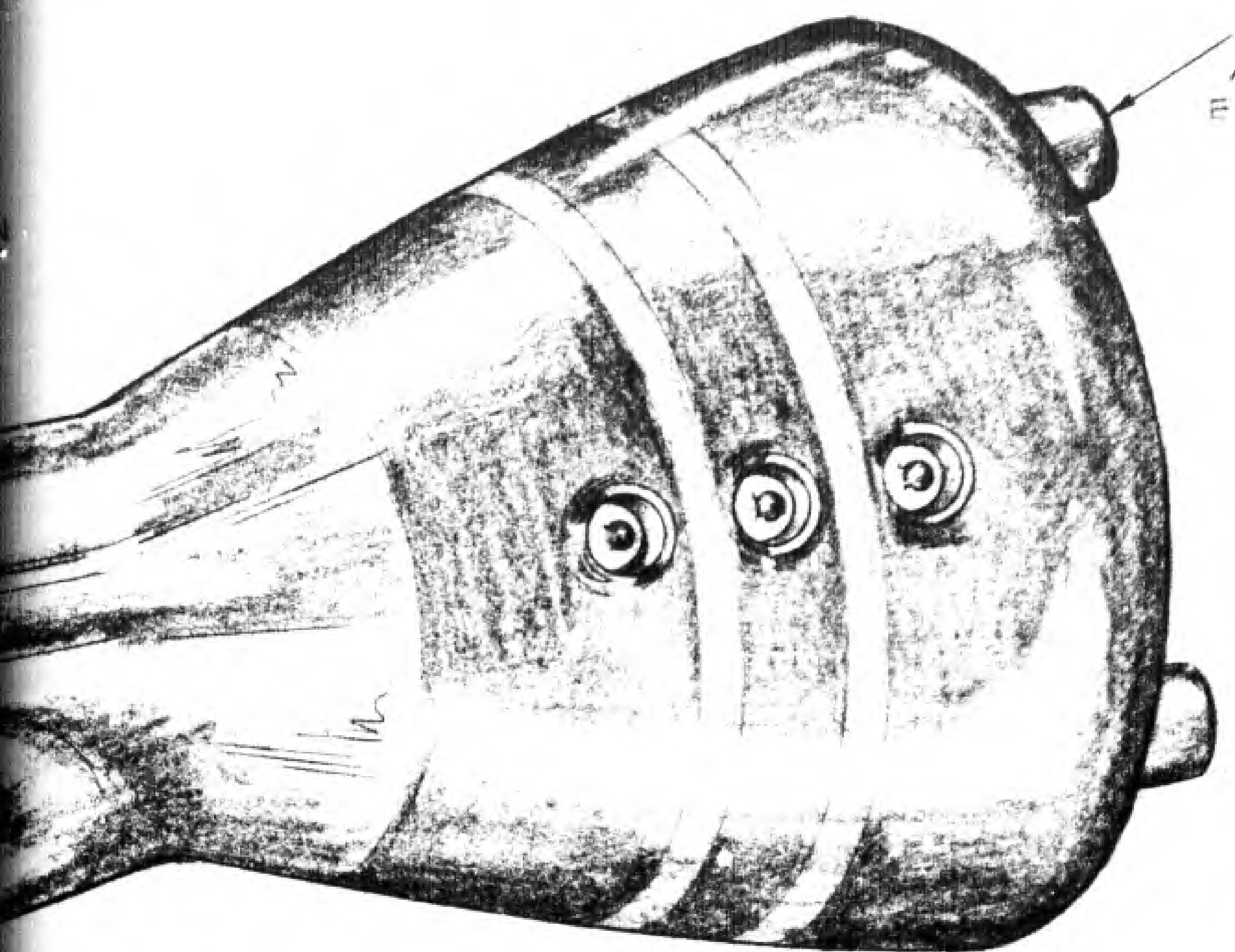
B-30889 USED IN G345 MEMO M-102



FIGURE

POSSIBLE INTERMEDIATE STO

2

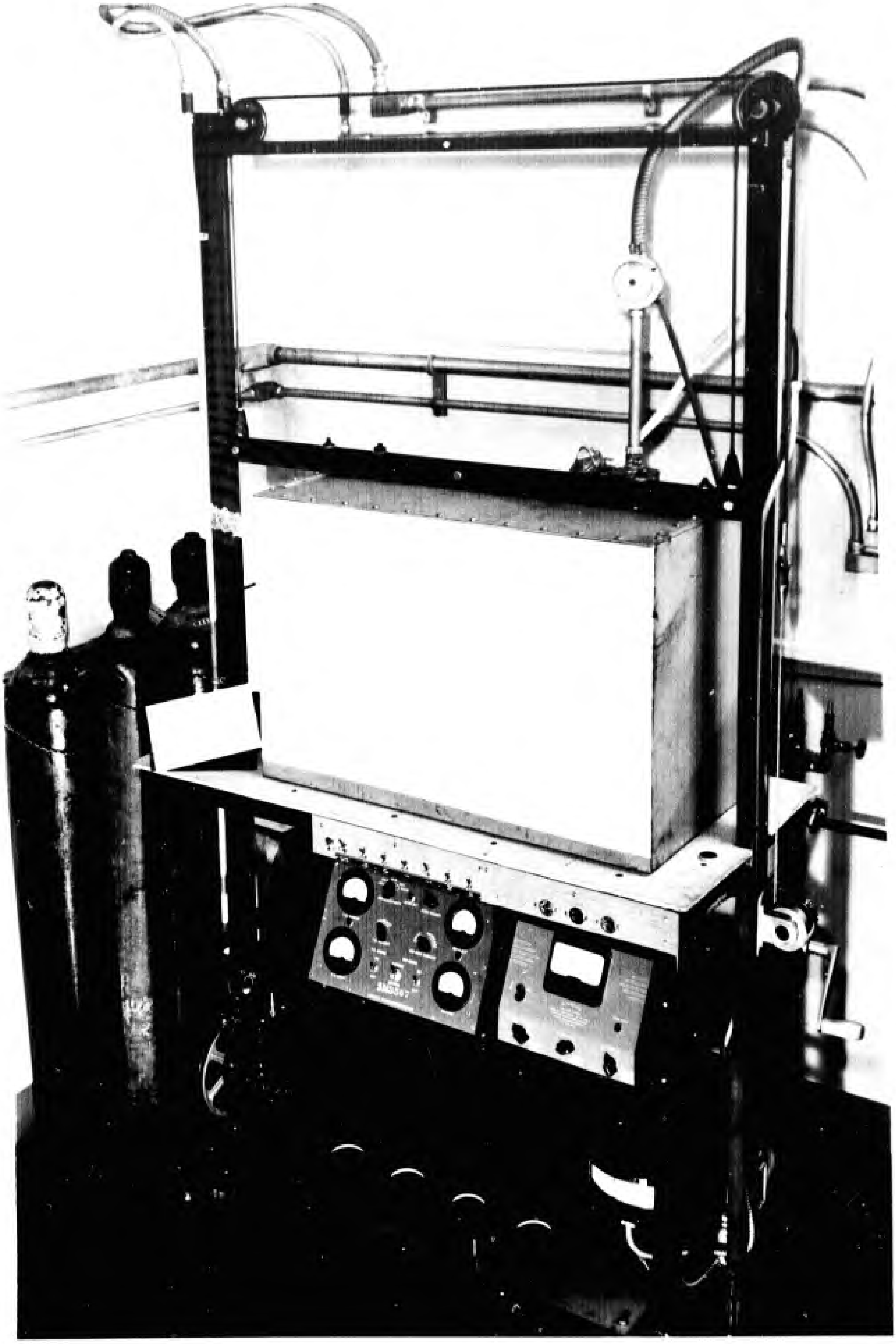


HOLDING GUN

FIGURE 8

TE STORAGE TUBE DESIGN

FB-197



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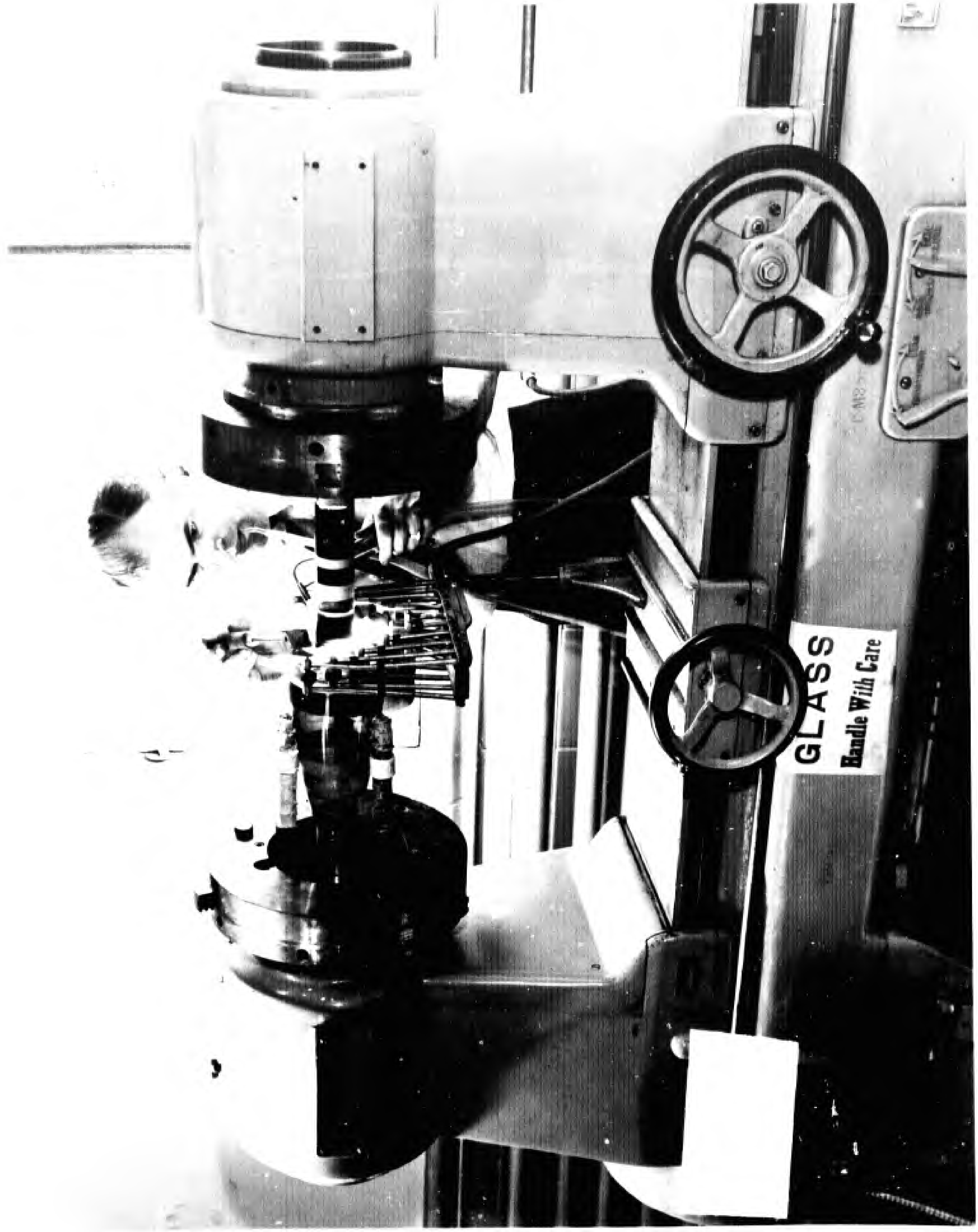
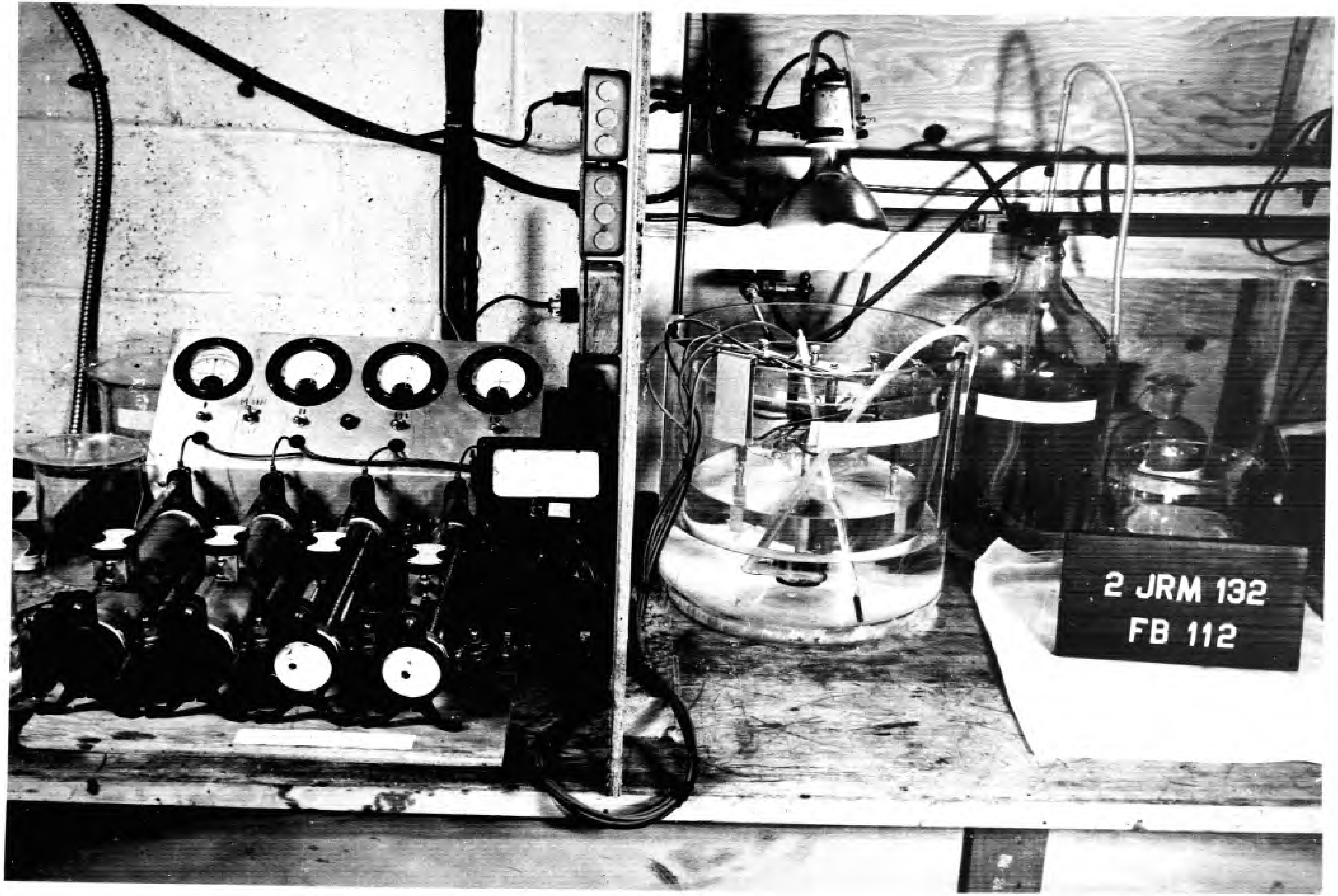
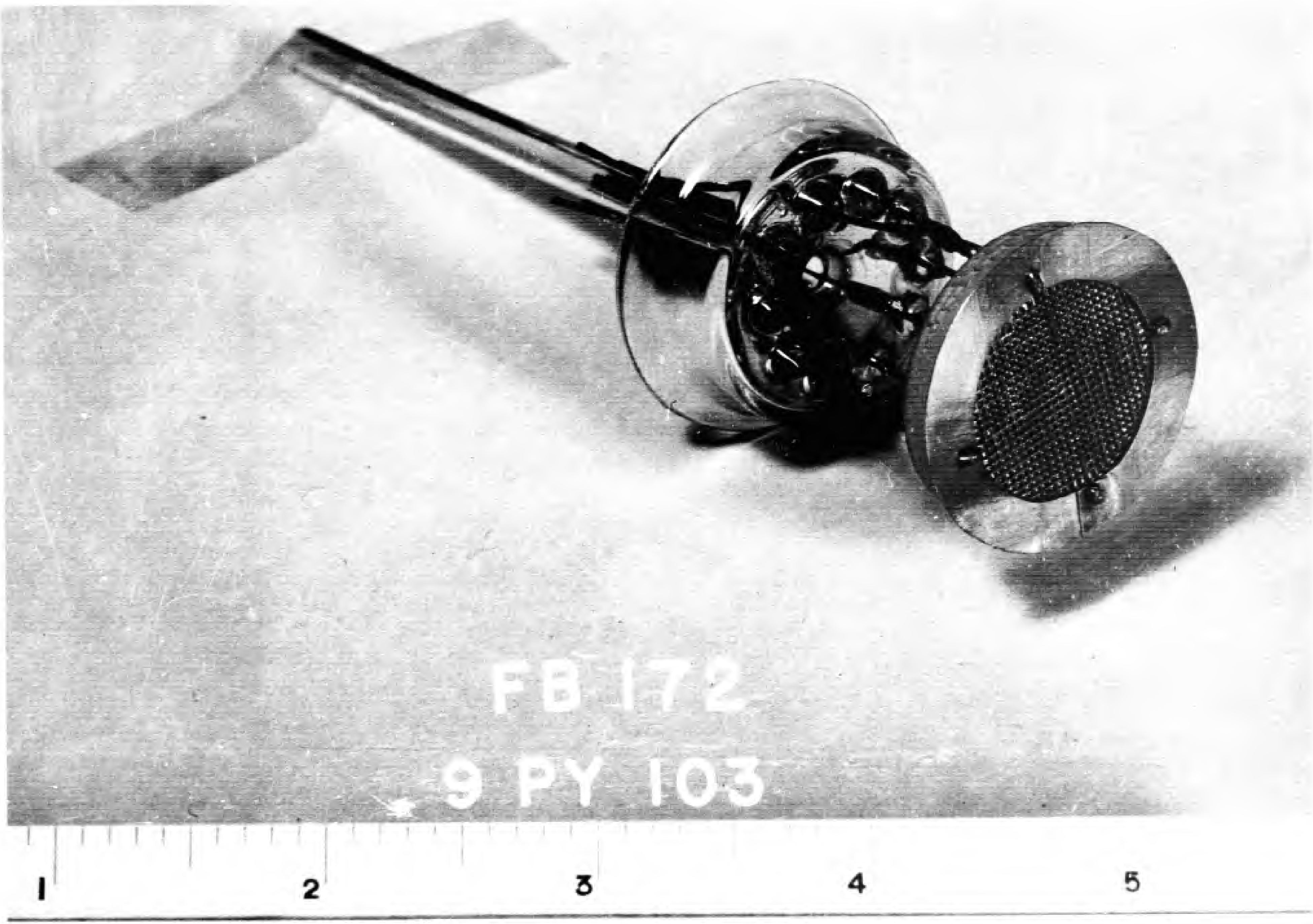
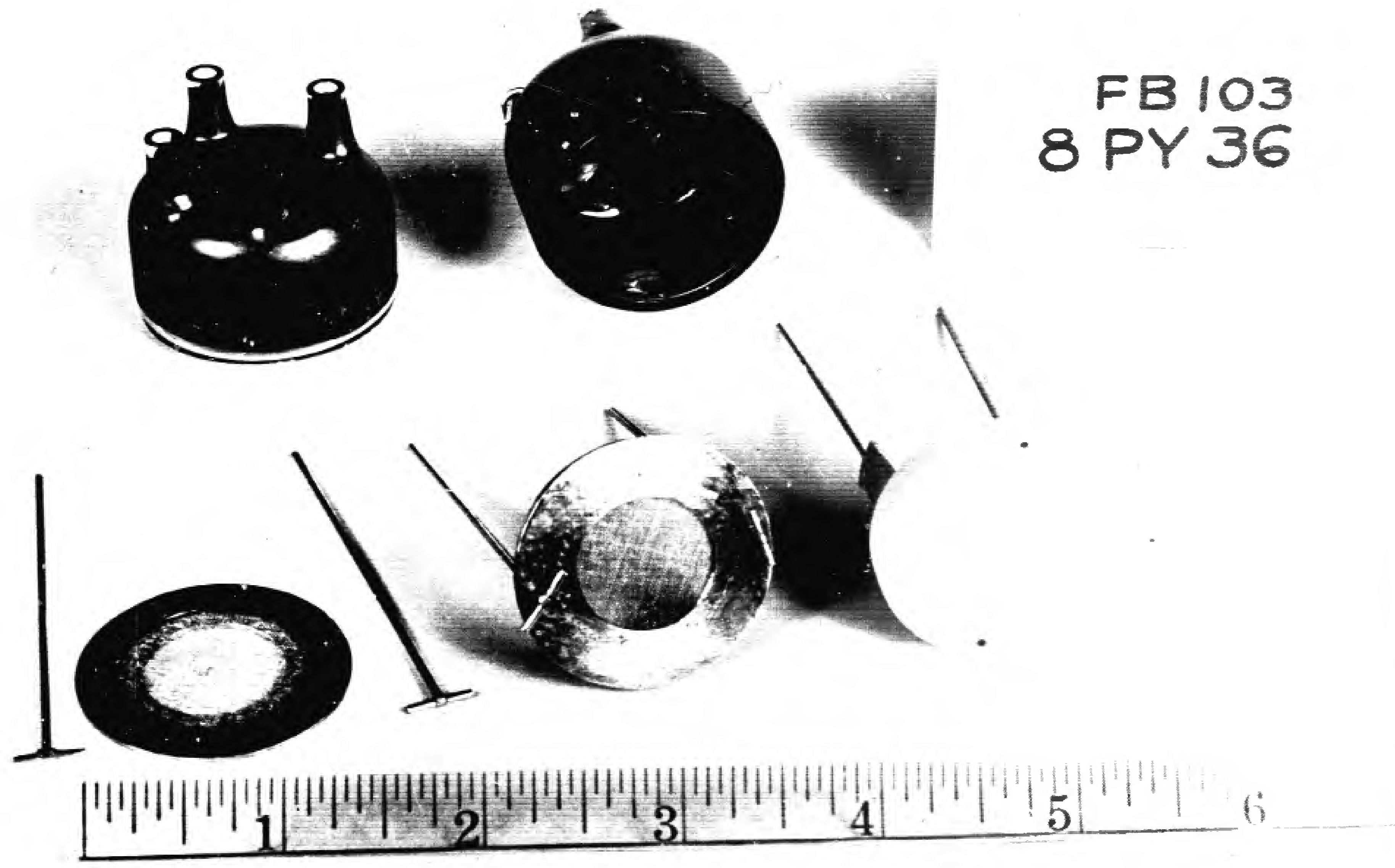


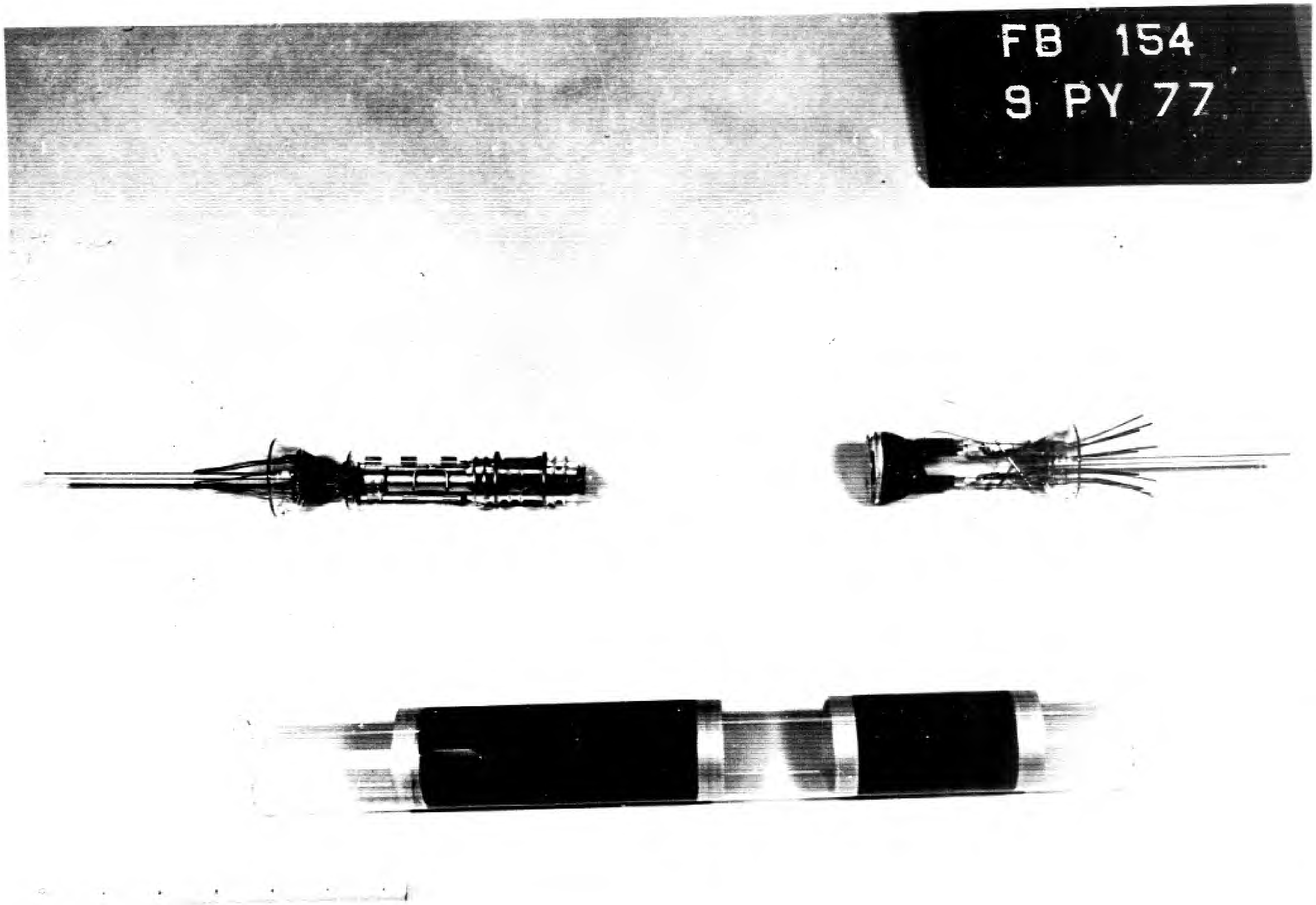
FB—194

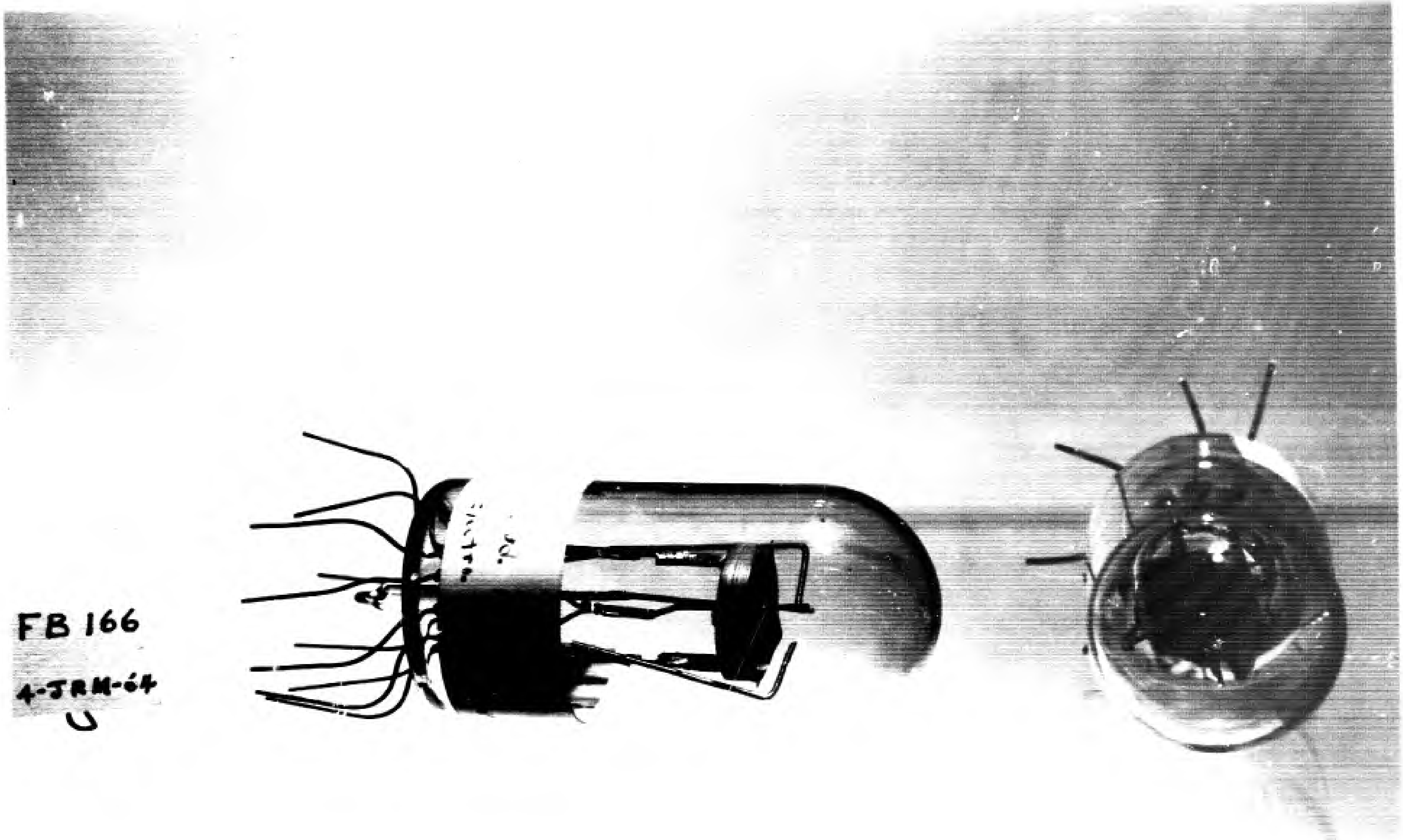

2 JRM 132
FB 112


FB 172
9 PY 103
1
2
3
4
5

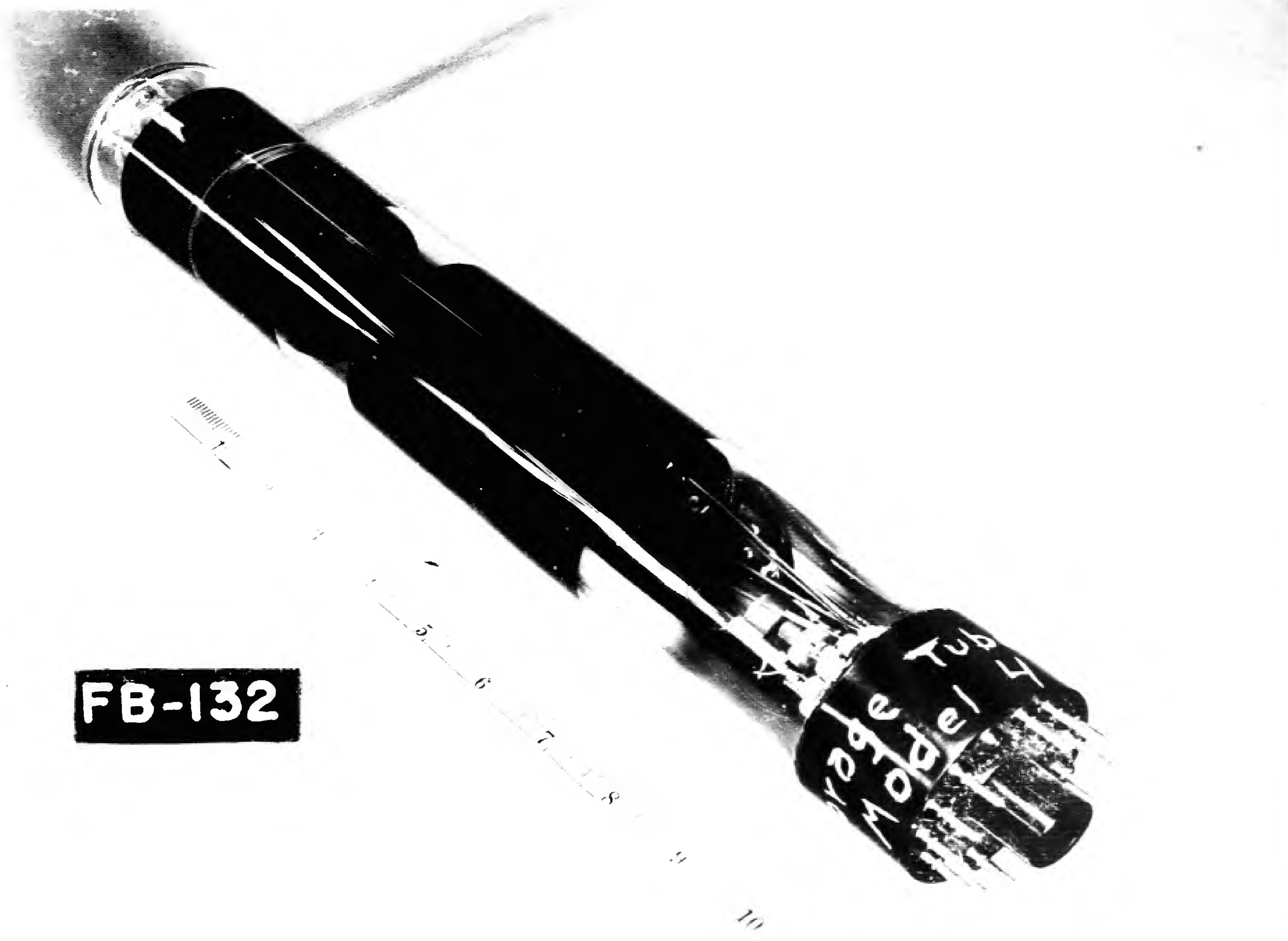


FB 103
8 PY 36
1
2
3
4
5
6


FB 154
9 PY 77


FB 166
4-JAN-64

FB-134


FB-132
Model 4

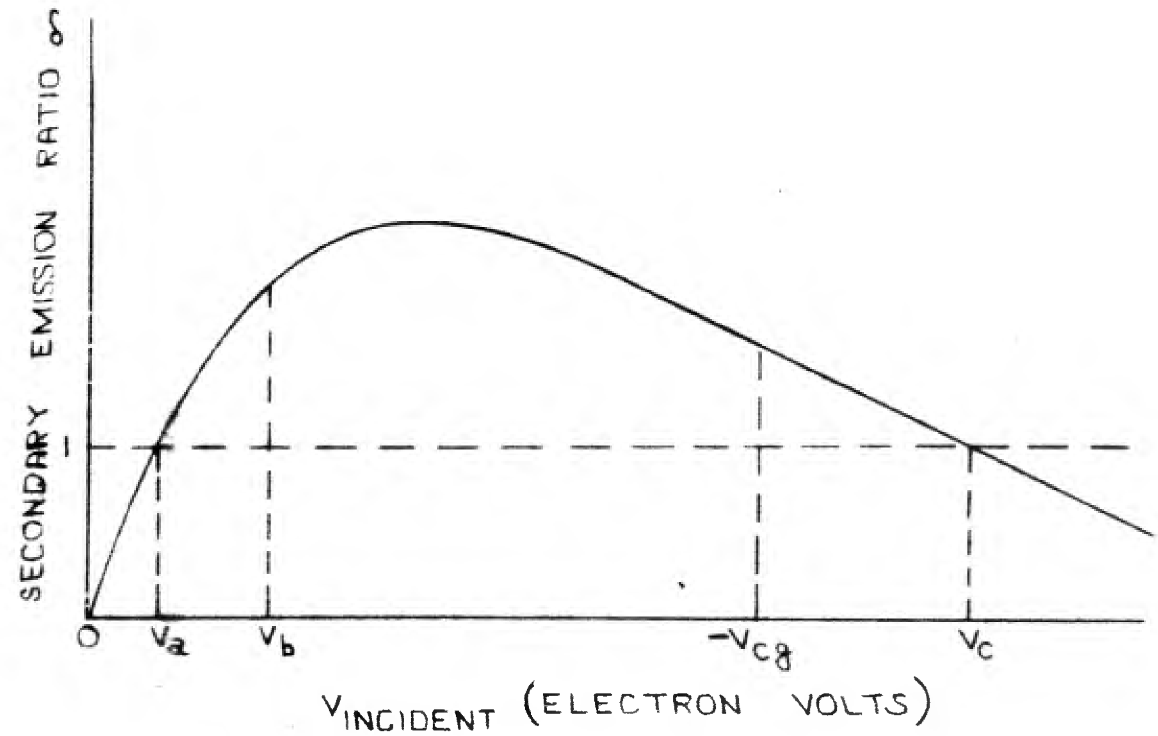


FIG. 19 SECONDARY EMISSION RATIO AS A FUNCTION OF THE ENERGY OF INCIDENT PRIMARY ELECTRONS.

6345
Report No. E-110

SERVOMECHANISMS LABORATORY
Massachusetts Institute of Technology
Cambridge, Massachusetts

Date of Report: January 13, 1947 | Page 1 of 6 pages

Subject: Electrostatic Storage Tubes | Drawing: A-30391

Reference: The following is a written manuscript for a discussion on electrostatic storage tubes presented to the Harvard Computation Symposium, Wednesday, January 8, 1947.

Written by: Jay W. Forrester.

This afternoon, we are to examine briefly electrostatic data storage and review the work of the Servomechanisms Laboratory at the Massachusetts Institute of Technology in applying electrostatic storage to high-speed electronic computation. This research is being sponsored by the Special Devices Division of the Office of Naval Research. For brevity, let me limit the discussion to storage requirements and objectives of the M.I.T. program. For proper perspective, let me say that the present status of the research is promising but not yet pursued to a complete or workable conclusion.

So that you may properly interpret a description of the electrostatic storage tube program, let's first review requirements that such a storage device must meet.

1. The contemplated computer, after passing through various growing stages, is emerging as a parallel digit transmission system. The storage must then receive and deliver binary digits on parallel buses.

2. Resulting from certain objectives of the M.I.T. work, a speed, high even for electronic computers, will be required. 20,000 to 40,000 computations per second must be possible. This will force the reduction of multiplication time to less than 50 microseconds, perhaps to as little as 16 microseconds. The time necessary to order and to operate the storage represents more than half of total time bringing

considerable pressure to speed up storage operation.

3. Because of operating speed requirements, time is not available in certain problems of interest for scanning tables of functions and coefficients. The storage must, therefore, give immediate access to all required data. This data may amount to some 10,000 numbers of 40 binary digits each, including program control information. Storage of about 16,000 numbers or 640,000 binary digits is being considered.

With these general computer characteristics in mind, we can now turn out attention to specific goals of the electrostatic storage tube work at M.I.T.

1. Signal to noise ratio must be high. In the interests of computer reliability only the most positive indication of zeros and ones can be tolerated.

2. The length of time that a number can be left in storage must be independent of the programming procedure; that is, the storage should impose no restrictions on the order or number of times that storage positions may be used. This can be achieved by a storage that is continuously self-sustaining; or one that is periodically reactivated, the period being short enough that storage is independent of any program sequence within the period. If the storage is periodically reactiviated, such reactivation time should consume only a small percentage of computer time.

3. Storage response time would appear in proper balance with other factors if 6 microseconds are allotted to storage control and operation. This would be divided as follows:

Transmission of control order	1 microsecond
Storage Selection Switching	2 microseconds

Digit Reading	1 microsecond
Digit Rewriting	1 microsecond
Transmission of number	1 microsecond

4. Mechanical and design characteristics of the storage tube must be simple, reliable and compatible with the construction and use of tubes in sufficient number for the storage of over a half million digits.

Now let us turn our attention to the specific electrostatic storage tube research at M.I.T. At first, we attempted to adapt the standard 5" cathode ray tube to the problem. The standard cathode ray tube with a signal plate applied over the screen outside the tube satisfied certain radar memory requirements and has exhibited signal storage of several hours. It does not show promise for computer applications. Signal level is the order of a millivolt and signal to noise ratio is poor. Operation appears to depend on second order rather than first order effects within the tube and signals at one point of the dielectric are affected by operation at all other points. The only possibility of using such a tube would appear to lie in cyclic reading and writing for the storage of a relatively small number of points.

As a result, we are now embarked on a research program of tube design and construction to meet the requirements earlier outlined. This work is being pursued by Dodd, Ely, Macdonald, Nolan, and Youtz at the Servomechanisms Laboratory with the suggestions and helpful advice of Professor Nottingham of the Physics Department.

Let me describe the general approach. See Fig. 1 and 2, Drawing A-30291. The tube will use an electron beam gun and envelop similar to a 5" cathode ray tube. At the screen end will be located a thin dielectric with a signal plate on the back surface away from the gun and a grid in front of the dielectric. Digits would be written and read with a stationary beam deflected to one of 1024 locations on the dielectric. Separate digits of a number would be stored at corresponing locations within separate tubes. Tubes would be used in banks, each bank consisting of as many tubes as there are digits in a number. Beam deflection and intensity at all tubes would be controlled in parallel. Only reading and writing voltage circuits would be separate for each tube.

The beam can be deflected to any point of a 32 by 32 array giving 1024 storage locations. Both ones and zeros will be uniquely stored as positive or negative charges on the dielectric with a small or zero charge being detected as improper operation. To make storage possible the dielectric must have a secondary electron emission ratio greater than unity, a characteristic common to nearly all materials. Operation depends on the fact that the dielectric where struck by the high velocity electron beam will hold these electrons if the spot is positive with respect to the grid. If the spot is negative with respect to the grid the dielectric will yield secondary electrons to the grid in numbers greater than those in the primary beam until the spot reaches a potential differing from the grid by a constant value. For purpose of explanation only, assume this constant to be zero.

In reading, if electrons are transferred to or from the dielectric, a voltage will be induced by capacity coupling on the signal plate.

Suppose a one is to be stored as a positive charge. The grid is changed to say plus 100 volts and the beam turned on. Excess secondary electrons will be attracted to the grid until the spot reaches the grid potential at which time secondary electrons equal the primaries in number and no further potential change occurs.

Storage of a zero would be accomplished by placing the grid at a negative potential so that electrons would be held on the dielectric to produce a negative charge.

Reading would be accomplished with the grid at neutral by striking the dielectric with the beam and detecting voltage changes on the signal plate. Charging of positive areas representing ones would produce negative output signals and discharging of negative areas would indicate zeros as positive voltages.

It is apparent that the reading of a digit causes erasure so that the block diagram of Figure 3 for coupling between reading and writing circuits would be used to rewrite the stored signal.

The reading circuit would have three stable states; zero, one and neutral. The circuit is externally reset to neutral before reading and is tripped to zero or one by a positive or negative signal respectively. After tripping, the reading circuit cannot be reversed or reset by voltages at the signal input and indicates a zero or a one at the output. This output signal initiates the writing circuit to rewrite the stored signal while the electron beam is still on. The stored signal, thereby, is left at full voltage. For storage of new data, writing signals are brought directly to the writing circuit without operation of the reading circuit.

Erasing of signals is not required since writing is unaffected by a number already in storage.

The output signal depends on thinness of the dielectric, reduction of capacitance from signal plate to ground, and the potential stored on the dielectric. Calculation and experiment indicate signals in the range of 0.1 volt from tubes of final size. Relative voltages on the various tube electrodes are open to considerable variation. The above values are selected for descriptive purposes but it is probable that in practice the grid would be grounded and the reading and writing operations combined at the signal plate.

Three tubes have been constructed with storage areas of 1 square inch to test general operating characteristics. These demonstrate operation generally as outlined above. Storage for several minutes without reactivation is possible and clean output signals are derived.

The following problems exist:

1. Stored signals expand outward from the point of beam impact for long pulses or repeated short pulses at the same grid potential. Control of secondary electrons must be established.

2. Electron gun beam current should be increased and, depending on the reactivation procedure, stray high energy electrons outside the beam may need to be reduced.

3. A reactivation procedure must be worked out, either by periodic reading and rewriting; or through the continuously self-sustaining characteristic of low energy electrons sprayed on the dielectric.

4. Final selection of materials must be made on the basis of further tests.

5. A rectilinear deflection circuit giving reliable and sufficiently accurate deflections of plus and minus 15 units along each axis must be perfected.

Possible solutions to all these problems exist but have not yet been tested.

The following favorable points have been indicated by work to date:

1. Clear output signals above noise level.

2. A tube design which will be easy to construct.

3. Freedom from serious ohmic leakage difficulties at the dielectric.

Jay W. Forrester
Jay W. Forrester

JWF:mla

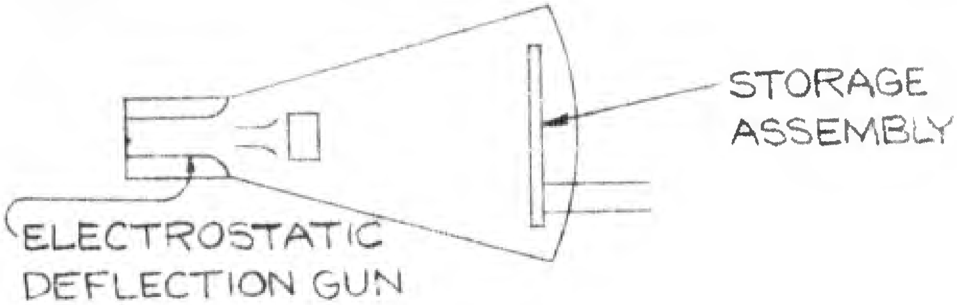


FIGURE 1

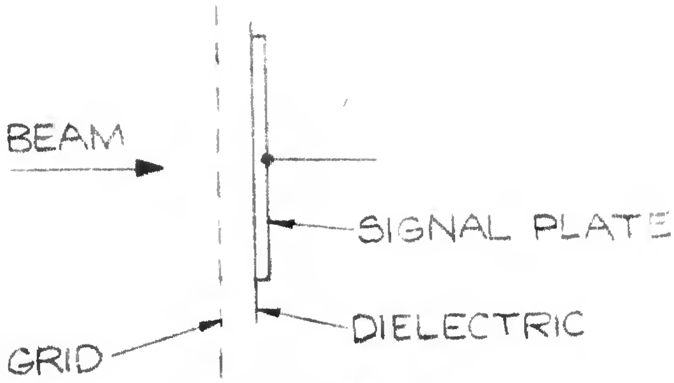


FIGURE 2

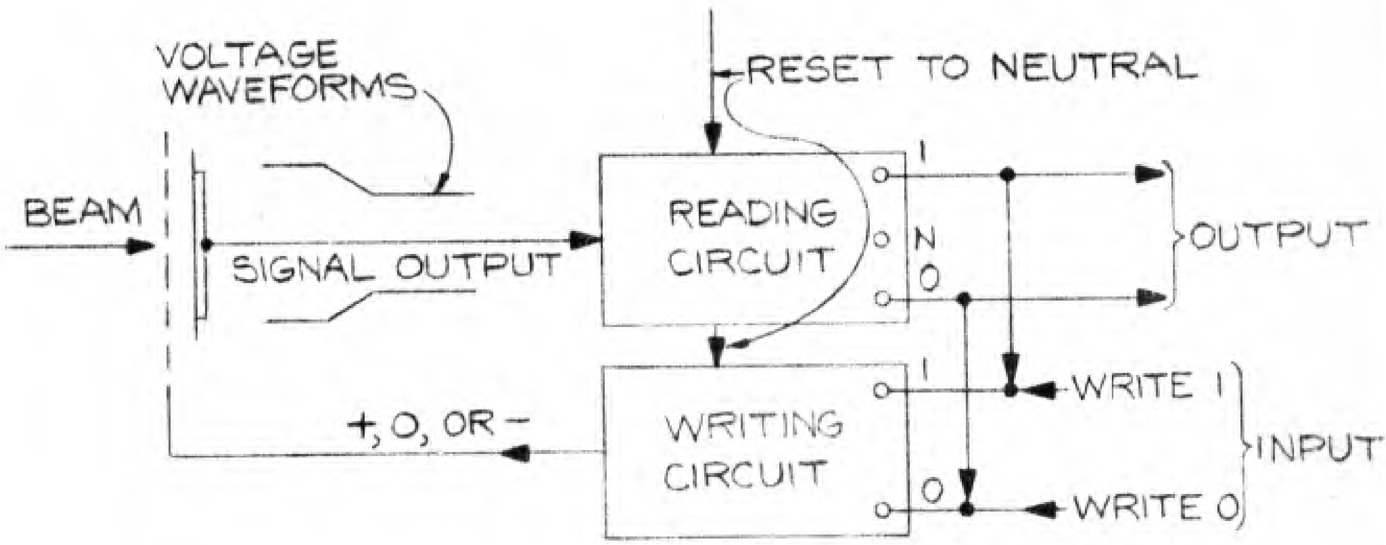


FIGURE 3

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SERVOMECHANISMS LABORATORY
DR. T.L. 1/14/47
A-30291

USED IN 6345 REPORT R-110

MEMORANDUM NO M-96

SERVOMECHANISMS LABORATORY
Massachusetts Institute of Technology
Cambridge, Massachusetts

To: Jay W. Forrester
6345

From: S. H. Dodd and P. Youtz
Drawing:

Subject: Progress Report and Development Schedule of Storage Tube Work
SA-39319

Date: August 15, 1947

Immediate Objectives of the Group

1. Demonstration unit for the electrostatic storage tubes.

2. Write reports on the electrostatic storage tubes, anodizing techniques, and dielectric investigations.

3. Finish anodizing studies.

4. Development of equipment for electrostatic storage tube testing

5. Processing and testing of models 7 and 9.

6. Evaporation of beryllium studies.

7. Moving

Immediate Objectives of Individual Members of the Group

1. C. H. R. Campling: Development of 1 μs to 100 μs pulser.

2. S. H. Dodd: Write report on model 5, memorandum on models 2, 3, 4, and consult on writing report of model 1. Develop clamping circuits.

3. J. R. Macdonald: Finish anodizing studies and write complete reports on all phases of his work.

4. W. J. Nolan: Design demonstration unit for electrostatic storage tubes. Write reports on electrostatic storage tube model 1 and 6.

5. P. Youtz: Process models 7 and 9 and conduct investigations of the evaporation of beryllium.

Progress Report and Outline of Storage Tube Projects

1. Model 8 tube had two storage surfaces and two electron guns. One storage surface was Al_2O_3 with a coating of willemite. The second surface was Al_2O_3. We were unable to process this tube so that it would have the necessary high vacuum. Grids from model 8 and new electron guns were put in the envelope of model 8 and designated model 8A. We were unable to keep a high vacuum in this tube. The envelope had almost twice the surface area of an ordinary cathode ray tube. Later Dr. A. S. Eisenstein processed a tube of comparable size which was coated by us. In the light of his investigations and the comments last December by Hilary Moss of England, we are prebaking all coated envelopes. (We were unable to follow this procedure until our own ovens were completed.)

2. Model 10 tube is a replacement for model 8. It has two electron guns and one storage surface of Al_2O_3 with a coating of willemite. This tube has been operating satisfactorily the past fortnight. Tests were completed with all available test equipment. These tests indicate the following:

a. Holding gun operation was satisfactory at low repetition rates. At high repetition rates the secondary redistribution seems to overcome holding gun operation.

b. Necessary to have separate second anodes to allow adjustment of accelerations in the two guns.

c. The combination of willemite and Al_2O_3 has too high a first crossover potential thus requiring excessively large switching pulses.

d. Indirect evidence that the high first crossover potential requiring high acceleration voltages in holding beam gun may be causing progressive breakdown of the dielectric.

e. Separate second anodes should allow higher holding gun currents.

f. Resolution was approximately five spots to an inch.

g. This would indicate the feasibility at the moment, of a 16 x 16 storage matrix for WWI.

Model 10 tube will be operated each day to detect any signs of faulty operation. Further tests of resolution, writing and reading times will be made when the necessary test equipment is developed.

3. Model 11 tube will be a possible replacement for model 10. Components for this tube will be kept in a desicator and assembled whenever model 10 fails to operate.

4. Demonstration Unit for Electrostatic Storage Tube will be designed by W. J. Nolan in consultation with Jay W. Forrester and S. H. Dodd. We will use as many as possible of the test units that have proved satisfactory in our test work. Construction of demonstration unit will be given to someone outside of the storage tube group. Testing and operation of the unit will be done by someone within the group.

5. Model 7 tube will be constructed in a 2 inch diameter glass envelope with a shielded construction to isolate stray electrons and will contain a flat Al_2O_3 dielectric and a perforated nickel sheet with a single one-eighth inch diameter hole. This tube will then be used to

a. determine the leakage and emission characteristic of Al_2O_3 and

b. observe these characteristics during a life test.

6. Storage surfaces other than Al_2O_3 seem desirable. The physical requirements of such a surface are:

a. high resistivity

b. high breakdown strength

c. high secondary emission ratio

d. low first crossover voltage

e. a material that can be processed reliably

f. reliable emission ratio as a function of time.

This requires a careful search of all materials or combination of materials which meet the above requirements. H. L. Heydt is writing a seminar on secondary emission. It was suggested that his thesis investigate the secondary emission characteristic as a function of time of materials that could be used as storage surfaces.

7. The high secondary emission requirement might be solved by a beryllium mosaic on Al_2O_3. The evaporation studies of beryllium will attempt to determine

a. best method of processing

b. creepage

c. uniformity

d. resistance

e. reaction with Al_2O_3

There will be consultations with Professor Harris and Professor Nottingham on the subject. The literature on the subject will be surveyed.

8. Model 9 tube will be constructed in a similar manner except a coating of beryllium will be applied to the top surface of the Al_2O_3 dielectric and connections to this metallic coating will be made available. This tube will be used to investigate

a. leakage of Al_2O_3 dielectric with a beryllium coating and techniques of applying this coating.

b. emission characteristics of this coating which may not be pure beryllium since it is expected that this coating will be evaporated on the dielectric and will be subject to contamination between time of evaporation and assembly in air in the model 9 tube.

c. these emission characteristics will be measured as a function of time in a life test.

9. Mosaic storage surfaces. If the first crossover potentials of the conducting areas and the dielectric differ widely this would prevent storage. The dielectric surrounding the conducting areas may be driven to cathode potential while the conducting areas should be at collector potential. The negative dielectric areas would prevent positive charging of the conducting areas.

10. Anodizing Investigations will be completed and written up completely in a series of reports. However the reaction of Al_2O_3 with different coatings must be investigated later.

11. Gas Data Storage studies have been postponed until October first. The subject and plans for further work will be studied at that time.

12. Moving Again. The group will move from the first floor of Barta Building to second floor within the next fortnight. The details and supervision of the moving will be handled by our technicians with the help of Al Taylor's men.

13. Vacuum system construction is progressing whenever there is manpower available to work on it. The ovens have been completed sufficiently to use them for annealing and baking of the glass. The glass for the vacuum system will be assembled on the system whenever we move into our new quarters and time permits.

14. Tube Construction Facilities. We have been using R.L.E. facilities. This is very inconvenient. However it will require at least six more weeks to procure parts and power for the R.F. Bomber. Most of the other facilities can be set up whenever they are needed.

15. Reports. A high priority has been assigned to the task of writing reports on all phases of our activities.

Agenda

In view of the above outlined objectives, the following tasks are necessary.

Model 10 Tube

1. Measurements of leakage resistance between electrodes in the storage assembly and guns.
2. Measurement of interelectrode capacitance for the storage assembly.
3. Use clamping circuits to allow observation of signals during writing and reading with holding beam on.
4. Test for time required for writing and resolution.
5. Evaluation of test results.

Model 11 Tube

6. Construction of all components.
7. Assembly of tube.
8. Processing of tube.
9. Testing for satisfactory operations.

Demonstration Unit for Electrostatic Storage Tubes

10. Design of the unit.
11. Development of new circuits.
12. Supervision of construction.
13. Testing of the unit.

Model 7 Tube

14. Processing of the tube.
15. Outline of tests for model 7.
16. Testing of model 7.

Model 9 Tube

17. Assembly of tube.
18. Processing of tube.
19. Outline of tests for model 9.
20. Testing of model 9.

Evaporation of Beryllium on Al_2O_3

21. Preparation and processing of Evaporation Tube model 2. This will have a wire across the open part of the mask.

22. Preparation and processing of Evaporation Tube model 3. This will have a screen across the open face of the mask.

23. Preparation and processing of Evaporation Tube model 4. This has a copper mask over an anodized embossed aluminum plate.

24. Evaporate beryllium on six differently treated samples of Al_2O_3.

25. Consultation with Professor Harris. Consultation with Professor Nottingham.

26. Survey of the literature to study evaporation techniques.

Anodizing Investigations

27. Investigate method of anodizing completely through ridges on griddle surface.

28. Measure anodized thickness with 1/2 normal acid concentration, 1/2 normal current density and with 1/2 normal acid and current.

29. Determine current versus voltage characteristics after different anodizing times to obtain estimates of best anodizing conditions.

30. Resistance measurements on beryllium coated samples in a high vacuum to determine the effectiveness of different Al_2O_3 sealing methods.

31. Apply insalute to anodized surface to observe reaction between insalute and Al_2O_3 in high vacuum.

32. Apply aquadag to anodized surface to observe reaction between aquadag and Al_2O_3 in high vacuum.

33. Perform experiments similar to items 31 and 32 for silver paint and silver paste.

Insalute Tests

34. To determine whether insalute supports introduce unnecessary leakage paths, a few simple insalute structures sealed in a high vacuum envelope will be tested for leakage.

Secondary Emission from Metals and Insulators

35. Survey of the literature.

36. Translation of significant foreign articles.

37. Summarize pertinent results from all available sources in a report.

Storage Surfaces other Al_2O_3

38. Survey of possible dielectric surfaces.
39. Investigate methods of producing those surfaces.
40. Investigate evaporation of quartz in form of a griddle surface on Al_2O_3.
41. Evaluate different sizes and shapes of griddle pockets.

Vacuum System Construction

42. Completion of ovens.
43. Completion of frames.
44. Assembly of frames and wiring.
45. Assembly of glass system for high vacuum work.
46. Testing and calibration of system for high vacuum work.
47. Assembly of second glass system.
48. Testing and calibration of second system.

Tube Construction Facilities

49. Power and water for R.F. Bomber.
50. Induction loops for R.F. Bomber.
51. Flexible leads for R.F. Bomber.
52. Repair R.F. Bomber.
53. Set up Glass-Working bench.
54. Procurements of tube components.

Reports

55. Memorandum on models 2, 3, and 4.
56. Model 1.
57. Model 5.
58. Model 6.
59. Anodizing procedures.
60. Measurement of high resistances and dielectric characteristics of Al_2O_3 layers.
61. Magnetic control for Secondary Electron Redistribution.
62. Studies with an Electrolytic Tank.

Test Equipment

63. Development of 1 μs - 100 μs pulser.

64. Supervision of the work in item 63.

65. Supervision of the modification of the portable test equipment.

66. Supervision of setting up test benches for holding-gun operation.

S. H. Dodd, VH

S. H. Dudd

P. Youtz

Patrick Youtz

SHD:PY/vh
August 18, 1947

cc: H. R. Boyd
F. H. Caswell
C. H. Campling
T. F. Clough
A. R. Curtiss
J. O. Ely
R. R. Everett
H. Fahnestock
M. I. Florencourt
J. R. Macdonald
W. J. Nolan
R. B. Palmiter

SA-39319

DATE	P. YOUTZ	W. NOLAN	S. DODD	J. MACDONALD	C. CAMPLING
AUG. 18	14 54 31 32	10 11 56 64	11 57	61	63
19	14 31 32 33	10 11 56 66	11 57 10	31 32 27 61	63
20	21 17 54 33	15 19 56 64	15 19 11	31 32 27 61	63 15 19
21	18	10 11 56 66	11 57	27 33 62	63 16
22	18 34	10 11 56 64	11 57 10	27 33 62	63 16
25	24 25 26	10 11 56 66 65	11 57	27 34 62	63 20
26	24 25 26	10 11 56 64	11 57	27 59	63 20
27	24 26	10 11 56 66 65	11 10	59 30	63
28	24 26	10 11 56 64	11 56	59 30	63
29	24 26	10 11 56 66 65	11 56 55 10	60 30	63
SEPT. 2	24 26	12 64 58 49	55	60 30	63
3	24 22 26	12 58 50	55	60 30	63
4	24 22 26	12 64 58 51	55	60 30	63
5	24 26	12 58 52	55	60 30	
				Items 28 & 29 Approx. Complete	

NOTE
MARGARET FLORENCOURT WILL TRANSLATE VARIOUS FRENCH AND GERMAN ARTICLES ON SECONDARY EMISION AND EVAPORATION.

TIME SCHEDULE-STORAGE TUBES

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SERVOMECHANISMS LABORATORY
DWG. NO. 6345 SA-39319

6345
Memorandum M-121

Project Whirlwind
Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

SUBJECT: PROGRESS REPORT AS OF OCTOBER 20, 1947 AND DEVELOPMENT SCHEDULE OF STORAGE TUBE GROUP FROM OCTOBER 20, 1947 TO NOVEMBER 15, 1947

To: Jay W. Forrester

From: S.H. Dodd, W.J. Nolan, and P. Youtz

Date: October 20, 1947

Summary of Report

The immediate objectives of the group are outlined briefly. The immediate objectives of the individual members of the group are discussed to show the proposed activity of each member during the next four week period. The next section is a brief progress report and an outline of all currently active storage tube projects. We find it difficult to prepare a detailed work agenda and schedule for a four week period. Unforeseen troubles, new results appearing in the test program and new ideas require a flexible work agenda which can be best prepared each day. No test work on new dielectrics is contemplated during this period. The section on storage surface material was added to summarize our thoughts on the subject.

Immediate Objectives of the Storage Tube Group

1. Complete demonstration unit for the electrostatic storage tubes.

2. Write reports on electrostatic storage tubes.

3. Until demonstration unit is operating satisfactorily, keep one test set-up in working order so that we can exhibit as a demonstration the storage principle on the most recent storage tube.

4. Storage Tubes Mods 11,14,15,16,17 will be constructed and tested to determine the relative effectiveness of griddle vs flat surfaces and the advantages of using beryllium spots to give better emission and signal stability.

5. Storage tube Mods 7,9,12 and 13 are the first of a series of tubes designed to measure the secondary emission properties of various storage surface materials and then to measure the life of these properties under conditions simulating actual storage tube operation.

6. At the end of the period covered by this memo we expect the tube construction and testing facilities will be far enough along toward

completion so that much of the personnel now working on lab and test bench construction can be released for more direct work on constructing and testing tubes.

Tentative Work Assignments of Individual Members of the Group

1. C.H.R. Campling: Test the 1 to 100 μs pulser. Supervise installation of power for life test facilities and demonstration.

2. F.H. Caswell: Construction work on r-f bomber. Power witing in and to demonstrator. Wiring of power for annealing oven. Construct pulser. Construct tube mount for demonstrator. Help with any tube construction in an emergency.

3. T.F. Clough: Procurement for vacuum tube work. Maintain vacuum tube room and facilities. Tube construction work. Finish construction work in vacuum tube room. Get one vacuum system operating satisfactorily. Set up gas data storage bench.

4. A. Curtiss: Set up two test benches. Construct life test racks.

5. P. Darvirris: Set up two test benches. Construct life test racks.

6. S.H. Dodd will work with W.J. Nolan and H. Heydt to help with testing. Work on reports on storage tubes. Expedite construction of demonstrator and any work except glass work farmed out to outside contractors.

7. M.I. Florencourt: Complete anodizing studies and any anodizing required for tube construction. Assist in the testing of dielectric surfaces. Start searches for new dielectrics.

8. H.L. Heydt will run the tests outlined in objective 5.

9. H.A. Ladd will construct test equipment such as trigger generator and work with F.H. Caswell.

10. R.F. Markel will renew his studies on gas data storage which were stopped last summer.

11. J.H. McCusker will process all vacuum tubes in Bldg. 20. Test our vacuum measuring equipment on R.L.E. facilities.

12. W.J. Nolan will assume responsibility for all testing. He will keep the present test set-up operating as a demonstration unit and use it to test all two-gun storage tubes. Consultation with S.H. Dodd, H.L. Heydt and M.I. Florencout on testing the storage surfaces. Layout and supervise construction of pulser. Put r-f bomber in operation.

13. Joel Simmons will work on demonstrator.

14. F. Youtz: Tube construction and design. Tube processing. Investigation and testing of new techniques for tube construction and processing. Set up a vacuum system and test it. Search for new dielectrics. Give a limited amount of assistance to gas-data-storage program.

Progress Report and Outline of Storage Tube Projects

1. S.T. Mod 11A was constructed same as S.T Mod 10, see M-95, except the screen was moved 15 mils from the griddle surface and second anodes of two guns not interconnected. Tests were made on this tube. These tests indicate the following:

a. Operation of second anodes of the two guns at different potentials is not satisfactory.

b. Operation of tube very sensitive to variations in holding beam velocity and current density.

c. Writing time and resolution about the same as Mod 10. (50 μs, 5 per inch)

2. S.T. Mod 12 was the same S.T. Mod 7, see M-96, with great care to prevent willemite from falling on $Al_2 O_3$ surface. This tube has been constructed.

3. S.T. Mod 13 is similar to Mod 9, see M-96, except with different type of leads to the beryllium surface see drawing SA-39364. This tube has been constructed. There was good continuity between the leads and beryllium.

4. S.T. Mod 14A is similar to S.T. Mod 11A except it has a flat dielectric of $Al_2 O_3$ with willemite instead of a griddle surface. This tube is being processed.

5. S.T. Mod 15 is similar to S.T. Mod 14A except it has a storage surface of a 40 mesh mosaic of beryllium on $Al_2 O_3$ instead of willemite. It has a 100 mesh screen with random alignment. (All components are prepared for this tube).

6. S.T. Mod 16 is similar to S.T. Mod 15 except it has a 100 mesh mosaic of beryllium on $Al_2 O_3$. It has a 100 mesh screen with the holes in the mesh over beryllium spots. One set of components have been prepared for this tube. We might attempt to get a better mosaic.

7. S.T. Mod 17 is similar to S.T. Mod 11A except the griddle surface is not covered with willemite but has beryllium in the bottom of the pockets.

8. S.T. Mod 18 is exactly like S.T. Mod 11A. This is intended as a replacement so that there will always be available a

workable storage tube for the demonstrator. Components are constructed but the tube will not be assembled and processed unless it is necessary.

9. S.T. Mod 19 is exactly like S.T. Mod 12. It is intended as a research tube to be used in the life test rack to check operation of S.T. Mod 12 and simulate operation of the holding gun in a storage tube instead of the writing gun.

10. S.T. Mod 20 is exactly like S.T. Mod 13. This will be operated in life test rack to simulate operation of the holding gun in a storage tube. Note: (It is hoped that the testing program will keep pace with the tube construction program. The data should be analyzed soon enough to forestall construction of any of these Mods, if the testing program should so indicate. However there has been a high mortality among the two neck tubes lately. This has been occasioned by the training of new personnel. Therefore tube construction has always been pushed because several accidents have always befallen each tube, Whenever any significant test results are obtained the rest of the program will be examined in the light of these results.)

11. E.S.T. Demonstrator.

a. Test facilities will be used as a demonstration until demonstrator is completed.

b. All circuit schematics have been completed.

c. Layouts for the control box and the gate-delay units are complete. Others still in process.

d. Control box constructed and gate-delay circuits being constructed.

12. Gas data storage studies will be resumed where they were stopped last summer. The gas-data-storage bench will be set up with a fore pump and the alphatron. This study will require construction of four more tubes.

13. Anodizing of aluminum investigations were completed and written up in a series of reports and memoranda by J.R. Macdonald. M.I. Florencourt has taken over this work. She has anodized sufficiently to check her own procedure and the equipment. Also she is checking four of J.R. Macdonald's tests. No further test work is contemplated until tests on the storage tubes indicate the necessity.

14. Test Program to Study Storage Surfaces.

a. H.L. Heydt with assistance from M.I. Florencourt will study emission from Mods 7 and 9 to acquaint themselves with the pulse techniques and equipment. They can obtain preliminary information on beryllium. W.J. Nolan will supervise this.

b. Provide a temporary test set up for life tests using present power supplies of benches 1 and 6 with extension cables, will require very little new equipment.

c. Mods 12, 13, 19, 20 and other mods may be tested in this equipment.

15. Test Program to study storage operation of the different electrostatic storage tubes. Mod 11A was tested on benches 1 and 2. Mods 14A, 15, 16, 17, will also be tested in this set-up. This can also be used for demonstrations if reasonable notice of visits is given.

The circuits used in this testing are being modified in an attempt to get more reliable operation.

16. Test Equipment.

a. Pulser will be constructed and tested.

b. Two extra gate and delay four-circuit units will be built along with the demonstrator by an outside vendor.

c. When time permits more suitable equipment will be constructed for life tests outlined in 14b.

17. Reports and Memos.

a. Mod 1 report substantially complete. W.J. Nolan is supervising the issuing of drawings.

b. Memo on Mod 5 is approximately one-half completed.

c. Memo on Mods 2,3,4 (one memo on all) not yet started.

d. Mod 6 report will be started during this period.

e. Reports on Mods 10 and 11A cannot be started during this period.

18. RF Bomber.

Construction work has been practically complete for some time. Actual use is dependent upon the arrival of RF Cables and some small parts, and possible operating troubles when first turned on. An estimate of time on this is very difficult.

19. Construction Work in Vacuum Tube Room.

a. Most of the heavy construction work has been completed.

b. Considerable work must be done on the glass lathe before it is useful for glass work.

c. Gas data storage bench must be set up and tested.

d. One vacuum system will be completed the evenings of October 28, 29, 30. This system will be tested as time permits. This system can be used to process tubes by the time the r-f bomber is ready.

e. Plans for an analyzer and an annealing oven are in the hands of H. Tonsing.

20. Storage Surface Material.

The type of electrostatic storage tube now being considered requires for its satisfactory operation a storage surface having the following characteristics:

a. Low first crossover potential 30 to 50 volts desirable.

b. High secondary emission ratio and high second crossover. A secondary emission ratio greater than two up to 3 or 4 KV would be desirable.

c. High insulation resistance to backing or signal plate and between storage elements.

d. Stability and long life under electron bombardment.

e. Capacity to signal plate of about 75 μμf per sq. cm.

f. Possibility of being formed into a griddle surface, if a griddle surface should be required.

All tests and studies in the literature indicate Al_2O_3 will not fulfill these requirements. The first crossover is high and maximum secondary emission ratio is low.

In the present series of tubes we will study a beryllium oxide mosaic on Al_2O_3. Mutter and Breckenridge have made studies of beryllium oxide which indicate it has many of the desirable properties that Al_2O_3 lacks. Under investigation are methods of preparing good beryllium oxide surfaces. There are two methods contemplated at present. One is to evaporate a film of the metal over a dielectric and oxidize it in the presence of a stream of oxygen. (There is some question how thick a layer of oxide can be obtained in this manner). The second method is to anodize beryllium. These studies might indicate the advisibility of a series of tubes using beryllium oxide as the dielectric as well as the emitter.

If a phosphor can be found having the desirable characteristics it would have the advantage of a visual indication of storage. Good light output efficiency may be necessary because of the low energy of the holding beam. We have started a search in this direction.

Studies and searches on materials other than phosphors and beryllium oxide cannot be started at this time.

21. Electron Gun.

The group realizes that design of a gun to meet the needs of our particular type of operation would be desirable, but we are unable to consider that problem at the present moment.

S. H. Dodd
S. H. Dodd

W. J. Nolan Jr.
W. J. Nolan, Jr.

P. Youtz
P. Youtz

SHD/WJN/PY/rp

cc: H. R. Boyd
F. H. Caswell
C. H. Campling
T. F. Clough
A. R. Curtiss
P. Darvirris
J. O. Ely
R. R. Everett
H. Fahnestock
M. I. Florencourt
H. Heydt
H. A. Ladd
R. F. Markel
J. H. McCusker
J. Simmons

Project Whirlwind
Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

SUBJECT: AQUADAG

To: P. Youtz, S. Dodd, F. Caswell

From: T. F. Clough

Date: October 7, 1947

Discussion of Aquadag Problems with Mr. Sentner of Acheson Colloids Corp.

Object of discussion was to obtain information as to the proper use and storage of Aquadag. Through the services of Mr. Morley's office the Atcheson Colloids service representatives called at our laboratories on September 30, 1947. We obtained much useful information as to the result of his visit.

Results of Discussion

1. Life of the Solution:

The maximum life of unopened jars of aquadag is one (1) year. The life of opened jars of aquadag is questionable. The suggested maximum length of time which a sodium silicate aquadag solution should be held, after mixture, is two (2) weeks. During this time the silicate tends to harden, the mixture flakes off the sides of the container and the carbon particles tend to agglomerate. If a skin forms on top of the solution it is an indication that the solution has progressed far beyond the useable stage.

2. Application

Surfaces must be very clean in order to insure good adhesion.

3. Thickness of Coating

In most cases where a thick coating is necessary it is desirable to apply several thin coats rather then one thick one. These thin coats should be air dried between applications, although baking is probably not necessary between coats. The resistance of one (1) thick coat is not appreciably different from that of several thin coats and the adhesion of the thin coats is better.

4. Mixtures

DuMont is experimenting using an EC-156 solution which is 15% solids in a 1-1 solution. This compares to a solids content in aquadag of 20%. The DuMont formula is 100 grams of EC-156 solution or aquadag, 20 cc of water, 30 grams of 30% silicate. This may be either sodium or potassium. The dilution of this formula should not be over 1-2. After the parts are coated they are air dried, and then baked ½ hour at 350°C. DuMont is seeking to prevent lifting of the coating adjacent to a third anode type of glass to metal seal.

Lifting is being caused in television tubes by high current density or high voltage gradient.

We have been given a sample of 154 dag which is graphite in alcohol. This must be diluted with alcohol, acetone, carbon tetrachloride etc. Do not use petroleum solvents or water. We have a sample of this dag which is advantageous for faster drying time and is used especially in machine assembly. This was brought by Mr. Sentner as he was not sure whether our problem involved machines or not.

5. Recommendations

Aquadag should be odered in cartons of 12, two oz. jars. First, because the small jars will prevent excessive deterioration which would come with the numerous openings of a larger supply. Secondly, because the price is reduced by 50% when ordering by the carton. Orders should be limited to a maximum of one years supply, much less if possible.

Dilution

Aquadag for brushing should be diluted 2 or 3 to 1 with distilled water depending on the desired consistency. Only a very small amount of Sodium Silicate should be added for good adhesion, say from ½ to 2%. Sodium Silicate tends to increase the resistance of the coating.

Surface Preparation

The surfaces to which aquadag is to be applied should be very clean. Glass should be chromic acid cleaned if necessary.

Drying

Before baking, the coating should be well air dried. After this drying, bake at 400-500°C for 3 - 4 hrs. with air circulating as at present. This baking and air circulation removes the vapors present during the breakdown of the organic aquadag binder.

Application

Avoid thick coats. Apply with a soft brush.

Signed T. F. Clough
T. F. Clough

TFC/sp

TO: J. W. Forrester, H. R. Boyd, R. L. Brown, F. H. Caswell, A. R. Curtiss, S. H. Dodd, P. Youtz, J. O. Ely, R. R. Everett, H. Fahnestock, W. J. Nolan, A. J. Taylor

FROM: J. R. Macdonald

SUBJECT: Preparation of Metallic Coatings for Grid Structures

DATE: December 18, 1946

A. Platinum Coating of Mica

Several mica plates were partially coated with platinum paint to serve as signal plates in the grid structures of storage tubes under construction. The paint used was Liquid Bright Platinum(colloidal) No. 05, manufactured by the Hanovia Chemical and Manufacturing Company, Newark, New Jersey. The procedure in applying and baking the coating was as follows:

1) Apply light coat on desired area with a small camel's hair brush. Bake for thirty minutes under the infra red lamp.

2) Place sample in electric furnace at 400° f. Leave door of furnace slightly open for ten minutes to allow fumes to escape.

3) Close door and adjust temperature for 600° f.

4) After ten minutes increase temperature to 800-850 degrees. Allow sample to remain at this temperature for 30 minutes to an hour to drive out all residual moisture.

5) Apply another coat of paint and repeat above procedure. If it is desired to have a heavy layer of platinum, two coats may be applied with only drying under the heat lamp between applications. This saves baking time. The two coats are then baked as above.

6) The nickel contact lugs are bent into position on the sample after the second or third coat has been baked. Then, the lugs are painted over with platinum paint to insure good contact, and the sample is heated and baked once again as above.

B. Silver Coating of Mica

The silver paint used was Liquid Silver, No. 122-A, manufactured by the Hanovia Chemical and Manufacturing Company. The application and heat treatment of the silver paint is the same as that above for the platinum, with the following exceptions:

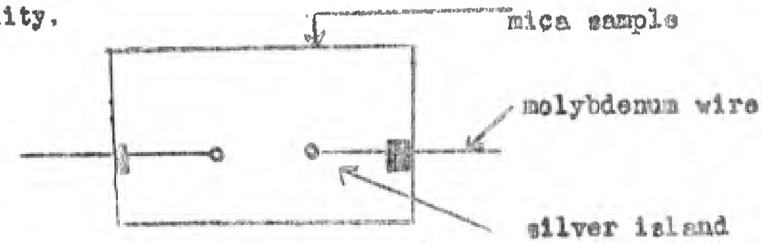
1) The silver paint is more viscous and is easier to apply.

2) The coating is thicker, so that two, rather than three coats give a thick enough layer.

3) The final phase of the baking can be carried out at 900-1000° f. Unlike the platinum the silver is porous enough to allow any water of hydration from the mica to pass thru it without bulging and bubbling. Temperatures greater than 1000° f should not be applied to the mica for any period of time exceeding five minutes or the mica permanently deteriorates.

In addition to the silver coating applied over a large part of the surface of several of the mica samples, silver was also applied in small spots or "islands". These were positioned to fall directly beneath the holes in the nickel grid structure. After two coats were applied to each spot and the baking carried out, fine molybdenum wires were securely attached at each edge of the sample with small nickel lugs, and one end of each wire painted down to a silver island.

After baking, these connections were found to have considerable mechanical rigidity.



It was found that connections to the silver could be made which had considerably less resistance than any possible with the platinum. This is due principally to the thinness of the platinum coating. Minimum resistance between terminals obtainable with the platinum coating was 3 ohms, with the average after three coats being about 6 ohms; whereas, that obtained with the silver paint was usually less than .1 ohm.

Due to the ease with which the silver can be applied, the superior continuity and conductivity of a silver surface, and the higher temperature at which it can be baked, it is recommended that future signal plates be coated with silver rather than with platinum.

It is further recommended that tests in vacuum be carried out to determine the relative behavior of silver and platinum coatings in vacuum as regards occluded gases, evaporation, and permanence.

J. Ross Macdonald
J. Ross Macdonald

JRM:has

c.c. Dr. Brown

MEMORANDUM NO. M-56

TO: J.W.Forrester, S.H.Dodd, R.R.Everett, J.O.Ely, H. Fahnestock, W.J.Nolan, H.R.Boyd, F.H.Caswell, A.R.Curtiss, A.J.Taylor, P. Youtz

6345

FROM: J. Ross Macdonald

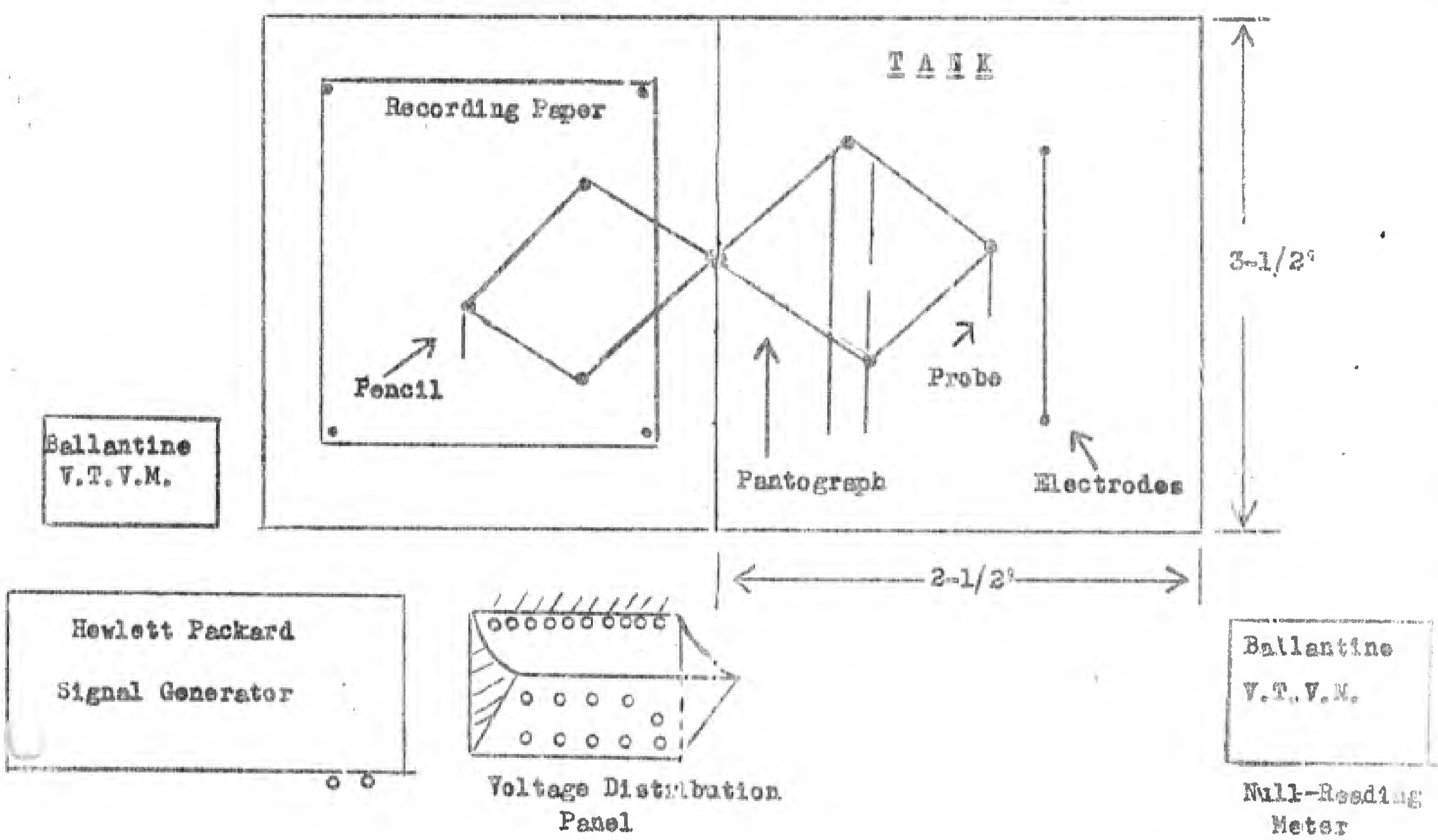
SUBJECT: Construction and Operation of an Electrolytic Plotting Tank

DATE: January 17, 1947

An electrolytic plotting tank has been constructed for the purpose of plotting equipotential lines. It has recently been applied to give information concerning relative field strengths and electron paths between electrodes in the experimental storage tubes.

The complete installation uses several pieces of equipment and test instruments in addition to the metal tank itself. A plan diagram is as follows:

ELECTROLYTIC PLOTTING TANK ASSEMBLY



The tank itself was constructed of 14-gauge sheet aluminum. The corners of the tank after forming were aluminum soldered, and the inside at the corners coated with plicene to insure water-tightness. Finally, four coats of plexiblack tar paint were applied to the inside of the tank. This paint never gets completely hard, so a thin sheet of rubber was placed over most of the inside bottom surface to keep objects placed in the tank from sticking to the bottom. The tank does not leak, and the resistance between the electrolyte and the outside of the tank is of the order of one megohm.

A wooden arm pantograph is employed in conjunction with the tank for use in moving the probe to determine points on an equipotential line, and to record the position of the points accurately.

Associated equipment consists of a Hewlett-Packard signal generator model 205AG, two Ballentine model 300 AC voltmeters, and a voltage distribution control panel.

The electrolytic tank is, in effect, an analogy type computing machine. Scaled electrodes representing the electrodes of the actual tube structure are placed in the tank in correct relative positions and are maintained at certain specific potentials by connection to the voltage distribution circuit. Static fields are set up by these potentials in the electrolyte which fills the tank, and the value of the potential at any position between the electrodes is directly proportional to the potential which would be caused by the same relative potentials on the electrodes in the storage tube.

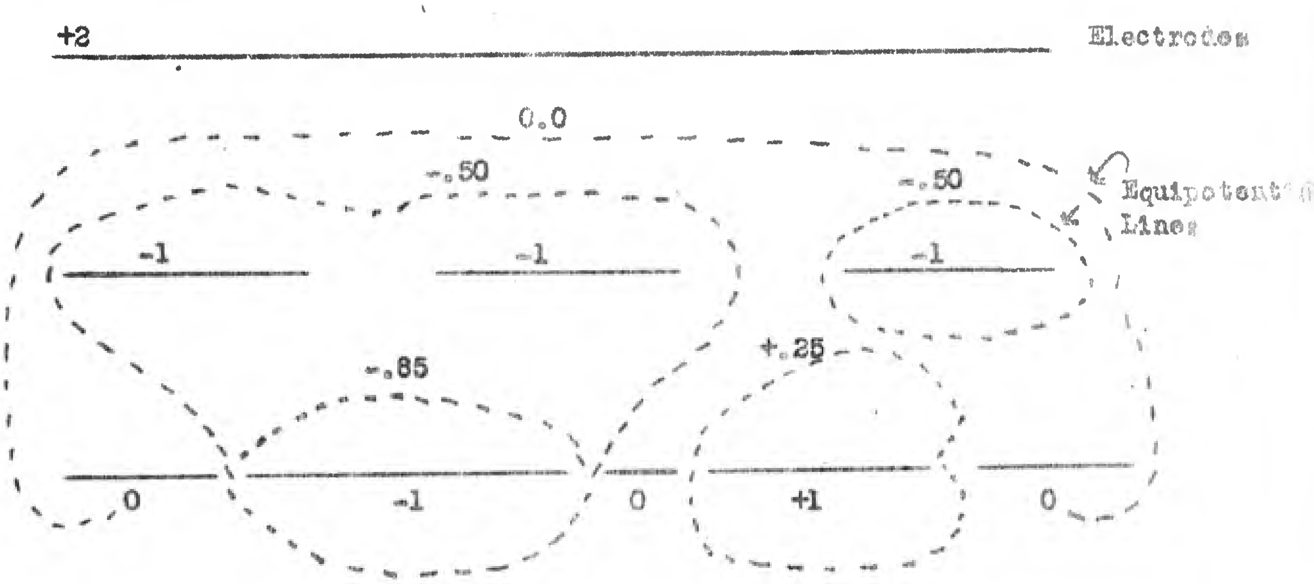
The electrolyte used is tap water with a very small amount of salt added. Its resistance as measured between small immersed wires is of the order of 500-2000 ohms.

In practice the plotting of equipotential lines is carried out as follows: A certain equipotential line is determined upon and the probe voltage set to the value of its potential. It can be seen that when the probe is at a position in the tank which also has this potential there will be no current flow between tank and probe. This condition is achieved by measuring the current, or actually a voltage proportional to it, on a Ballantine voltmeter and moving the probe in the tank until a minimum reading is obtained on the voltmeter. After a point has been so obtained and recorded on the adjoining paper, the probe is moved a bit in the expected direction of the equipotential line and another point determined by moving the probe at right angles to the equipotential line, around this adjoining point until another minimum position is determined. Thus the final equipotential line consists of a number of closely spaced experimentally determined points.

Alternating current is used with the tank to minimize electrolysis effects which would cause the principal voltage drop to occur very close to the surface of the electrodes, and would hence distort the field. A frequency of about 250 c.p.s. was selected to minimize phase shifts and pickup. Maximum voltage available across electrodes is four volts. The system is grounded and all wires shielded, but initially considerable trouble was caused by 60 cycle pickup which materially reduced the sensitivity of the device. The effect of this condition was practically eliminated by putting a high pass filter in the circuit between the probe and the null-reading voltmeter. This filter was designed to have an infinite rejection characteristic at 60 c.p.s. and was accurately tuned to this frequency. Its nominal cut off is 100 c.p.s. Through its use sensitivities of the order of a ratio of 1 to a 1000 between minimum and maximum readings have been easily attained.

The voltage distribution circuit consists of a number of 50 -ohm wire-wound potentiometers so connected that as many as five instantaneously positive separate voltages and five instantaneously negative voltages can be obtained as outputs for use in adjusting electrode potentials. The probe is connected so that it can easily be adjusted to either a positive or negative voltage with respect to the arbitrarily designated positive side of the two phase line. The probe itself consists of a short piece of 24-gauge stainless steel wire and is adjusted in length so that from a 1/8 to a 1/4 of an inch of it is immersed in the electrolyte during plotting. Further details of the circuits of the voltage distributer and filter can be found in 1FHC89-90.

This tank has thus far been used with several different electrode configurations, and the equipotential lines plotted for each for several different values of electrode potentials. Results of considerable interest have been obtained and the tank promises to afford much information concerning electron behavior in the storage tube. A simple configuration of electrodes and equipotential lines is given below.



J. Ross Macdonald
J. Ross Macdonald

JRM:has
c.c. Dr. Brown

Project Whirlwind
Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge. Massachusetts.

SUBJECT: POTENTIAL PLOTTING WITH AN ELECTROLYTIC TANK

Written by: J. Ross Macdonald

Date: September 22nd, 1947

Purpose of Potential Plotting

An electrolytic tank was constructed to allow the following experimental investigations to be carried out:

a) A determination of the equipotential lines between a simulated storage-tube grid structure and charged spots on a dielectric surface

b) A determination of the penetration of electric fields into pockets and the effect of differences in potential between pocket walls and bottoms.

Introduction

The electrolytic tank is, in effect, an analogy-type computing machine. Scaled electrodes representing the electrodes of an actual electron tube are placed in the tank in correct relative positions and are maintained at specific potentials by connection to a voltage distribution circuit. A static two-dimensional field is set up in the electrolyte by the potentials of the electrodes, and the value of the potential at any position between the electrodes is directly proportional to the potential which would be caused by the same relative potentials on the electrodes of the electron tube. By means of a movable probe attached to a pantograph the equipotential lines may be plotted and so the character of the field determined.

Description of Apparatus

The layout of the complete apparatus used to plot equipotential lines is shown in Drawing A-30911. The source of voltage is a Hewley-Packard Signal Generator, Model 205-AG. The voltage distribution panel shown in Drawing A-30911 is used to adjust the voltages of as many as ten different electrodes in the tank. The circuit of this panel is shown in Drawing A-30912. One Ballantine Model 300 a-c voltmeter (V_1) is used to adjust electrode voltages while the other (V_2) is employed as a null-reading meter to position the probe accurately.

The tank used was made of 14-gauge sheet aluminum. After forming, the corners of the tank were aluminum soldered and the inside of the corners coated with plicene to ensure water-tightness. Finally, four coats of plexiblack tar paint were applied to the inside of the tank. Since this paint never becomes completely hard, a thin sheet of rubber was placed over most of the inside bottom surface to keep objects placed in the tank from sticking to the bottom. It was found that the tank did not leak, and the resistance between the electrolyte and the metal of the tank was of the order of one megohm. The electrolyte used was plain tap-water with a very small amount of salt added. Its resistance measured between small immersed wires was of the order of 500 to 2000 ohms.

The pantograph shown on Drawing A-30911 was constructed with wooden arms. A pencil is placed at one end, while the metal probe, which dips about one-quarter of an inch into the electrolyte, is at the other end. Thus, motions of the probe are duplicated at and recorded by the pencil on the recording paper. Alternating current is used with the tank to minimize the electrolysis effects of direct current, which would cause the principal voltage drop to occur close to the electrodes and would hence distort the field pattern. A frequency of 250 cycles was selected to minimize phase shifts and yet be high enough above line frequency so that signal voltage could be effectively separated from line pick-up voltage. The maximum voltage available between electrodes was four volts. Although all connecting wires were shielded, considerable 60-cycle pick-up was initially encountered. Through the addition of the filter shown in Drawing A-30912, the effect of pick-up was practically eliminated, however, and a sensitivity of 1000 to 1 between maximum and minimum readings of the null-reading meter was attained.

Operation of the Tank

In practice, the plotting of equipotential lines is carried out as follows: a certain equipotential line is selected for plotting and the probe voltage set to its potential. When the probe is placed in a position in the tank which is also of this potential, there will be no current flow between tank and probe and the null-reading meter will read zero (neglecting noise and pick-up voltages). However, for any position of the probe in the tank which is not at probe potential, a current will flow, causing the null-reading meter to read different from zero. After a point in the electrolyte has been found which is at probe potential, the probe is moved slightly in the expected direction of the equipotential line and a minimum (or zero) reading obtained by moving the probe back and forth at right angles to the equipotential line. This process is repeated until the complete equipotential line has been plotted. Then, the probe voltage is changed and other equipotential lines determined in like manner. The final equipotential lines so found consist of a large number of closely spaced points which can easily be joined by smooth curves.

Simulated Storage-Tube Grid Structures

In accordance with the first objective on page 1, the tank was first employed to plot equipotential lines for simulated grid structures. Some of the results of this investigation are given in Drawings B-30939 and B-30938.

Both electrodes and equipotential lines are marked with their respective potentials. However, the potentials shown in these drawings are 100 times greater than those actually used in the electrolytic tank. The drawings themselves are reduced by a factor of two from the original size of the plots on the recording paper.

Both Drawing B-30939 and B-30938 represent the case in which two neighboring spots on the dielectric are charged negatively and positively respectively. The spots are separated on either side by uncharged (zero potential) regions. The signal grid is negative since this is the condition when most secondary electron redistribution takes place. In Drawing B-30939 the electrodes are effectively one-dimensional, whereas in Drawing B-30938 some account is taken of the finite thickness of the signal grid on an electron size scale.

The lines of electric flux can be derived from the equipotential lines by drawing in a network of lines everywhere orthogonal to the equipotential lines. Finally, electron trajectories can be determined by any of several successive approximation methods described on pages 78 to 83 of Reference 1. The determination of neither flux lines nor trajectories has been carried out, however, because of the only approximate correspondence between the potential lines shown here and the actual equipotentials in a storage tube. There are two main causes of this lack of complete correspondence: first, the scaling down of the electrode configuration is only approximate, and second, the use of equipotential charged regions on the "dielectric" surface is only a rough approximation of the actual space distribution of potential of a charged spot on a dielectric having small but finite conductivity.

Since an electron's path will roughly follow electric flux lines in the direction of increasing potential, the approximate path of an electron can easily be seen on Drawings B-30939 and B-30938. Secondary electron redistribution mainly occurs during charging of a spot negatively. Therefore, it can be seen that redistribution electrons will leave the spot being charged as it becomes more and more negative, will travel approximately perpendicular to the equipotential lines, and will either reach the uncharged region between spots or finally reach the adjoining positive spot and gradually discharge it. Thus, these two drawings graphically illustrate the redistribution phenomena and show its deleterious effects.

The Penetration of Fields into Pockets

The penetration of electric fields into pockets is illustrated in Drawings A-30914 through A-30920. The electrode configuration employed is illustrated on each of these graphs. It consists basically of a pocket made up of five metal plates which can be moved relative to each other so that the depth of the pocket and the overhang or closure of the plates at the top of the pocket can be varied independently. For each of these curves, the potential was measured along the center line, x, from the back plate out to the outside of the pocket. Curves are given for different values of the ratio d/w, different top closures, and different plate potentials.

The actual field at any point on the center line, x, may be derived from these curves by taking the negative of the slope of a curve at the desired point, $-\frac{\Delta V_x}{(\Delta x/d)d}$, where the factor d must be introduced because of the normalization of the abscissae of the curves. For example, using a value of 0.04 centimeters for d, the field at $x/d = 0$ for curve B of Drawing A-30914 is:

$$E_x = \frac{-[(-60) - (-50)]}{[.25 - 0] \times .04} = \frac{-10}{10^{-2}} = 10^3 \text{ volts/cm}$$

However, the absolute value of the field is not of most interest, since it depends upon the potentials used on the metal plates of the pocket of the model. It is the change in the field with different pocket configurations and different plate potentials that is most important. The three small inset curves on Drawings A-30914, A-30915, and A-30916 give the slope of the curves A, B, C, D at $x/d \cong 0$ as a function of the difference in potential between the bottom and side plates of the pockets for three different pocket configurations. The slopes plotted are the tangents of the actual angles on the graphs obtained by direct measurement for the different curves at $x/d = 0$ and are hence proportional to the negative of the electric field (i.e., the force on an electron) at this point. These three curves show the effect of static charges on the sides of the pockets upon the field at the bottom. As might be expected, the potential of the sides, and not the potential at the top of the pockets, is the determining factor, although the degree of plate closure at the top and the ratio d/W may also have an appreciable effect on the field. Although the use of metal plates, rather than a charged dielectric surface as in an actual pocket, causes the different parts of the pockets to be equipotentials, the degree of approximation is still adequate for general conclusions to be drawn from the graphs.

Drawing A-30917 shows the effect of increasing the closure upon the potential distribution along the center line of the pocket. The potential of the sides and bottom are the same, since this is the condition which would obtain when a pocket was first being charged up. In the region of interest within the pocket, $0 \leq x/d \leq 1$, there is surprisingly little difference between the three curves, and the difference between half and complete closure is negligible in this region. The degree of closure is thus not a very important parameter when $d/W \cong 1$

In Drawing A-30918, the effects of varying both d/W and the closure are compared for the same plate potential conditions as in Drawing A-30917. The inset curves give the initial slope obtained for these different conditions as a function of d/W and of closure. These few points can indicate only a trend; however, it can be seen from the spacing of the two pairs of straight lines that decreasing d/W increases the initial field much more than does increasing the closure. Nevertheless, the effect of increasing closure increases as d/W is decreased. Finally, Drawings A-30919 and A-30920 indicate the effect of a positive external plate, or anode, in front of the pocket upon the center-line potential distribution. Inside the pocket, the effect is practically negligible for the relative potentials considered.

The principal conclusions to be drawn from these graphs are: first, that adequate penetration of an electric field into a pocket when walls and bottom are at the same potential can be achieved by designing the pockets so that $d/W < 1$ and so that there is some top closure, and second, that the above design materially decreases the shielding effect of static charges on the walls of the pocket. In an actual application, the effect of almost complete closure would be obtained because the wires of the signal grid would pass over the top of each pocket as well as make electric contact with the tops of the walls of the pocket. However, these electrolytic tank studies show that the shielding effect produced by having the walls of a pocket at a different potential from the bottom may inhibit fields external to the pocket from penetrating to the bottom. In practice, however, the potentials of walls and bottom will usually not differ greatly because both primary and secondary electrons will strike the walls and will therefore charge them up at a rate only slightly different from that of the bottom, provided walls and bottom are of the same material. Therefore, as long as the relation $d/W < 1$ is maintained, the actual configuration of the pocket can be determined from other considerations than the limitations imposed by inadequate field penetration (within wide limits).

References:

1. Zworykin, V.K. and Morton, G.A., Television (New York: John Wiley and Sons, Inc., 1940)

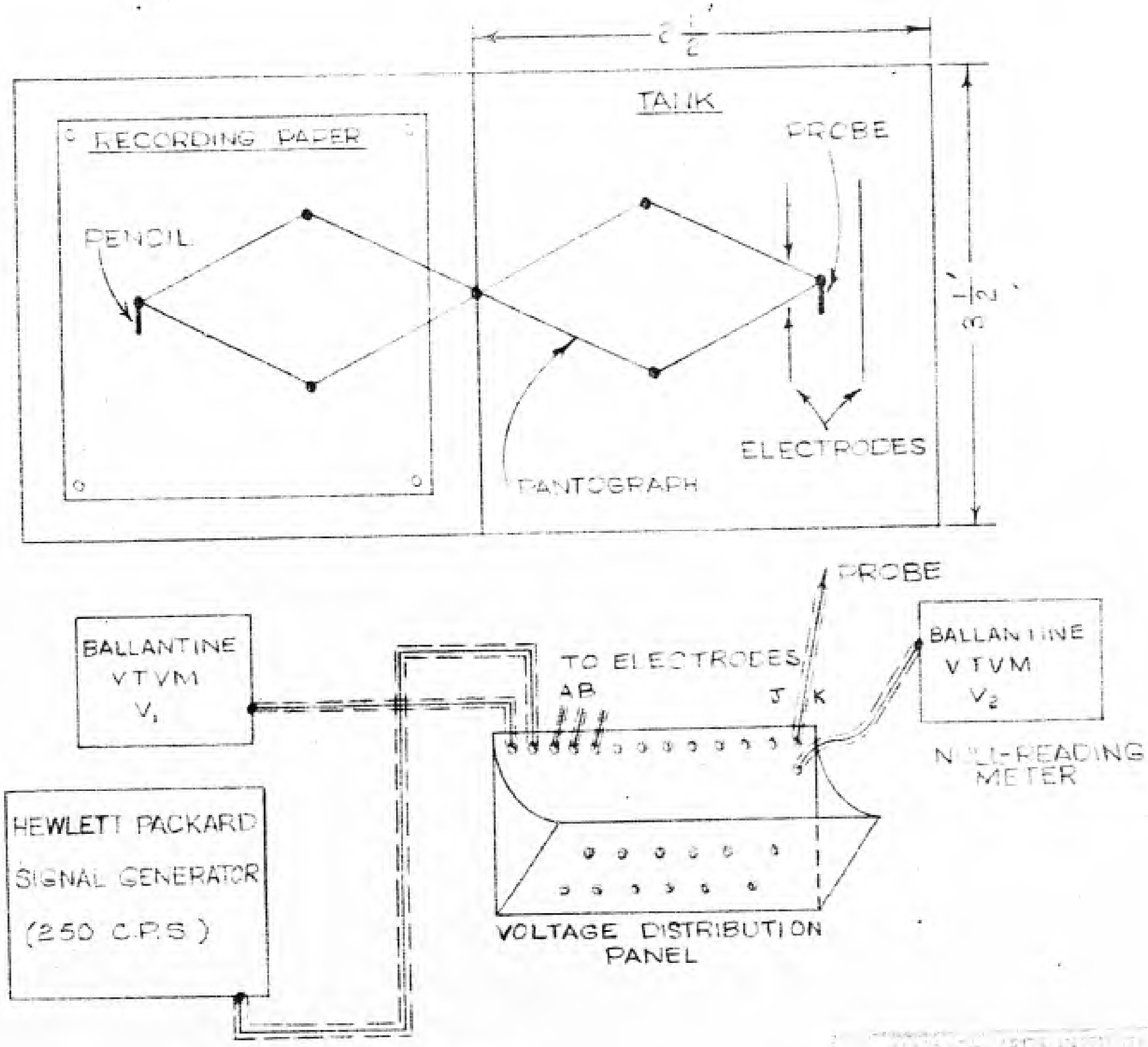
2. Macdonald, J. R., "Construction and operation of an Electrolytic Plotting Tank", Servomechanisms Laboratory Memorandum M-56, (January 17, 1947).

List of Drawings

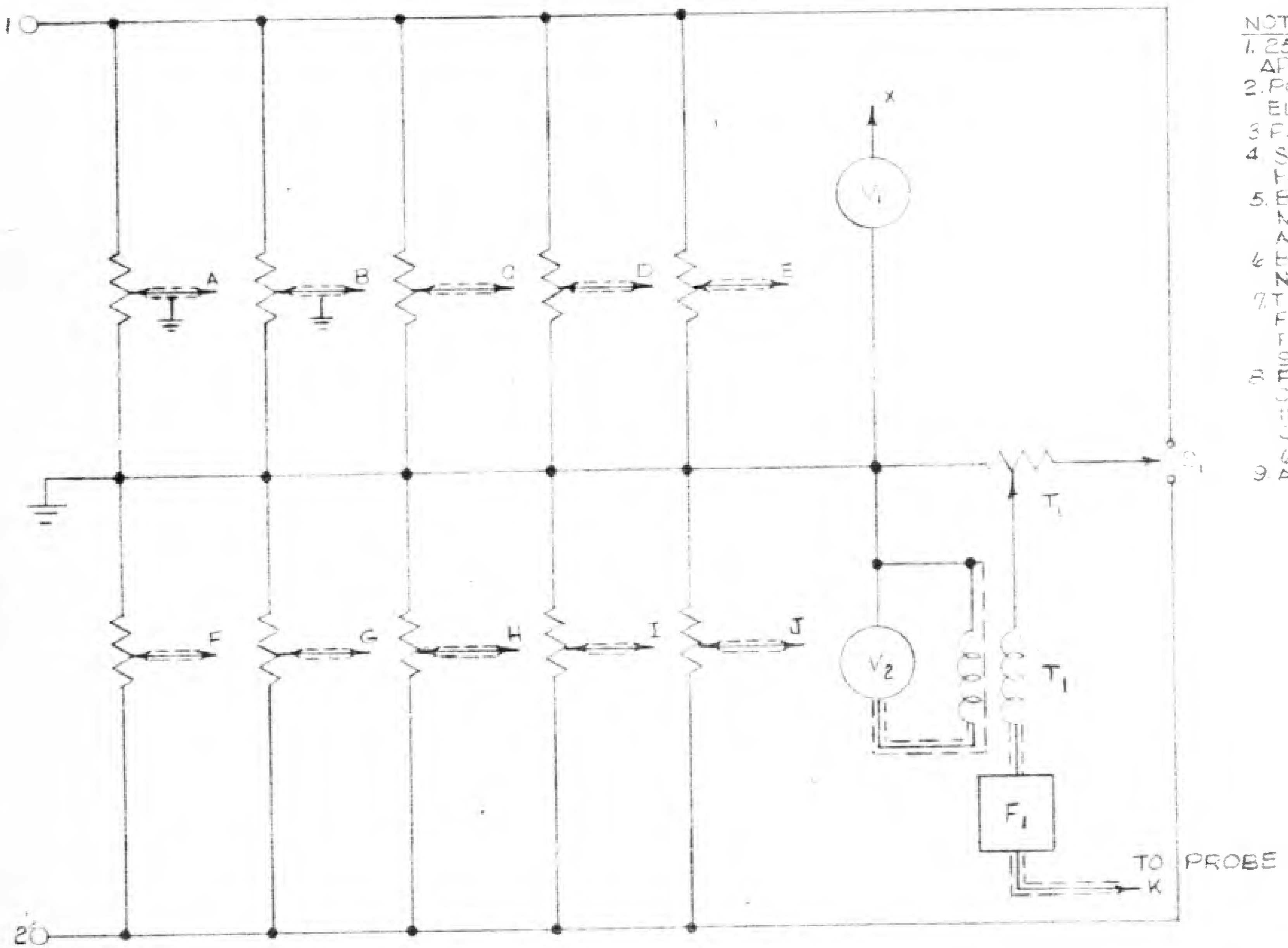
A-30911
A-30912
A-30914
A-30915
A-30916
A-30917
A-30918
A-30919
A-30920
A-30938
A-30939

Written by J. Ross Macdonald

Approved Jay W. Forrester



POTENTIAL PLOTTING APPARATUS



NOTES
1. 250-CYCLE INPUT VOLTAGE APPLIED AT POINTS 1-2
2. POINTS "A" TO "J" GO TO ELECTRODES IN BATH
3. POINT "K" GOES TO PROBE
4. SWITCH S_1 USED TO CHANGE POLARITY OF PROBE
5. BALLANTINE V.T.V.M. V_1 MAY BE SWITCHED TO ANY OF POINTS A TO K
6. BALLANTINE V.T.V.M. V_2 IS NULL-READING METER
7. TRANSFORMER T_1: FERRANTI [illegible] #431, PRIMARY [illegible] SECONDARY [illegible]
8. FILTER F_1: HIGH PASS; CUT-OFF [illegible]; INFINITE REJECTION CHARACTERISTIC AT 60 CYCLES
9. ALL POTENTIOMETERS 50 [illegible]

CIRCUIT OF THE VOLTAGE DISTRIBUTION PANEL

MASSACHUSETTS [illegible] OF TECHNOLOGY [illegible] 6345 | JRM A-30912

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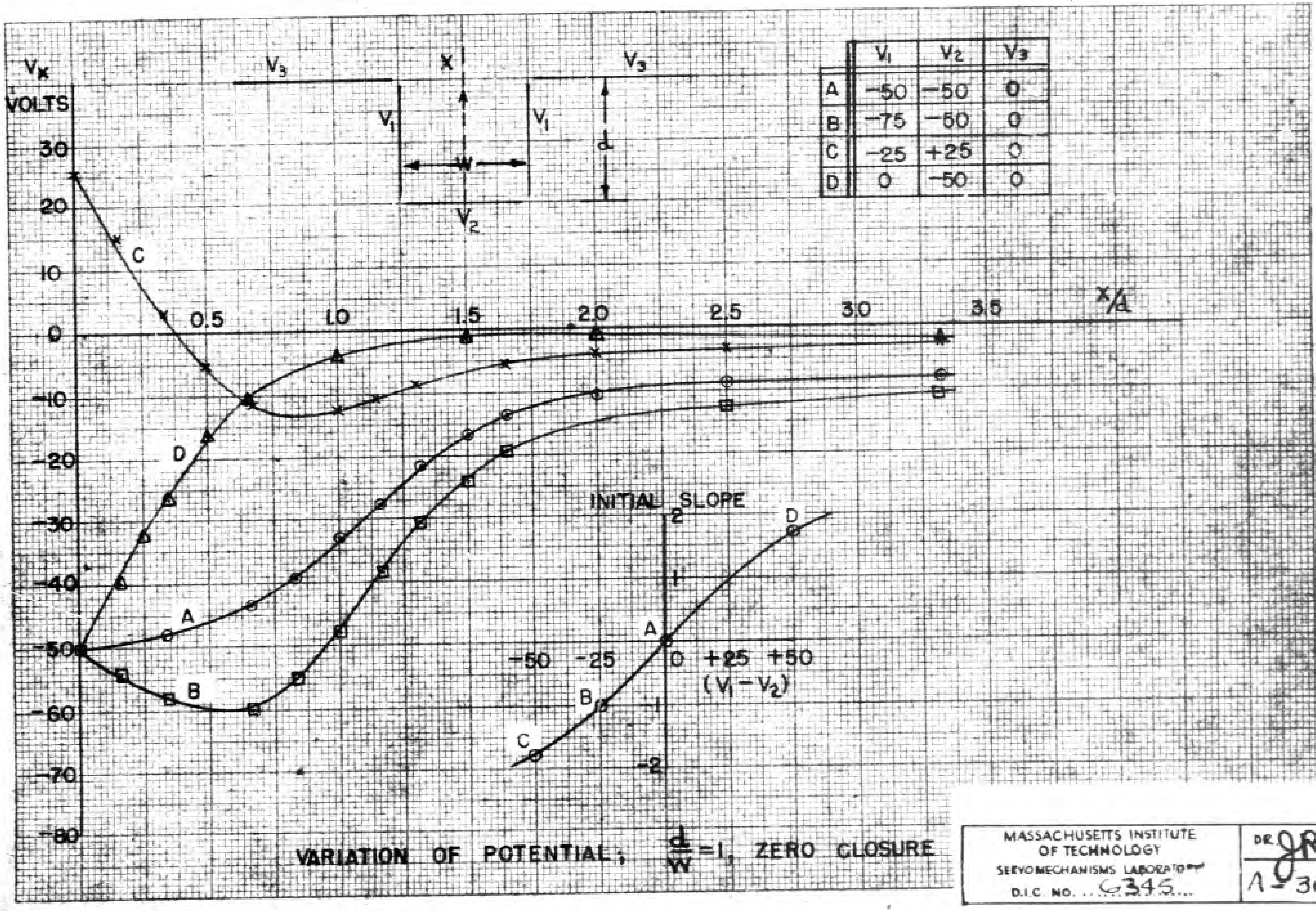

	V_1	V_2	V_3
A	-50	-50	0
B	-75	-50	0
C	-25	+25	0
D	0	-50	0

VARIATION OF POTENTIAL; $\frac{d}{W}=1$, ZERO CLOSURE

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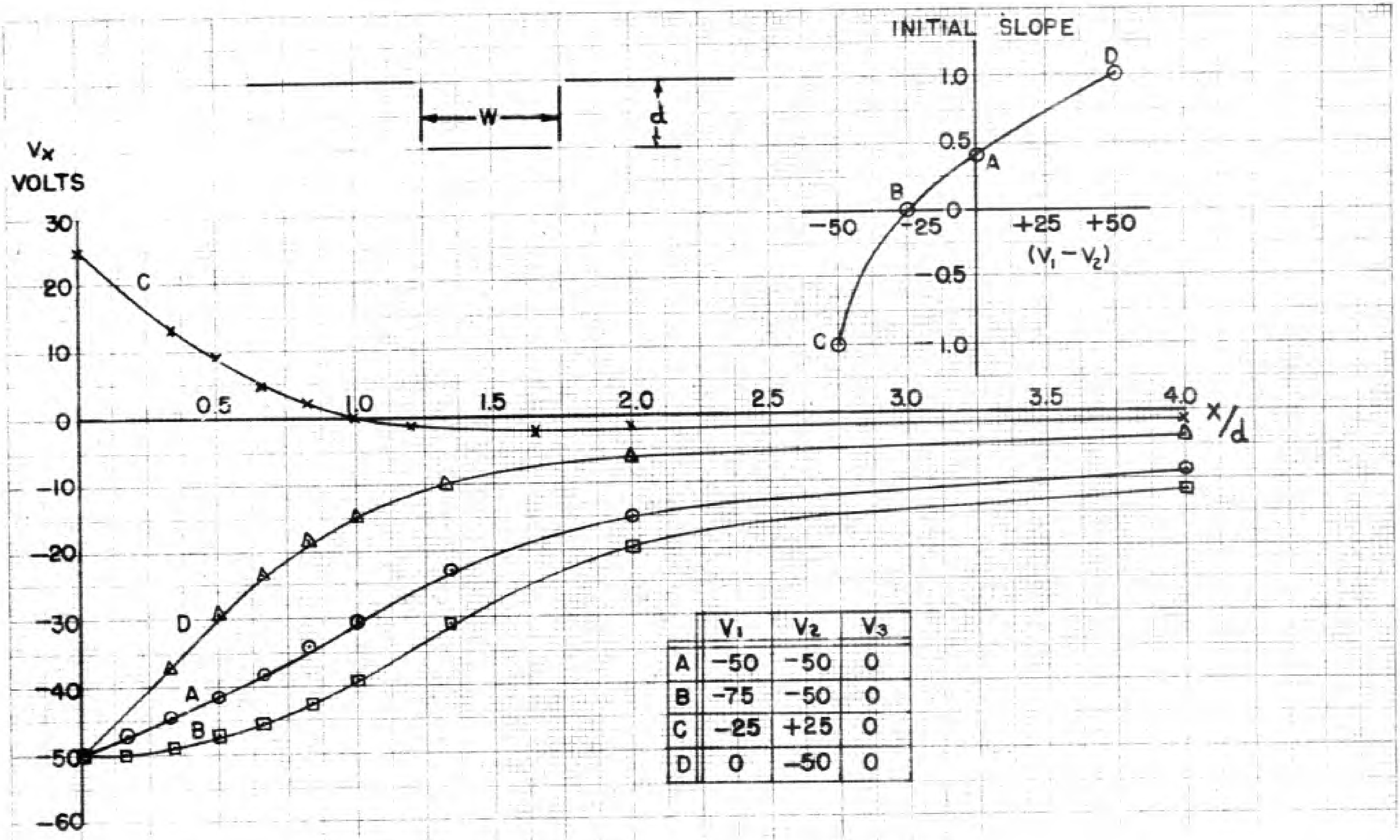

	V_1	V_2	V_3
A	-50	-50	0
B	-75	-50	0
C	-25	+25	0
D	0	-50	0

VARIATION OF POTENTIAL; $\frac{d}{W} = \frac{1}{2}$, ZERO CLOSURE.

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A-30916 USED IN 6345 REPORT NO. R-130 9.

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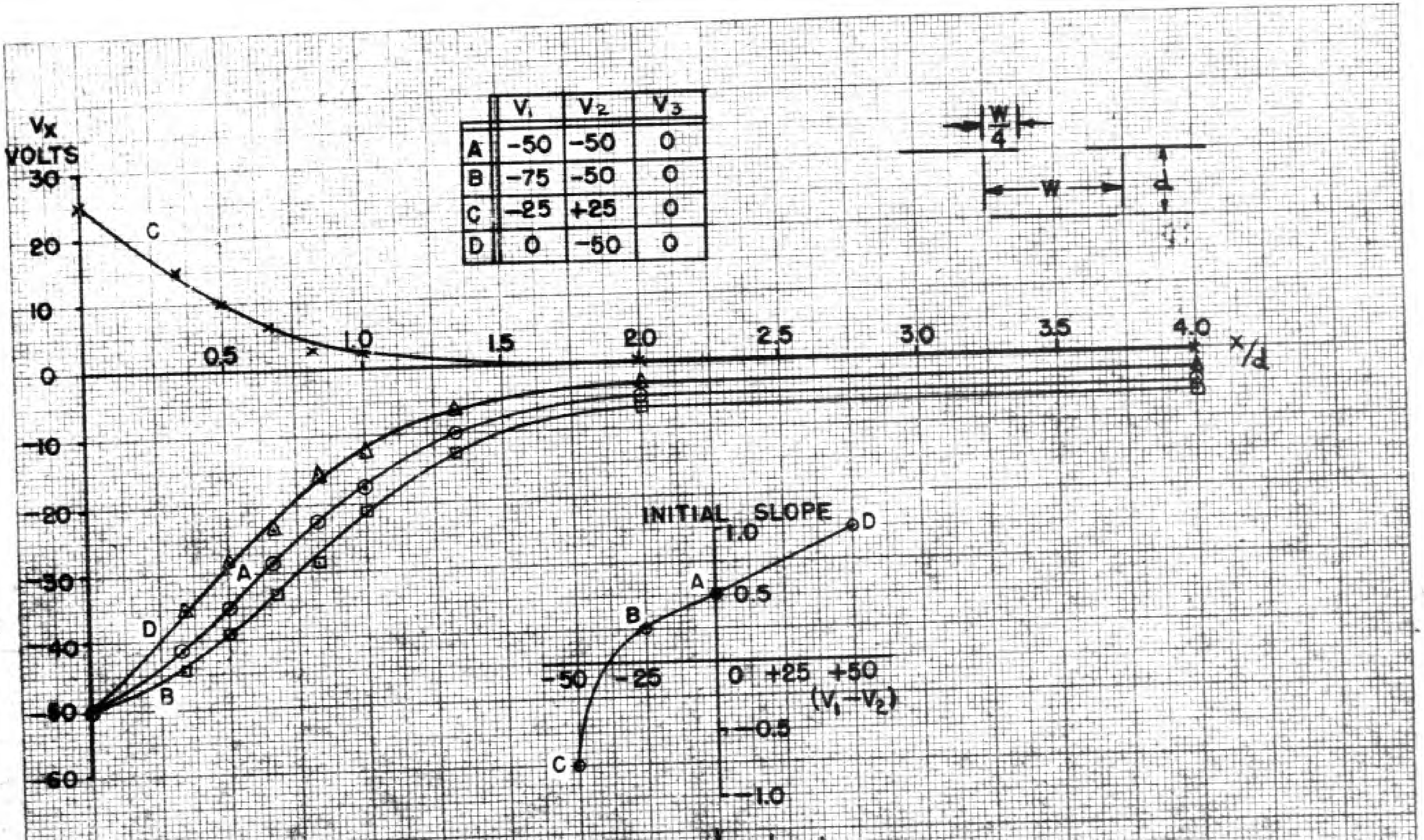

	V_1	V_2	V_3
A	-50	-50	0
B	-75	-50	0
C	-25	+25	0
D	0	-50	0

VARIATION OF POTENTIAL; $\frac{d}{W} = \frac{1}{2}$, $\frac{1}{2}$ CLOSURE.

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A - 30916

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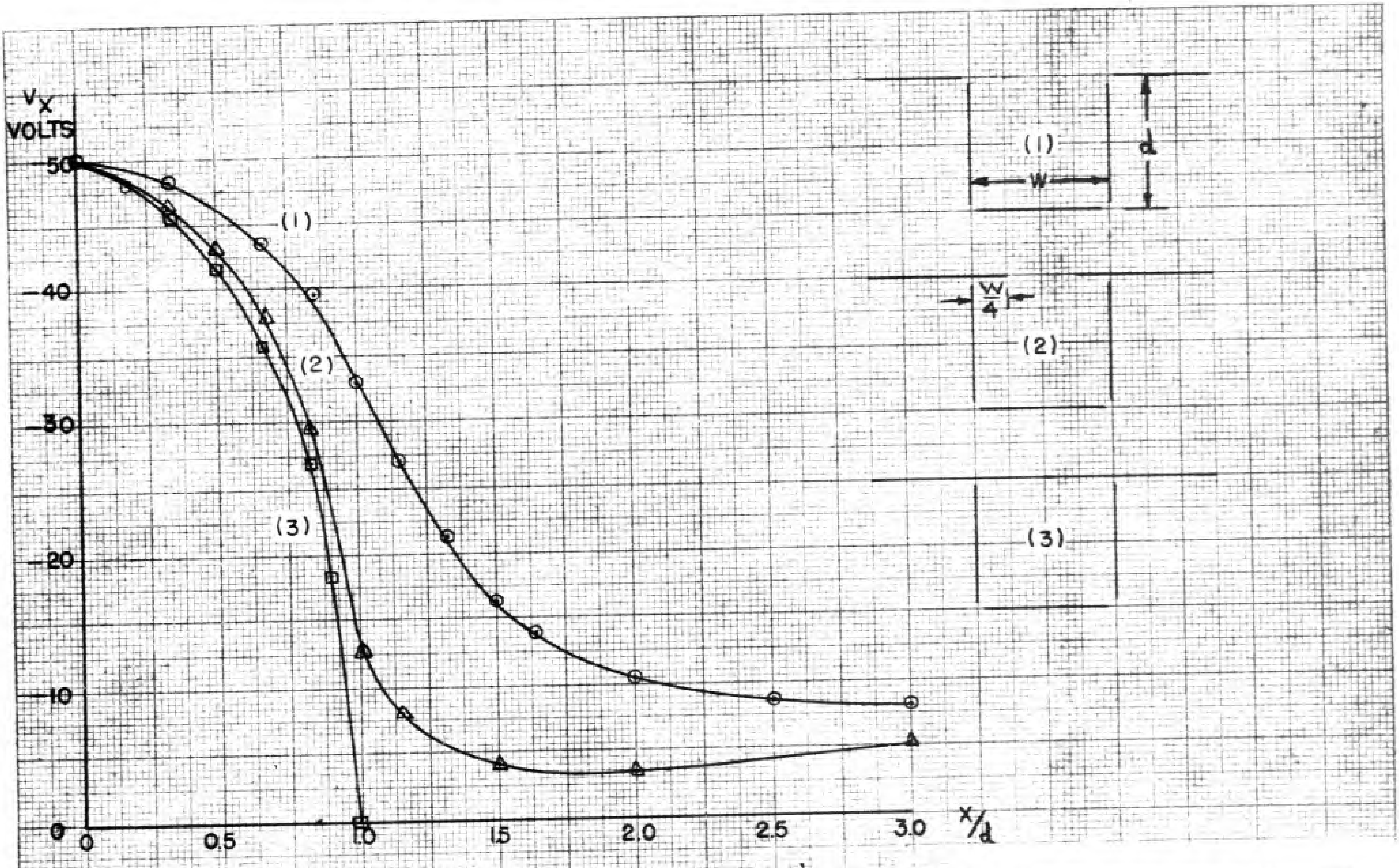

VARIATION OF CLOSURE; VOLTAGES: A, $\frac{d}{W} = 1$

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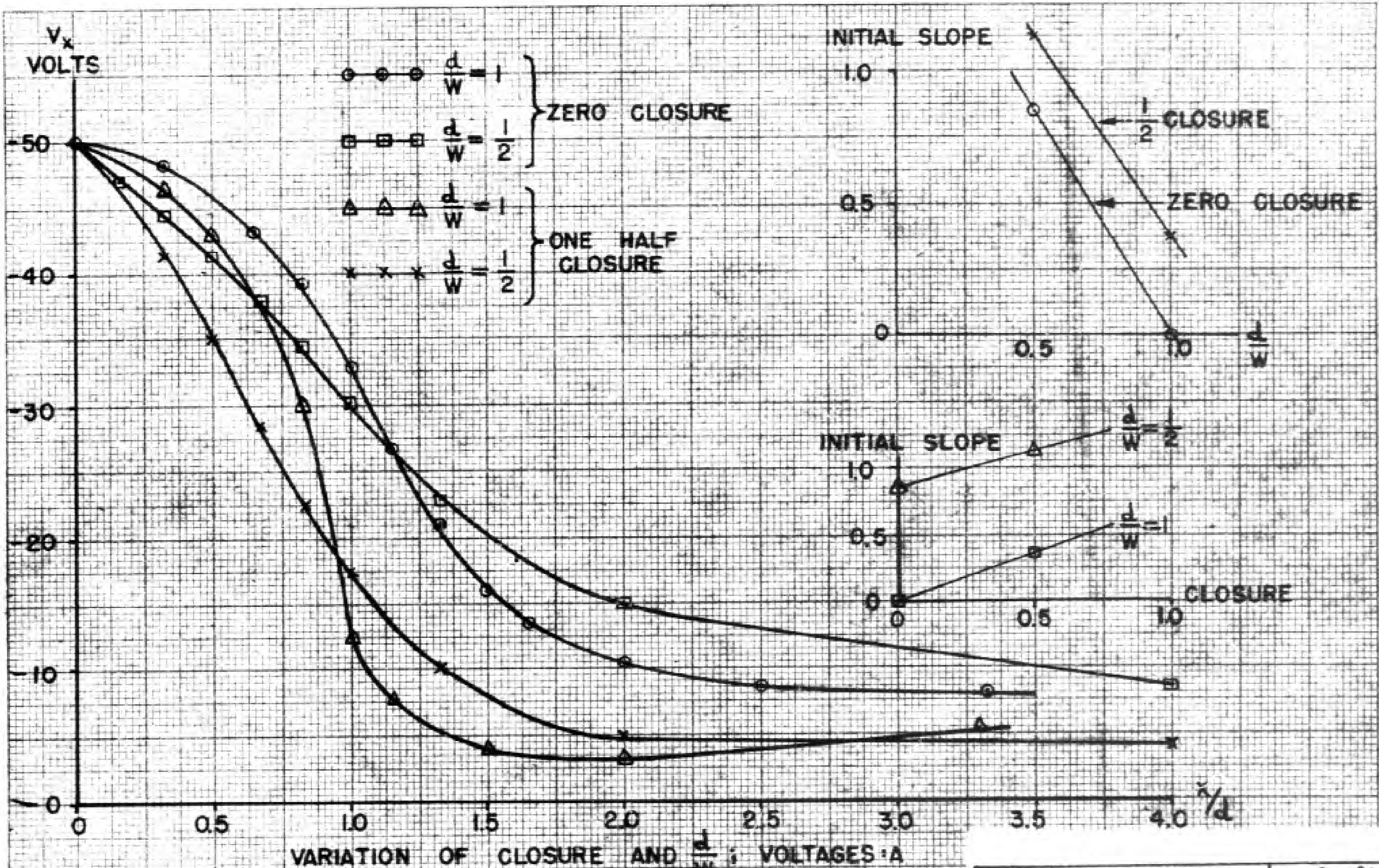
	A-30917



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D.I.C. NO. 6345

DR. JRW

A-30918

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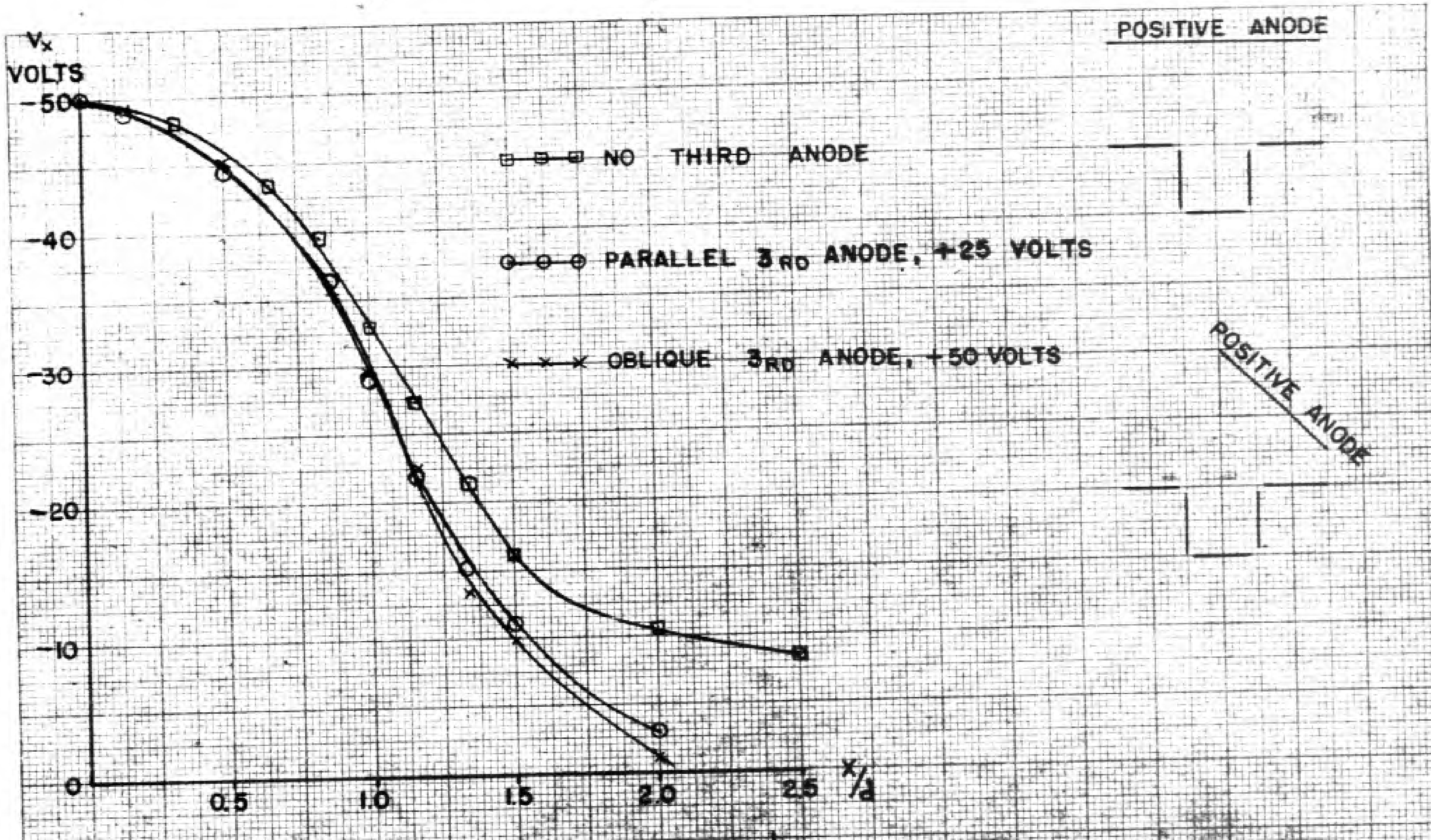

EFFECT OF POSITIVE ANODE; $\frac{d}{W}=1$, ZERO CLOSURE, VOLTAGES: A.

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DR. JRM

A-30919.

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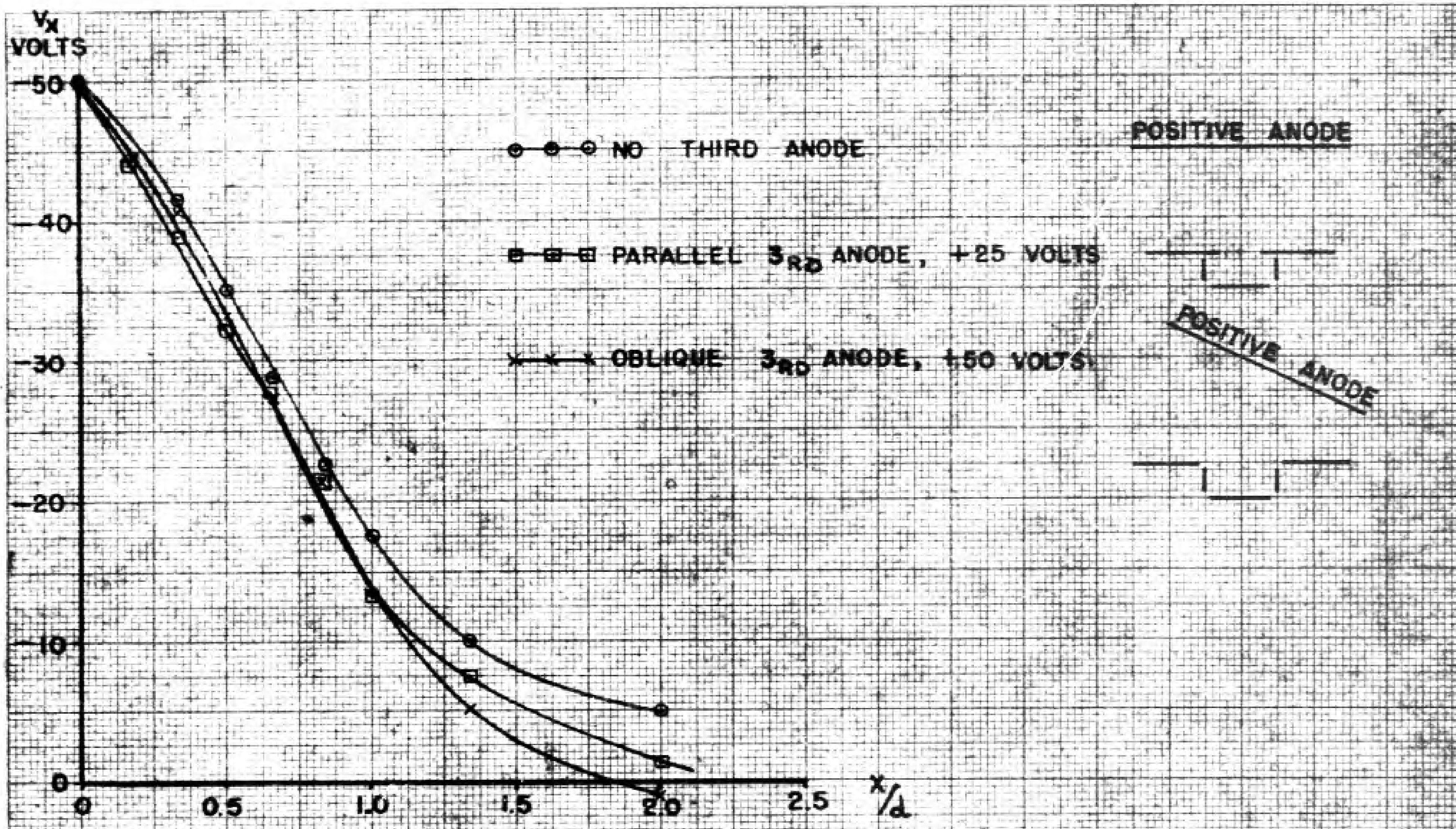

EFFECT OF POSITIVE ANODE, $\frac{d}{W} = \frac{1}{2}$; $\frac{1}{2}$ CLOSURE, VOLTAGES A

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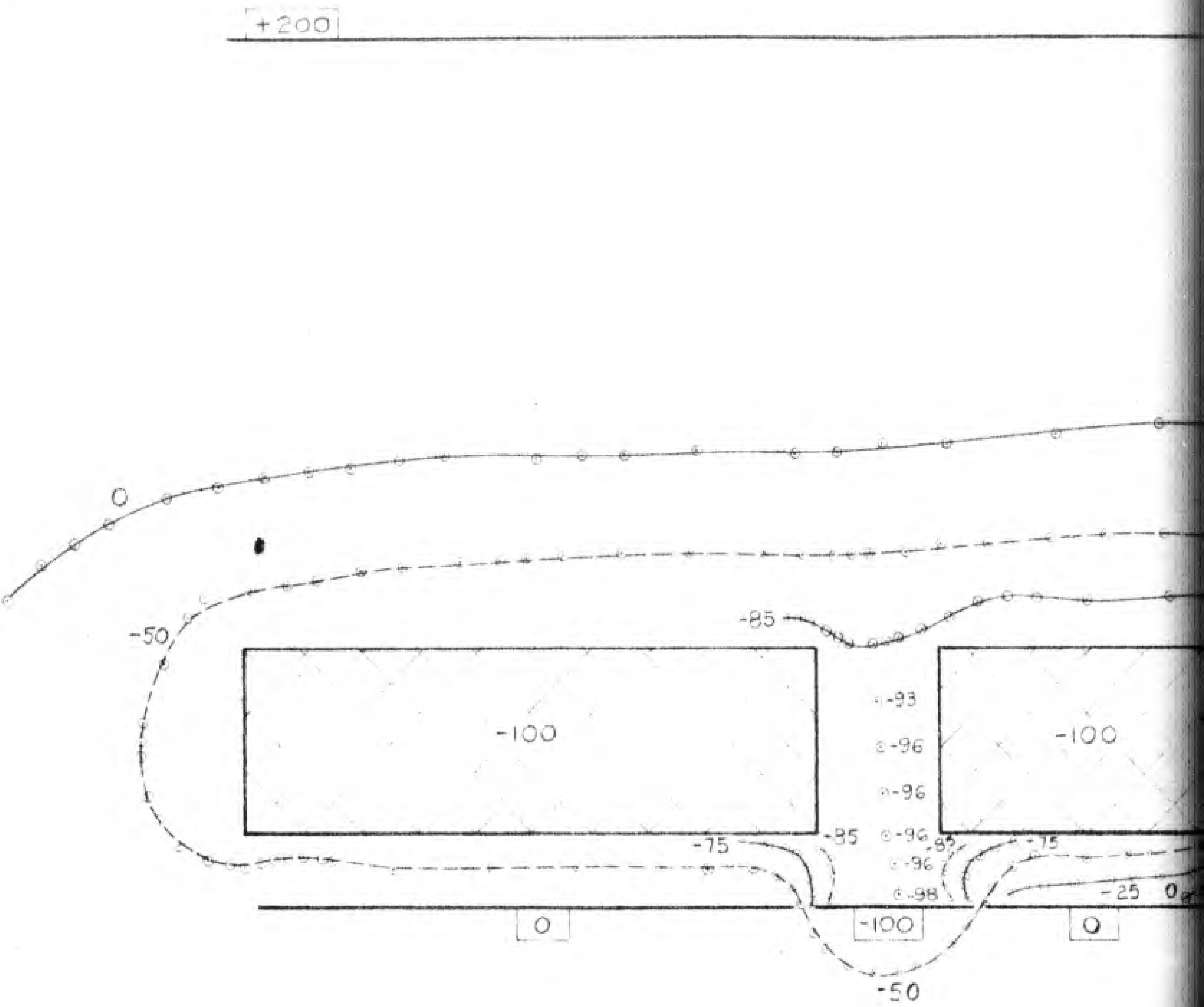
DR. [illegible]

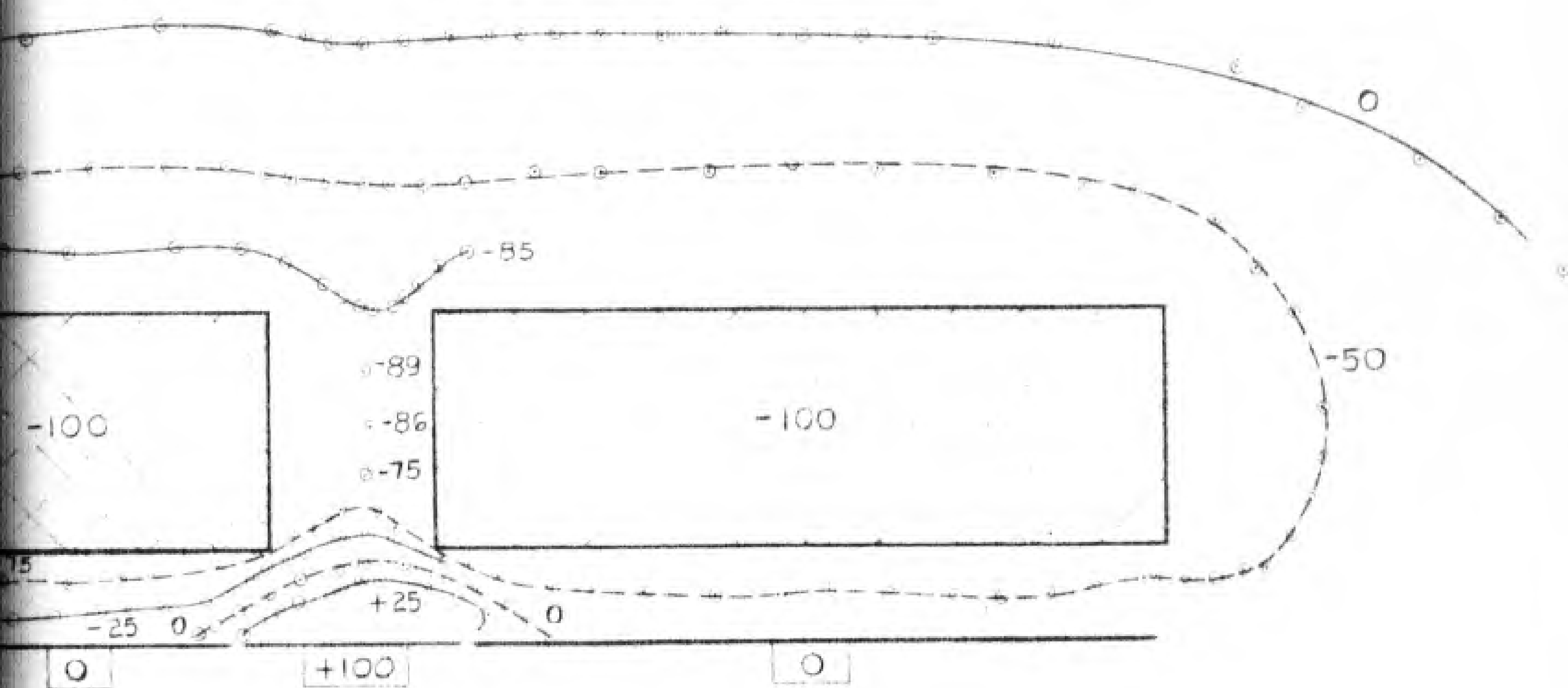
A-30920

1



EQUIPOTENTIAL LINES FOR SIMULATED STORAGE-TUBE GRI

2



E-TUBE GRID STRUCTURE

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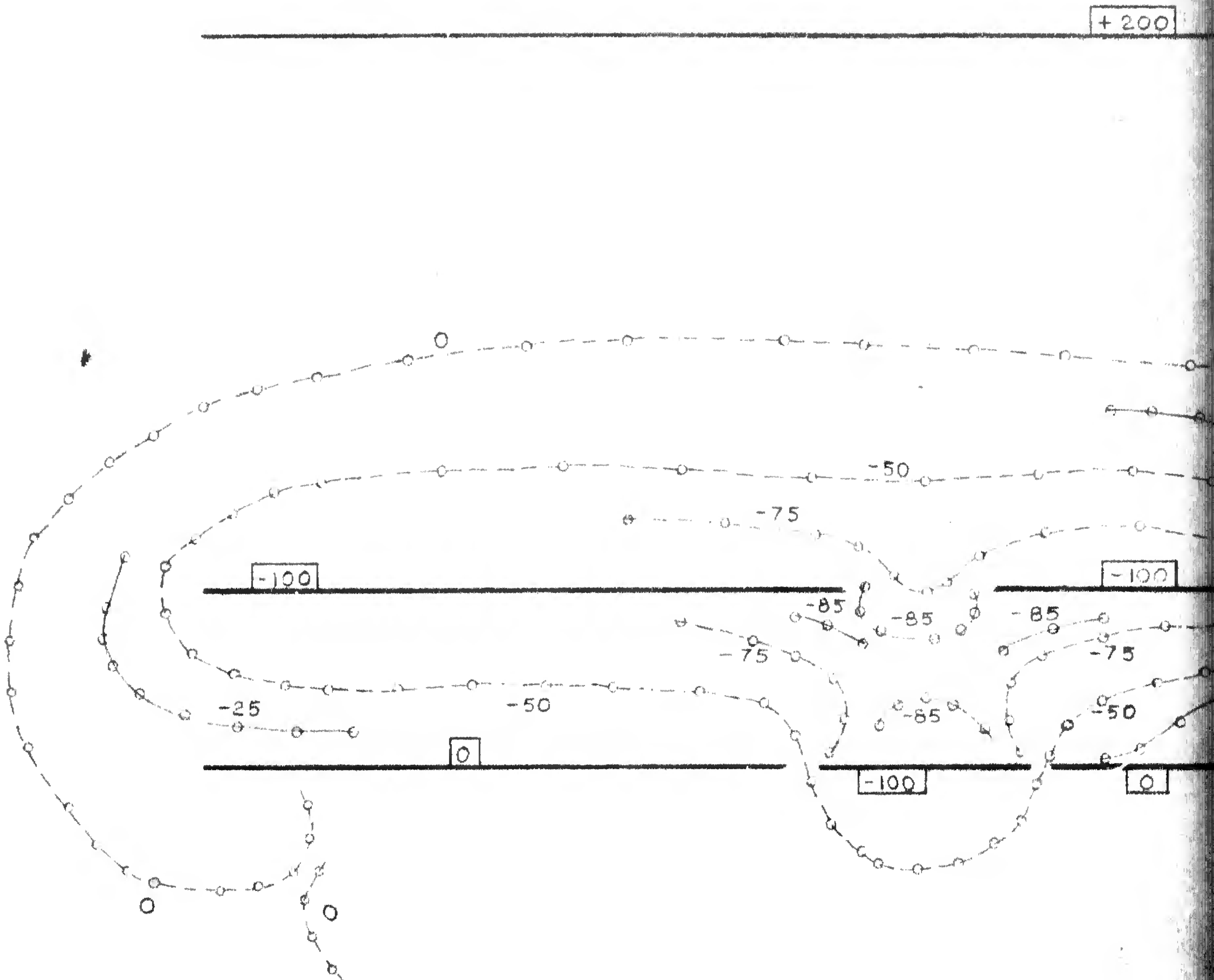
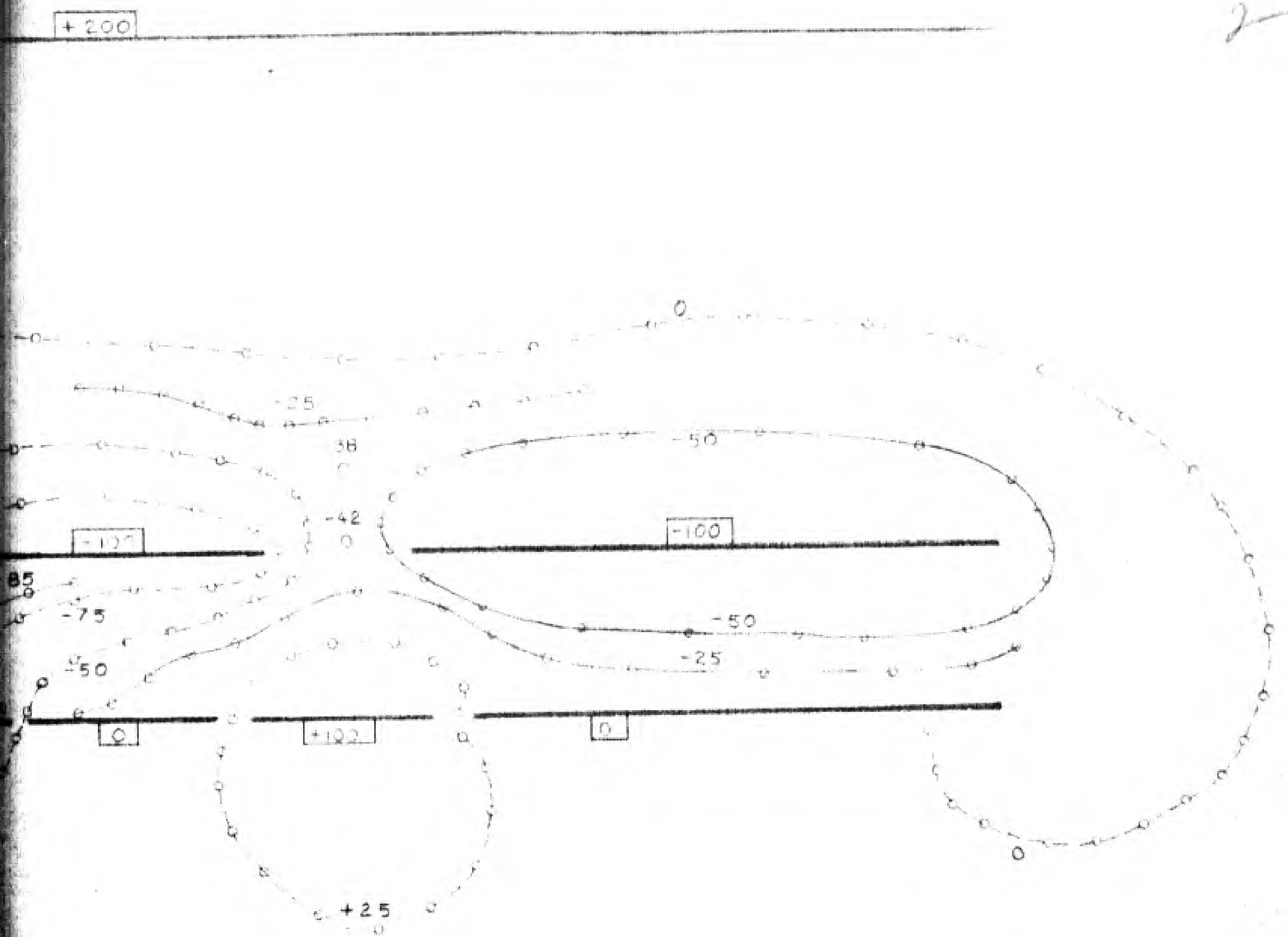
JRW	B-30938

1



EQUIPOTENTIAL LINES FOR SIMULATED STORAGE-



D STORAGE-TUBE GRID STRUCTURE

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