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HANDBOOK FOR THE
NANOSECOND ELECTRON ACCELERATOR
(NSEA)

by

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I. INTRODUCTION

The apparatus to be described was designed primarily for the study of scintillation decay times in the nanosecond region. When used for this purpose the equipment may be broken down into three principal systems: a pulsed electron accelerator, a light detector, and a readout device.

The accelerator is of the direct-voltage type, the high voltage being furnished by two Cockcroft-Walton power supplies. The special feature of the accelerator is its production of short pulses of electrons rather than a steady beam. The pulses may be as short as 0.5 nsec in duration at an accelerating potential of 75 kV. There are about 6000 electrons in each such burst, so that the burst has a total energy of about 500 MeV.

The light pulses produced by a scintillator excited by the electrons are detected by a fast photomultiplier tube. These electrical pulses from the phototube are in turn fed to a high-speed oscilloscope. The over-all arrangement is such that a response time of about 1.5 nsec is attainable for the system.

The electron bursts are delivered repetitively at the rate of 60 per second. Thus the resulting display on the cathode-ray tube has the appearance of a steady, continuously displayed pulseform. This pulseform may be transcribed for measurement by the usual photographic method. An associated system, however, can automatically and directly produce an enlarged replica of the waveform in either linear or semilogarithmic form on 10 X 17-in. graph paper in a few minutes. The shape of a scintillation pulse may thus be measured in a very short time.

II. GENERAL DESCRIPTION

This section describes the equipment in a general way for the prospective user. Another section presents a detailed description for the maintainer or interested user. The oscillogram transcriber, however, will be touched upon only very lightly. It is covered thoroughly in a separate ANL report¹ which will be found appended to this handbook.

A. The Electron Accelerator

The accelerator (Fig. II-1) produces pulses of electrons by causing a beam of electrons to sweep quickly across a narrow slit. Each time the beam crosses the slit, a "bunch" of electrons passes through the slit and is subjected to a further increase in energy, finally leaving the accelerating tube through a very thin window.

Fig. II-1 shows the laminated shield of mu metal and copper surrounding the electron gun at the top of the accelerating column. This gun is from a commercial cathode-ray tube and has a heater, an oxide-coated cathode, a grid, focusing and accelerating anodes, and X- and Y- deflection plates. The gun, and certain electronic circuitry associated with it, are at the high-potential end of the column and therefore are housed in a corona-ringed structure known as the "hot-top," which is mounted on large stand-off insulators.

About half-way down the accelerating column a plate intercepts what would normally be the path of the electron beam. A slit measuring 0.016 in. wide is cut in this plate. The top surface of the plate is coated with a phosphor so that the beam can be "seen." A 24-kV accelerating potential, divided among four stages, is applied between the gun

¹ Argonne National Laboratory report ANL-5985, "A New Method for Graphical Reproduction of Cathode-Ray Oscillograms," by Robert K. Swank and Eugene A. Mroz.

Fig. II-1. An over-all view of the accelerator.

cathode and the slit plate. Thus the cathode is at -24 kV relative to the slit plate. This voltage comes from an audio-frequency power supply located in the hot-top.

The beam of electrons coming from the cathode is focused on the slit plate and positioned to one side of the slit (Fig. II-2). Voltage for beam positioning and focusing are derived from supplies also located in the hot-top. However, the beam is normally cut off by grid-to-cathode bias. A signal from a master pulse generator triggers a sweep circuit (also in the hot-top) through a high-voltage capacitor in one of the insulators supporting the hot-top. Upon receipt of this signal, the sweep generator gates the electron beam "on" by applying a positive rectangular pulse of voltage to the grid of the electron gun and at the same time it develops a voltage ramp across the Y-deflection plates of the gun, causing

Fig. II-2. Schematic diagram of the accelerator and detection system used for measuring decay times of scintillators. Here T is the slit across which the electron beam is swept, A_1 and A_2 are accelerating electrodes, S is the scintillator to be measured, C_1 and C_2 are 16-ft lengths of RG-63/U coaxial cable, and Z_0 is the termination of the traveling-wave deflecting system.

the beam to sweep across the slit. Thus, below the slit plate one has bursts of electrons, the duration of each burst being determined by the speed of the beam in crossing the slit and the width of the slit.

The electron bursts are acted upon by another accelerating voltage introduced between the slit plate and ground and furnished by a separate supply located in a cage at floor level and to the right of the accelerator. Although this supply is capable of delivering 150 kV, only 50 kV is ordinarily used. The maximum usable accelerating voltage is currently limited to 75 kV because corona discharges from various parts of the hot-top take place above 80 kV. A string of resistors divides this voltage into 5 equal steps between the electrodes along the column. In this manner the slit plate is held at a potential of -50 to -70 kV relative to ground and the cathode of the electron gun is an additional 24 kV below this (-74 to -94 kV below ground potential).

The fully-accelerated electrons enter the drift tube, which is at ground potential. Closing the bottom of the drift tube is the "snout," having an axial hole of 0.040-in. diameter. The floor of the snout is covered with a fluorescent phosphor so that the location and focusing of the beam may be seen through the inspection window. The bottom of the snout carries the "nose-piece," which also has an axial 0.040-in. hole but is covered by a nickel foil with a thickness of 1 micron (0.00004 in.). The pulsed beam is steered into the holes through the two pieces and emerges from the accelerator column through the foil. It is estimated that on the average each electron in the beam loses about 20 keV of energy in passing through the foil.

The beam in the drift tube is steered by the electromagnet near the top of the drift tube. Although the primary purpose of this magnet is to focus the electron beam into the exit hole in the snout, the magnet is adjustable mechanically about two lateral axes so that the beam can be shifted into or out of the hole as desired. The beam focuses

into a spot approximately 0.010 in. in diameter and there is ample clearance for its passage through the holes in the snout and nose pieces.

As has been mentioned, the duration of each electron burst (and hence the energy per burst) is determined by the speed of the beam across the slit and by the width of the slit. In this case the slit width is fixed but the sweep speed may be changed by changing the capacitor in the plate circuit of the sweep tube (4X150A). Since this circuit is located in the hot-top, the sweep capacitors (which are mounted on special plates together with a charging resistor) cannot be changed while the accelerator is running. The shortest burst currently obtainable is approximately 0.5 nsec. The most intense usable beam is about $10\mu\text{A}$. Thus in the shortest bursts there are about 6000 electrons having a total combined energy of 500 MeV.

Because the system is not in a hard vacuum, the cathode of the electron gun is susceptible to rapid poisoning and must be activated each time before the accelerator voltage is run up. This is done by drawing a comparatively heavy current from it under a higher-than-normal temperature. Details of the activation procedure are given in Sec. III a. 4, "Operating Procedure."

The controls provided for the electron gun regulate x position, y position, focus, and intensity. Since these controls are situated in the hot-top, electric motors drive them by means of long plastic shafts. The motors are outside of the protective cage and are switched from the front control panel, or alternatively from a hand-held box connected to the control panel via a long flexible cable. Electron-gun filament voltage, high voltage (that applied between slit plate and ground), and the input voltage to the power supply for the hot-top are controllable from the main control panel.

B. The Detection System

The detection system consists of a high-speed oscilloscope connected to a photomultiplier tube which "looks" at the scintillator being irradiated by the electron beam.

The photomultiplier is mounted in a black probe box with a hole in its top. This assembly can be rolled underneath the snout of the accelerator. The tube is an RCA-1P28 which has an S5 spectral response. The photocathode is buried in the dynode structure and is viewed through the side of the tube. Because the cathode is some distance from the glass of the envelope, the light-collecting efficiency is rather poor. Nevertheless the low transit-time spreading inherent in the 1P28 makes it a desirable tube for looking at fast light pulses. To obtain high gain and to reduce transit time, this selected tube is operated with unusually high interdynode voltages, namely, from 185 to 390 V. These high voltages also reduce space-charge effects.

In order to further reduce the time spreading, the number of stages used is reduced by taking the signal from stages earlier than the tenth. Since the Edgerton, Germeshausen, and Grier (EG&G) cathode-ray tube is designed for a push-pull signal input, a positive signal is taken from the sixth dynode and a negative signal is taken from the seventh dynode. A co-axial cable transmits these signals directly to the vertical deflection helices of the cathode-ray tube.

The oscilloscope is of the traveling-wave type and has a rise time of about 0.2 nsec. At the available sweep speeds, the pattern (a length of 0.5 in.) is traversed in from 20 to 5000 nsec. Another feature of this instrument is a very small spot diameter which makes for high sensibility, i.e., a large amount of information from low-amplitude traces. For further information consult the instruction manual for the Edgerton, Germeshausen, and Grier type 2236 traveling-wave oscilloscope.

C. Readout Methods

1. The "Scope-O-Graph" Transcriber

The Scope-O-Graph (SOG) automatically plots the waveform from the oscilloscope upon 10 X 14-in. graph paper to provide quick and accurate measurements as well as a permanent record of the pulse shapes. The graphical presentation may be either linear or (through the use of the Logarithmic Converter) semilogarithmic.

The main components of the Scope-O-Graph are: the perceiver (which is fastened to the front of the oscilloscope), the scanner, the restorer, the logarithmic converter, and the power supply for the SOG photomultiplier (located in a rack on a table to the right of the accelerator bench) and the X-Y recorder.

The perceiver optically views a narrow vertical strip of the cathode-ray tube screen while the waveform is being moved horizontally across the screen by the scanner. The recorder pen is caused to move in its horizontal (X) direction in synchronism with the horizontal movement of the waveform. The perceiver detects any deviation of the waveform from a horizontal reference line at any instant; and the restorer, through a null technique, measures the amount of deviation and sends to the Y input of the recorder a signal proportional to that deviation. The degree of magnification of the transcribed waveform in both the X and Y directions is controllable by the operator.

In case a semilogarithmic transcription of the oscilloscope display is desired, a special circuit termed the logarithmic converter can be used. This circuit, whose output voltage is proportional to the logarithm of the output voltage of the restorer, can be interposed between the restorer and the Y input of the recorder. With this mode of presentation, any exponentially decaying portion of the scintillation pulse displayed on the oscilloscope will be transcribed onto

the recorder chart as a straight line. The decay time can readily be determined from the slope of this line.

The waveform displayed on the oscilloscope screen must be kept there for 3 — 5 min if the Scope-O-Graph is to make a permanent transcription of the pulse. The time scale of the drawing is calibrated by displaying a sine-wave from a calibrated UHF signal generator on the oscilloscope and causing the Scope-O-Graph to trace this sine wave onto the drawing.

2. Photographic Transcription

An alternative method of transcribing the oscilloscope presentation involves photographing the waveform displayed on the oscilloscope. This is accomplished with a Century Graphic camera on a mount which attaches to the front of the oscilloscope. The camera has a 103-mm f/4.5 lens and a specially-constructed back which accommodates glass photographic plates of the 6.5×9 -cm size. A periscopic viewer allows the oscilloscope waveform to be observed visually with the camera mount in place.

In photographing the scintillation pulses, exposure time of approximately 10 sec are employed. This accomplishes a certain degree of averaging-out of the small fluctuations in amplitude and shape of successive pulses.

The photographed pulses may be enlarged for visual examination or reduced to digital form by reading off the X and Y coordinates of the pulse with a photoelectric comparator.² For the latter, it is desirable to photograph a baseline with each pulse so that corrections can be made for possible curvature of the baseline. To prevent overlapping of the two images, the photograph of the baseline may be

² H. B. Phillips, Rev. Sci. Instr. 25, 971 (1954).

displaced with respect to the photograph of the pulse by translating the plate holder, without rotation, along accurately-machined ways on the camera back. The Y coordinates of the pulse are then measured from the baseline, the displacement being subtracted from each measurement. The results are then plotted on semilogarithmic graph paper and the decay constant is determined in the usual manner. About eight pulses with baselines, together with two timing waves, are recorded on each plate.

This photographic method of transcription has the obvious disadvantage of being very time consuming. A time lag of about a day is not uncommon between the running of a scintillator sample and obtaining the value of the decay constant.

III. OPERATING PROCEDURE

The machine is a complex of various instruments and much time would be required of a new or occasional operator to learn the function of each and every control and its exact place in the over-all picture. To save time for the user, this section will give step-by-step instructions for a typical operating session involving the measurement of a scintillation pulse. In some instances, in which it is felt that further information may be quickly needed by the operator, references to specific paragraphs of the DETAILED DESCRIPTION are given.

It is assumed that the vacuum-pumping system has been operating and that column pressure is down to at least 3×10^{-6} torr (mm Hg). The alarm circuits for the fore pump, diffusion pump, thermocouple gauge, ion gauge, and diffusion pump are on continuously.

It is also assumed that the initial activation of the cathode of a new electron gun has been made. The details of the initial activation which differs somewhat from the day-to-day activation, are given in Sec. V B. 3.

A. Startup

1. Warm-up

For stability during operation, warm up the instrument by closing the power switches on the following components: (1) electron gun activation and magnet-current power supply; (2) detector-photomultiplier supply (fil.); (3) master pulser; (4) oscilloscope; (5) scanner; (6) restorer; (7) logarithmic converter; (8) power supply for photomultiplier of Scope-O-Graph; (9) X-Y recorder; and (10) UHF signal generator. (See Fig. III-1.) The time required for the remainder of the start-up procedure is approximately 30 min. This provides a sufficient warm-up period.

Fig. III-1. Identification of components of the control panel.

2. Filling the Cold-Trap

The capacity of the liquid-nitrogen cold trap is 2 liters. It is filled automatically once each day at 4:00 PM. This filling is usually sufficient, but it is good practice to fill the trap just before each operating session by pressing the "MANUAL FILL" button on the Automatic Filling System panel. The chassis is located on the back of the accelerator structure next to the cold trap. The filling will stop automatically provided that there is enough liquid in the storage Dewar to completely fill the trap. A normal filling takes about 2 min (Sec. IV E. 4).

3. Pressure Check

Check pressure in the vacuum system by inspection of the Ion Vacuum Gauge control panel. The gauge should be "ON" continuously. The "ON" condition is evidenced by the glowing of the blue panel light and by the glow of the ion gauge as seen through a rectangular port in the Diffusion Pump Control panel. The GAUGE-DEGAS switch should be on GAUGE and the START-SAFETY switch on SAFETY. The grid-current meter should give a reading of 5 mA; re-adjust as necessary. Turn the RANGE switch to CHECK and adjust the plate current to zero. Now turn the RANGE switch to the position that allows the best reading of the plate current (pressure). This reading may vary from 40 on the 0.3 scale down to 45 on the 0.1 scale. (See Table C Sec. IV E. 2 for conversion of meter readings to torr.) A reading higher than 40 on the 0.3 scale indicates a malfunction of the vacuum system and the run should be postponed. Except when taking a pressure reading, the RANGE switch is left on the "100" position.* Record the pressure reading in the log book.

* If for any reason the pressure (plate-current) meter is allowed to reach 100 μ A, at any setting of the range switch, the ion gauge will shut off, turning off the diffusion pump (as well as the electron-gun filament and the high voltage if they should be on) and causing the diffusion-pump alarm to sound. Restore proper operation by placing START-SAFETY switch on START, pressing ion-gauge START button and pressing diffusion-pump START button (on DIFFUSION PUMP CONTROL panel). After a minute or so, return START-SAFETY switch to SAFETY.

4. Cathode Activation

Open the door of the hot-top cage and ground the corona rings of the hot-top with the lucite-handled grounding chain which hangs on the right-hand side of the cage just inside the door. Leave the corona rings grounded during the entire activation procedure.

The socket of the electron gun is accessible through an opening in the top plate of the hot-top. Pull off the socket from the base of the gun and install the adapter socket. This socket normally hangs on the left outside of the cage and is connected via a flexible cable to the power supply for electron-gun activation. Replace the electron-gun socket on top of the adapter. Turn the function-selector switch of the ELECTRON GUN AND MAGNET supply to ELECTRON GUN. Going to the MAIN CONTROL panel, check that all large knobs of the three variable transformers are at zero. Turn on the MAIN switch (white lamp will glow) and then the ELECTRON GUN FILAMENT switch (yellow lamp will glow).

The actual filament voltage to be used for activation and for operation will depend on the condition of the cathode. The cathode is subject to continued poisoning because of the porosity and perhaps continual outgassing of cements used to seal the glass-to-metal joints of the column. Therefore as time passes successively higher temperatures are required to obtain the needed current from the cathode. The voltages used on the previous activation may be used as a guide. What one wants to do here is to draw a heavy current from the cathode. At first the surface is inactive so that the cathode needs to be heated to a higher-than-normal temperature. Once the top layer is either reactivated or boiled away, the temperature may be reduced somewhat without reducing the emission current.

Let us assume that the gun is relatively new. Set the electron-gun filament control to obtain 7.0 V on the heater. This voltage is read on the large upright ac meter inside the hot-top. The ELECTRON GUN AND MAGNET power supply has already been switched on so that

50 V dc is being applied between cathode and grid. Record in the log book the time at which both of these voltages have been applied and also record the voltage used. The dc collection voltage is symbolized as E_B , and the filament voltage as E_f . An arrow ($\rightarrow$) between the symbol and the number of volts should be used to indicate that the voltage has been set to that number rather than found to be there as an equal sign (=) would indicate.

After a few minutes the cathode current will rise. This current is indicated on the milliammeter of the ELECTRON GUN AND MAGNET supply. This supply is constructed and adjusted so as to limit the current to 40 mA, to prevent damage to the cathode. From 5 to 10 min after the beginning of activation, the current should reach 40 mA. A few (3 — 5) minutes after this limit has been reached, the filament voltage should be reduced by 0.5 V. Wait for 5 min at this setting. If the current (I_B) remains at 40 mA the activation may be considered complete.

Suppose, now, that at $E_f = 7$ V the current I_B does not reach 40 mA within the 10-min period. One would then increase E_f by 0.5 — 7.5 V and in the log book would record this change, the time of the change, and the magnitude of I_B just before the change. Unless the gun is at the end of its life, an E_f can be found for which I_B will reach 40 mA after a few minutes. (Although this E_f meter reads only up to 10 V, a voltage as high as 12 V may be used for activation by extrapolating on the dial of the variable transformer.)

After a few minutes at 40 mA, reduce E_f by 0.5 V and wait 5 min to see if the cathode will retain this emission. In many cases, after 5 min E_f may be further reduced (in 0.5-V increments). Should I_B decrease when E_f is lowered, allow 5 min for I_B to climb back to 40 mA at the reduced E_f . If I_B does not recover, revert to the E_f at which I_B becomes 40 mA, wait 5 min, and again try to reduce E_f . Occasionally the machine must be operated with the same E_f as was used for activation. To guide the next activation, list all changes and times of changes in the log book.

It is seen that there can be considerable variation from one activation to the next. The only hard and fast rule that can be given concerning the procedure is that the E_f should not be raised beyond the value necessary to obtain the required I_B of 40 mA. Keeping the cathode at temperatures higher than necessary or at elevated temperatures for unnecessarily long times reduces the useful life of the cathode. This is not to be construed as meaning that the accelerator should not be operated with the cathode at very high temperatures. The average life of a cathode is 80 hr of operation. When the cathode nears this figure, it may be necessary to activate and operate it at the maximum available E_f (12 V).

There are times when maximum cathode emission is not necessary, e.g., when looking at scintillators having a short decay time but a large pulse height. For these an I_B of 20 mA may be ample. A well-used gun not capable of maximum emission may still be useful for this type of work.

A cathode begins to "die" rapidly as soon as current is no longer being drawn from it, so that when the activation is complete the next step should be taken in as short a time as possible.

5. Turning on the Hot-Top

Remove the grounding chain from the corona rings, and hang the chain and its rod on the inside of the cage just inside the door. Remove the adapter socket from the electron gun, reinstall the regular socket on the gun, and replace the cover of the access opening. Close the door of the hot-top cage, being certain that the interlock plug on the door is fully inserted into its receptacle. Turn on the HOT-TOP POWER switch on the MAIN control panel (green light will glow) and adjust the HOT-TOP POWER knob so that the right-hand small meter in the hot-top reads 6.3 V. After about 1 min the oscillator in the hot-top will begin to "sing," and shortly thereafter its pitch will drop. At this point, re-

adjust the HOT-TOP POWER knob so that the above-mentioned meter once again reads 6.3 V. Now the left-hand small meter in the hot-top will read full scale (500 V). (Section IV A. 4.)

The electron beam accelerated through 24 kV should now be impinging on the slit plate and, if the intensity control is set high enough, the beam can be seen on the phosphor screen of the slit plate. The following section gives instructions for varying the intensity control.

6. Electron-Gun Controls

At this point it may be necessary to adjust the intensity of the electron beam, so let us digress to explain the electron-gun controls.

Just above the EG&G oscilloscope is a narrow black panel containing one set of electron-gun controls. The power switch at the extreme right is usually left ON continuously. Next is a rotary switch that selects one of the four functions: X-AXIS POS. to move the beam along a line parallel to the slit of the slit plate; Y-AXIS POS. to move the beam along a line crossing the slit; FOCUS to bring the beam to a sharp spot on the slit plate; or INTENSITY to vary the beam current. The selected control may be rotated clockwise or counterclockwise by the spring-loaded lever switch. If, for instance, one wants to increase the beam intensity, he will turn the selector switch to INTENSITY and push the lever switch against the clockwise stop. Holding the lever against the counterclockwise stop will of course decrease the intensity. Springs normally hold the lever in the center OFF position. These switches actually cause motors to operate, and these in turn rotate the potentiometers in the hot-top by means of lucite shafts. Thus there is some overtravel as the motor coasts after the lever switch is released. Flicking the lever will allow the operator to position the control exactly. Slip clutches prevent damage to the motors when a potentiometer reaches the end of its travel.

At the extreme left of this panel is a LOCAL-REMOTE switch. In the REMOTE position, this switch transfers the control from the panel to a hand-held box which is connected to the panel via a long flexible cable. A function selector and lever switch identical to those on the panel are mounted on the box. This allows the operator to manipulate the controls while viewing the beam on the slit plate from atop a ladder.

Returning now to the start-up of the accelerator, as the 24-kV supply in the hot-top comes into full operation (as evidenced by a change in pitch of the "singing") the beam impinging on the phosphor screen of the slit plate may be too intense. The maximum usable intensity is that which allows the spot on the slit-plate screen to be just visible under normal ambient lighting.

7. Turning on the High Voltage

It may be well to point out again that the total accelerating voltage on the electrons is the sum of the 24 kV applied above and the voltage that will be applied now. An interlock prevents the high-voltage (0-150 kV) supply from being turned on unless the HIGH VOLTAGE knob is at zero. Press the high-voltage ON button and slowly rotate the knob to obtain the desired high-voltage setting (70 kV max.). This voltage is read on the kilovoltmeter at the upper left of the MAIN control panel. Note that this meter responds slowly to changes in variac setting. If the variac is advanced rapidly, the Sensitrol relay at the upper right-hand corner of the MAIN control panel may trip and automatically turn off the high-voltage supply. If this should occur, restore the high voltage by turning the high-voltage variac back to zero, pressing the RESET button, and then pressing the high-voltage ON button.

8. Beam Adjustments and Production of Electron Bursts

In order to get any electrons beyond the slit plate, the beam must be swept across the slit. The voltage ramp for this sweep is generated in a circuit located in the hot-top, but is triggered by the MASTER PULSER located in the center rack of the control panel.

The MASTER PULSER generates rectangular pulses at a rate of 60 per second when the PULSE RATE switch is in the 60-cps position. This pulse is used to trigger the hot-top sweep, the oscilloscope sweep, and the UHF signal generator to maintain synchronism among these.

On the front panel of this unit is a brass tube housing a mercury-wetted switch actuated by the solenoid which surrounds the tube. A pulse-forming cable connects to the top of the tube, and a pulse-splitting tee connects to the lower end of the tube. The bottom outlet of the tee feeds a 50- Ω cable which connects to a pulse-inverting transformer which in turn feeds the hot-top and the UHF signal generator. The side-arm output of the tee connects, via a variable delay line with a range of 0-1.5 μ sec, to the trigger input of the oscilloscope.

To trigger the hot-top sweep, the voltage dials of the master pulser are set to 20 V, the polarity selector is set to +, and the pulse-rate switch is flipped to 60 cps. The trace of the beam across the slit of the slit plate can be seen, but only in very dim light. However, by looking into the viewing port at the lower end of the drift tube, one can see a glowing spot where the electron bursts impinge on the phosphor surface of the snout. Under the conditions given thus far, the spot will be dim and unfocused. Now switch the ACTIVATION AND MAGNET power-supply selector to MAGNET and the spot should fall into focus. The focus is adjusted by the MAGNET-CURRENT CONTROL of this power supply. Besides falling into focus, the spot may also shift into the hole and thus may not be seen. A small permanent magnet (usually kept handy) can be brought up to the drift tube to dislocate the beam temporarily.

The location of the beam is determined by the current in the focusing magnet as well as by the position of this magnet. Set the current to give best focusing of the spot and then steer the beam into the hole by mechanically positioning the magnet by means of the two knurled knobs on the magnet support.

The beam should now be coming out through the exit foil in readiness for irradiation of a sample. However, until the sample is in place and the detection system is ready, cut off the electron bursts by setting the RATE switch of the master pulser to EXT.

9. Radiation Hazards

There exists no radiation measurable above background on the outside of the hot-top cage, the high-voltage cage, and the drift tube. Thus, when the machine is used to irradiate plastic or liquid scintillators, no precaution against radiation is necessary. The operator is cautioned to provide shielding if the electron pulses are to be used to bombard a target from which x radiation may be expected.

B. Irradiation of the Sample and Detection of the Light Pulse

1. Insertion of the Sample

A clear plastic arm is attached to a switch box on the control panel at about the level of the lower end of the drift tube. Turning this arm actuates a switch in the line applying voltage to the photomultiplier tube of the detector. Voltage can be applied to the tube only when the arm is rotated so that the curved section is against the light hood. This serves as a safety feature to remind the user to remove the voltage from the photomultiplier before exposing it to light. Note that this is not a high-voltage type switch and should not be used to switch the full photomultiplier voltage (normally 2 kV) on and off. This switch is intended only

to disconnect the minimum output voltage of the photomultiplier supply, which (with all selectors at their lowest positions) is 500 V.

After checking that the safety switch is open (away from the light hood) and that the voltage selectors on the photomultiplier power supply are at their minimum positions, turn on the H.V. switch of the photomultiplier supply. Place the scintillator and reflector in place on the probe box over the phototube. Release the lock at the right-hand edge of the rolling table (by turning the knob counterclockwise) and roll the unit underneath the drift tube. CAUTION: Scraping an object across the foil or even touching the foil can rupture it. Be sure the probe box is low enough as you roll it into place. Once the table is against the left-hand stop, lock it in place. Only moderate finger pressure is required on the locking screw. Raise the probe to bring the scintillator close to the foil, a clearance of at least $\frac{1}{32}$ in. being desirable. This can be judged accurately enough by sighting across the foil and against one of the white meter faces.

Now screw down the light hood, making certain that the annular projections on the bottom of the hood fit into the grooves of the detector box to complete the light seal.

2. Viewing the Pulse on the Oscilloscope

Consider now the EG&G oscilloscope and the PERCEIVER mounted on the front of the oscilloscope. The oscilloscope controls should be set as follows.

SWEEP SPEED: as required. Position 2 presents the fastest sweep, position 7 the slowest. Position 4 is a good starting point.

COUNT-DOWN RATIO: at HI.

SYNC. SENSITIVITY: full clockwise.

SWEEP STABILITY: full counterclockwise.

ASTIGMATISM: about 7.2.

10 kV - 20 kV: at 20 kV.

V POS.: disregard. (Control disconnected.)

H POS.: disregard. This is controlled by the large scanning knob on the SCANNER.

INTENSITY: at about 8.5, but set later at a point just below that at which the spot on the screen "blooms."

Access to the top of the oscilloscope chassis is gained from the back of the accelerator structure. Locate the TOP HELIX INPUT of the cathode-ray tube. Check that the cable connected to this point is the one labeled FROM 1P28 D7. On the left side of the PERCEIVER is a knob labeled VIEWING MIRROR. Set this knob so that its pointer is in the VIEW position. If you now look into the periscope you should see the undeflected spot. You will also see a reticle, each division of which represents approximately 1 mm on the face of the cathode-ray tube. Controls for illumination of the reticle are found on a small box at the right of the perceiver.

Trigger the oscilloscope sweep by turning the RATE switch of the master pulser to 60 cps, and the swept "base line" will be seen. Apply voltage to the detector photomultiplier by rotating the plastic safety-switch arm against the light hood and turning up the selector switch of the "DET. PM" supply to obtain a meter reading of 2000 V. Adjust the variable delay line to a dial setting of 2 and view the pulse.

A pulse will then appear on the baseline if all of the aforementioned steps have been taken properly and provided that there has been no drifting since they were completed. The probability is very high that there will be no pulse. If there is none, use the following check list.

- a. Electron-gun filament: Meter should still register at the post-activation voltage, but at least 6.3 V.
- b. Hot-top power: Small meter in hot-top should indicate 6.3 V.
- c. High voltage: Should be 50-70 kV.

- d. Electron-gun intensity: Spot on phosphor surface of slit plate should be just visible.
- e. Master pulser: Should be set on 60 cps, 20 V, and +.
- f. Electron-gun and magnet-current supply: Should be on MAGNET CURRENT.
- g. Beam should be arriving at nose piece at bottom of drift tube. Check by deflecting beam with permanent magnet.
- h. Beam must be "in the hole." Adjust focusing magnet to steer beam into the hole of the nose piece.
- i. Light hood must be screwed down properly. No light leaks at junction of hood and detector box.
- j. Photomultiplier safety switch: Plastic arm should be against the photomultiplier housing.
- k. Photomultiplier supply meter: Should read 2000 V.
- l. Cables from detector box should be connected to the cathode-ray tube.
- m. Variable delay line should be set at 2. Try varying the delay over the range from 0-4 dial units.

3. Manipulation of the Waveform

The entire trace is positioned in the X direction by the scanning dial of the SCANNER. The pulse is positioned along the baseline by the variable delay line.

The height of the pulse may be varied by varying either the intensity of the electron beam or the voltage on the detector phototube. However, since the voltage on the phototube affects not only the gain of the tube but the transit-time spreading as well, it has been the practice to use a standard 2000 V on the tube and to use only the electron-gun intensity to control the pulse height. If the scintillator being studied

has a short decay time, the pulse will probably be very high. Reduce the beam intensity by pressing the lever switch counterclockwise. The greatest pulse height that can be handled by the Scope-O-Graph as it is arranged here is 4 mm.

Adjust the Y-POS. control of the electron gun to the setting that gives the greatest pulse height. Clockwise rotation moves the undeflected spot toward the slit, counterclockwise moves it away from the slit. Moving the Y position of the beam also causes the pulse to move along the baseline on the oscilloscope.

One should avoid causing the undeflected beam to cross the slit while adjusting the Y-POS. control. This is sometimes difficult, especially when one is working alone, since one cannot watch both the motion of the spot and the change of the pulse height at the same time. However, letting the undeflected spot cross the slit results in violent vertical jumping of the baseline on the oscilloscope screen. Thus the operator can avoid repeating this blunder if he notes the X position of the pulse when this jumping occurs.

When working with a scintillator having low pulse heights, the operator will have to make careful adjustments in order to obtain the maximum possible height. Adjust the electron gun to the maximum usable intensity, i.e., so that the undeflected spot on the slit plate can just be seen. It should be pointed out here that the pulse height could be increased by pushing the electron-gun intensity beyond this "maximum usable" value. However, doing so not only damages the grid of the electron gun but also results in the electron bursts desired at the exit foil being replaced by a steady beam with electron pulses superimposed.

For scintillators having very low pulse heights, the voltage on the detector phototube may be as high as 2300 V, but this is very close to the breakdown voltage of the selected tube and should be avoided. Breakdown in the phototube is indicated by violent jumping of the baseline.

Because of the small spot diameter of the EG&G oscilloscope and the sensitivity of the Scope-O-Graph, much information can be gleaned from a pulse having a height as small as 0.3 mm on the oscilloscope screen.

The hot-top voltage and the filament voltage of the electron gun tend to drift somewhat during a run. The operator should check these frequently and reset them.

Because of redistribution of charges along the insulators of the accelerating column, the beam often jumps out of the exit hole and must be returned by mechanical readjustment of the focusing magnet.

When not viewing or plotting a pulse, turn the RATE switch of the master pulser to EXT. to conserve the mercury relay and avoid accidental damage to the phototube by turning down its high voltage.

C. Using the Scope-O-Graph and Plotting the Pulse

1. Readying the Recorder Pen

Perhaps the first step in plotting the pulse should be the mundane task of clearing the recorder pen. If the pen has been used the previous day, it may be necessary only to moisten the tip with a wet tissue. A more severe blockage is removed by pressurizing the ink reservoir with a rubber bulb provided. Merely press the tip of the bulb securely against the opening of the reservoir and squeeze, but remove the tip from the opening before releasing the bulb. A blockage resulting from a week or more of inactivity is removed by "rodding-out" the pen with the fine wires provided.

The pen stays clean longer if the ink is diluted with distilled water. Half fill the reservoir with ink from the bottle and then bring the level up to the opening with distilled water. A special needle-type filler is provided and is housed in a glass jar labelled "Contactene Injector."

2. Checking Voltages of the Logarithmic Converter

The accuracy of the logarithmic converter depends on the voltage of its supply and the voltage across the logarithmic resistance string. If the production of semi-logarithmic plots is contemplated, these voltages should be checked weekly or at the beginning of each series of runs. On the rear apron of the logarithmic-converter chassis are two sets of banana-type receptacles. Use a 0-1 precision potentiometer to measure the voltage between the terminals marked "SUPPLY TEST, 0.411 V." A knob on the front panel marked "SUPPLY ADJ." resets the supply voltage. Now measure the voltage between the terminals marked "LOG ADJ. TEST 0.750 V" and reset as necessary with the ADJ. LOG duodial on the front panel.

3. Making a Linear Plot of the Pulse

Check the following controls on the Scope-O-Graph rack and the X-Y recorder.

Scanner

SCAN DIRECTION: Set on FWD.

WIDTH: This controls the width of the presentation to be made on the X-Y recorder and can later be set according to the information desired from the presentation. For this trial, set this control at 300.

SCAN MODE: Set on OUT-MANUAL.

SCAN TIME: Set on 1000 sec.

SCAN DIAL (Large duodial): Set on 0 (full counterclockwise).

Restorer

GAIN, CHANNEL 1, and CHANNEL 2: Set according to sweep speed being used on EG&G oscilloscope.

(See Table A.)

JACK SELECTOR: Set at F.

BALANCE SPEED SEL.: Set at TEST.

Logarithmic Converter

FUNCTION: Set at LIN. This is the only logarithmic-converter control that is used during a run. All other controls are for calibration and alignment only and are not to be touched.

Voltage Supply for Photomultiplier of Scope-O-Graph (SOG PM SUPPLY)

OFF-ST'D BY-ON: Set at ON.

POLARITY: Set on NEG.

VOLTAGE: Set according to sweep speed being used.

(See Table A.)

X-Y Recorder

PEN: Set at ST'D BY (stand by).

X-SCALE SENS.: Set at 5V/in.

Y-SCALE SENS.: Set at 1 mV/in.

TABLE A. Conditions to provide minimum response time of the restorer circuits of the Scope-O-Graph at various settings of the sweep speed of the oscilloscope.

CRO swp. spd.	CRO intensity	PM voltage	P. A. GAIN	
			CH. 1	CH. 2
2	8.5	1150	22	22
3	8.5	1150	7	7
4	8.5	1050	6	6
5	8.5	950	0	0
6	8.5	750	0	0
7	5.8	750	0	0

Now adjust the zero positions of the X-Y recorder, the dc amplifier, and the reference mirror in the perceiver as follows. Place a sheet of linear graph paper (K & E 359-11L) on the recorder and align the paper with the two crosses at the bottom right-hand and left-hand corners of the bed. Move the PEN switch to ON, close the shorting microswitch at the Y input of the recorder, and by means of the X and Y zero controls bring the pen to the X and Y zero lines at the lower left-hand corner of the graph. Release the shorting switch and adjust the AMP. ZERO control of the AMPLIFIER to bring the pen back to the Y zero line. Put the pulse waveform on the oscilloscope screen by flipping the master pulse-rate switch to 60-cps and turning the detector phototube voltage to 2000 V. Looking at the waveform through the periscope, position the pulse along the baseline with the variable delay line so that the pulse is just to the right of the vertical

Fig. III-2. Approximate position of a pulse along the baseline with respect to the reticle of the periscope, at the start of a scan. At any instant the perceiver "sees" that part of the waveform covered by the vertical center line of the reticle.

center line of the reticle (Fig. III-2).

At any instant the Scope-O-Graph "looks at" that part of the waveform that is covered by the vertical center line of the reticle. Retract the viewing mirror (there is a detent at the RETRACT position) and switch the BALANCE SPEED SEL. to 1 K. Adjust the reference mirror (REF. MIRROR) to bring the pen to zero. Turn the REF. MIRROR adjusting knob counterclockwise to bring the pen downward. Slowly rotate the scan dial (clockwise) and the pen will trace out the waveform, although at this time the pen is not writing. Rotate the scan dial until the pen is at

the peak of the pulse and adjust the PEAK HEIGHT to bring the pen near the top of the graph. Bring the scan dial back to zero, recheck the zero setting of REF. MIRROR and cause the pen to draw the waveform by simultaneously pushing in the SCAN MODE knob and flipping the PEN switch to PEN.

When the scan dial has reached its limit and the pen has reached the edge of the graph, the scanning will automatically stop. Pull out the SCAN-MODE knob and lift the pen by throwing the PEN switch to ON. Manually scan back across the waveform, stopping at three or four points (including the peak) to be sure that the accelerator has not drifted during the tracing, and that the amplitude is the same now as it was at the beginning of the tracing. If the manually scanned check points coincide with those of the automatic scan, the trace may be considered a replica of the waveform on the oscilloscope. Put the PEN switch to ST'D BY, the BAL. SPEED SEL. to TEST, the RATE switch to EXT, and remove the detector phototube voltage.

Whenever other functions are not in use, always leave the following switches in the noted positions.

PEN: Set on ST'D BY.

BAL. SPEED SEL.: Set on TEST.

SCAN MODE: Set on OUT, MANUAL.

RATE: Set on EXT.

DETECTOR PMV SELECTORS: Set on MINIMUM (all

photomultiplier-voltage selectors turned counter-clockwise to the stop).

4. Calibration of the Time Base

In order to calibrate the time scale, draw a 1-kMc/sec sine wave on the graph by the following procedure. Remove the cable marked "From 1P28 to Top Helix" from the cathode-ray-tube terminal

labeled TOP HELIX INPUT at the back of the oscilloscope chassis. In its place connect the cable marked "From Sig. Gen. to Top Helix."

CAUTION. Use care in removing and installing these connectors to avoid breaking the glass-to-metal seal of the CRT terminal or bending the central pin. Only moderate finger pressure is necessary on the cable clamps.

Set up the UHF Signal Generator by turning the CW-PULSE 2 switch to EXT. MOD., adjusting the OUTPUT LEVEL to obtain a reading of 0.4-0.5 on the OUTPUT VOLTS meter, and switching the CW-PULSE 2 switch back to PULSE 2. Set the output voltage of the master pulser to 60 and the rate switch to 60 cps. Set the variable delay line to 8 and look at the oscilloscope screen via the periscope and viewing mirror. The output of the signal generator is a pulsed wave train. Adjust the variable delay line so that the approximate center of the train is seen and the amplitude appears constant. Transcribe the timing wave just as you did the pulse, except that the peak height should be set at 500 and the Y knob of the recorder should be adjusted to position the wave where it will least interfere with measurements on the pulse. Of course, the SWEEP SPEED and WIDTH settings must be the same for the timing wave as for the pulse.

When the timing wave has been drawn, set the PEN switch to ST'D BY, the BAL. SPEED SEL. to TEST, the RATE switch to EXT., OUTPUT VOLTS (master pulser) to 20, and the OUTPUT LEVEL of the signal generator against the counterclockwise stop. Also remove the signal-generator cable from the input to the cathode-ray tube and reinstall the cable from the phototube.

The 1-kMc/sec timing wave is always plotted with the FUNCTION switch at LIN. and at a PEAK HEIGHT of 500. It might be pointed out here that it is not necessary to plot a timing wave immediately after each pulse. One might run several pulses over a period of say 2 hr and then make one timing wave to suffice for all these. Alternatively,

at the end of the period one might put a timing wave on each graph. In this way the number of changes from the setup for plotting pulses to the setup for plotting timing waves is minimized and time is saved (as well as wear and tear on the connector to the cathode-ray tube). The stability of the system is such that any drift over a period of 3 hr or more is not resolvable on the timing-wave plot.

5. The Semilogarithmic Transcription

A semilogarithmic representation of the transcribed pulse-form will be obtained if the FUNCTION switch on the panel of the log converter is placed in the LOG position. In this mode of operation, the vertical deflection of the recorder pen (measured from the bottom of the chart) may be taken as being proportional to the logarithm of the output voltage from the restorer. With proper adjustment, an output voltage of 100 V from the restorer gives a full 10 in. of pen deflection.

The semilogarithmic transcription is customarily traced out on a sheet of 2-cycle semilogarithmic graph paper (K & E 359-62L or equivalent) having a ruled area 10 × 15 in., and with the vertical (logarithmic) scale labeled to cover the range 1-10-100. With this arrangement vertical scale readings from the graph paper (hereafter referred to as "chart readings") may be interpreted as output voltages from the restorer circuit and as proportional to the intensities of the scintillation light.

The above relations are not strictly valid for very small values of the variables concerned. Inasmuch as $\log y \rightarrow -\infty$ as $y \rightarrow 0$, it can be appreciated that the baseline (zero signal level) would be depressed an infinite distance below the chart if the log circuit possessed a truly logarithmic response. This situation, which would prove inconvenient even if physically realizable, has been evaded by designing the log circuit to have a linear response to inputs less than 2 V and a logarithmic response to higher input levels.

These features of the log circuit are of importance to the operator in several respects. First of all, since any portion of a trace lying below a chart reading of 2 in the lower decade is not actually transcribed in the desired semilogarithmic mode, the PEAK HEIGHT and other gain controls (such as BEAM INTENSITY, etc.) should be adjusted so as to yield a transcribed pulse whose peak lies near the top of the chart. Also, it is usually of little value to trace the trailing edge of a pulse beyond the point where the pen deflection drops below a chart reading of about 2, since not only does the response become nonlogarithmic but the sensitivity (incremental gain) becomes very high and gives rise to excessive vertical "jitter" of the pen.

The zeroing adjustments of the recorder, dc amplifier, and perceiver may be performed or rechecked with the FUNCTION switch in the LOG position as well as in the LIN. position, since the baseline should lie at the bottom of the chart in either mode of operation. However, when the recorder pen is near the bottom of the chart, the over-all sensitivity for vertical deflection is about 10 times as high in the LOG mode so that the adjustments to the dc amplifier and perceiver may appear to be correspondingly more critical and less stable.

6. Miscellaneous Comments on Operation of the Scope-O-Graph

The PERCEIVER cannot "see" the waveform on the oscilloscope screen when the viewing mirror is in the VIEW position. The retraction of this mirror is frequently overlooked.

If one tries to look at the waveform through the periscope and the BAL. SPEED SEL. is at a position other than TEST, the waveform will drift upward off the screen. Always place this switch at TEST when using the periscope.

Adjust the zero of the amplifier and the reference mirror at the beginning of each plot.

The 1-kMc/sec timing wave is resolvable only on the fastest sweep speeds, i.e., on speeds 2 and 3. Since the apparatus was designed for fast pulses, there is no provision for presenting a timing wave of lower frequency. However, calibrated delay cables may be inserted in series with the trigger pulse to the hot-top to mark longer time intervals. The bottom of the tee on the master pulser is the output to the hot-top.

When removing a scintillator, swing the plastic arm of the safety switch away from the light hood, unscrew the light hood as far as it will go, and lower the table by means of the spoked adjusting screw before rolling the unit out from under the snout.

When there is to be a long period between measurements, cover the detector phototube with the aluminum cover to keep dust from the glass.

D. Shutting Down the Accelerator

Turn the high-voltage dial to zero, but do not push the OFF button until the reading on the high-voltage meter drops to about 20 kV. Meanwhile, turn off:

HV and FIL. on DET. PM SUPPLY.

MASTER PULSER PWR.

ELECTRON GUN & MAGNET SUPPLY AC.

UHF SIGNAL GENERATOR PWR.

EG&G OSCILLOSCOPE PWR.

PWR. on all SOG chassis and recorder.

Push high-voltage OFF button. Turn HOT-TOP POWER
to zero and turn off toggle switch.

Turn ELECTRON-GUN FILAMENT to zero and turn off
toggle switch.

Turn off MAIN switch.

Cover recorder.

E. Brief Outline of Operating Procedure

1. Close the power switches on:
 - Electron-gun activation and magnet current supply.
 - Detector-photomultiplier supply (FIL.).
 - Master Pulser.
 - Oscilloscope.
 - Scanner.
 - Restorer.
 - Logarithmic converter.
2. Fill the cold trap (Sec. III A. 2).
3. Check the pressure in the vacuum system and record the pressure reading in the log book (Sec. III A. 3).
4. Activate the cathode of the electron gun (Sec. III A. 4). When the activation is completed, immediately:
5. Close the door of the hot-top cage and turn on the hot-top power (Sec. III A. 5).
6. Adjust the intensity of the electron gun to get a barely visible glow on the slit plate (Sec. III A. 6).
7. Turn on the high voltage and set to desired value (Sec. III A. 7).
8. Trigger the hot-top sweep by operating the master pulser and observe the glow where the electron bursts impinge on the phosphor screen of the snout (Sec. III A. 8).
9. Switch the selector of the power supply for the electron-gun activation and magnet to the magnet position. Focus the spot if necessary (Sec. III A. 8).
10. Steer the beam into the hole by mechanically adjusting the magnet. Then shut off the sweep until the sample and the detection system are ready. (Sec. III A. 8).
11. Place the sample on the probe box, roll the box into place, and screw down the light hood (Sec. III B. 1).

12. Close the curved safety switch, turn up the phototube voltage, and view the pulse on the oscilloscope. If there is no pulse on the oscilloscope, see the check list in Sec. III B. 2.
13. Adjust height and position of the pulse of the oscilloscope (Sec. III B. 3).
14. Check voltages of the power supply and logarithmic resistance string on the logarithmic converter (Sec. III C. 2).
15. Make zero adjustments on the X-Y recorder, restorer, and reference mirror (Sec. III C. 3).
16. Make appropriate adjustments to controls of the restorer, set the function switch of the logarithmic converter as desired, and plot the pulse.

IV. DETAILED DESCRIPTION

A. Electron Accelerator.

1. Gun and Accelerating Column.

The electron gun is a commercial assembly, a Du Mont type 5XP, which is obtained without being sealed into a complete cathode-ray tube and with the cathode in an unactivated state. The assembly as received consists of a base, cathode and heater, preaccelerator and focusing electrodes, and both sets of deflection plates. The glass envelope is extended only about $\frac{1}{4}$ in. beyond the X-deflection plates. This assembly is sealed onto a metal flange with Apiezon W vacuum sealing wax. The flange is then bolted to a mating flange at the top of the accelerator column, the vacuum seal being made by a rubber o-ring.

The electrical circuit for the gun is shown in Diagram 1. Electrical power for the heater is supplied by the circuit on the left in this figure. The voltage on the heater is variable and is controlled from a variable transformer on the main control panel. Isolation transformer T1, a large transformer located at the center-rear of the structure, combines the functions of stepping down the voltage and isolating the secondary circuit from laboratory ground. Its output insulating column extends upward through the floor of the isolating cage surrounding the hot-top. Transformer T2 prevents the leakage current in T1 from flowing to the cathode and thereby affecting its operating potential. The heater voltage is monitored by meter M, which is located in the hot-top but is visible to a person standing on the floor of the laboratory.

All grounds shown on this figure are made to the hot-top structure. This structure must be isolated from laboratory ground because the hot-top is at -70 kV with respect to laboratory ground when full operating voltages are applied.

Grid bias and focusing voltages for the gun are obtained from the network R_2 - R_7 , the voltage across this string being supplied by the -4 kV tap on the electron-gun power supply. The FOCUS and INTENSITY CONTROL potentiometers (R_5 and R_2) are two of the four electron-gun controls driven by electric motors operated from the electron-gun control panel or box. The four NE-2 neon lamps regulate the grid bias, and the capacitors C_1 and C_2 serve as filters for the grid and focusing voltages.

The positive gate or unblanking pulse from the sweep generator is applied to the grid via pin 3 of the gun. R_1 isolates this signal from the shunting effect of C_1 , and other circuit impedances.

Positioning voltages are obtained from the main hot-top power supply and the positioning controls are located on the chassis of that supply. Capacitors C_3 , C_4 , and C_5 bypass the deflection plates to protect them from the effects of spurious transient voltages; and resistors R_9 - R_{11} prevent such transients from getting into the power supply. Resistor R_{12} serves a similar function by keeping the signal coming in via capacitor C_6 from reaching the supply.

The distance from gun to slit plate (measured down along the column) is equal to the distance from gun to screen in the standard 5XP cathode-ray tube. This electrode is at the highest post-deflection potential of -20 kV. The two electrodes between the gun and the slit plate carry potentials of -6.6 and -13.3 kV. These three voltages also come from the 24-kV electron-gun power supply via the voltage-distributing column.

The slit over which the electron beam is swept consists of a pair of razor blades (of the "Injector" type) positioned over a $\frac{1}{4}$ -in. hole in the center of a metal plate and spaced by a pair of wires of 0.016 in. diameter projecting from the plate. Eight holes of $\frac{1}{2}$ -in. diameter near the outer edge of the plate allow the gun and the insulating column above this point to be pumped out from below. An area around the slit is coated with a P-11 phosphor so that either the swept or the undeflected beam may be "seen."

The sweep speed is such that the trace on the slit-plate screen can be seen only if there is very little ambient lighting. The intensity of the beam may be adjusted, however, so that an undeflected spot is visible; and the beam is positioned and focused with it as a guide. The undeflected beam rests on the side of the slit that is toward the front of the structure. When a voltage ramp from the sweep generator is applied to one of the Y plates the beam is swept across the slit toward the back of the structure.

The high voltage applied between the slit plate and ground from the 150-kV supply is divided into five equal steps between the plate and the lower end of the accelerator column by the use of a resistor string and four intermediate electrodes along the column. Ten 1000-M Ω resistors comprise the string, two resistors being connected in series between each pair of successive electrodes. The junction of each such pair of resistors is supported by the insulated voltage-dividing column. The bottom of the string is connected to ground, not directly but rather through a 0-50 μ A meter located on a panel to the right of the main control panel and labelled COLUMN CURRENT. This meter is useful for determining whether voltage is actually being applied to the column. It is shown schematically in Diagram 21.

The drift tube becomes the last electrode of the accelerating column and is at the laboratory ground potential.

2. Power Supply for Electron Gun

This unit supplies four voltages to the electron gun: -4 kV, +6.6 kV, +13.3 kV, and +20 kV. These voltages provide all the necessary accelerating and focusing potentials from the cathode to the slit. The gun supply consists of two parts. The transformers, rectifiers, and filters are contained in an oil-filled can. This is a commercial unit, the type-420 power supply manufactured by Tektronix, Inc. The primaries of the transformers are supplied by two audio oscillators. The oscillators and

regulator circuits are mounted on a separate chassis. The circuits are identical with those used in the Techtronix type-517 oscilloscope, but were built at this laboratory, since this section was not available separately from the oscilloscope.

The circuit of the gun supply is shown in Diagram 2. Components are designated by the same symbols as are used in the diagram of the type-517 oscilloscope. The high-voltage supply is a voltage quadrupler employing four type 1X2 rectifiers. A resistor string divides the voltage to provide +3.3 kV and +6.6 kV. A single 1X2 in a half-wave rectifier circuit provides -4 kV. All the components within the dashed rectangle are mounted in the oil-filled can. Tube V_{303} is the oscillator that provides ac at a frequency of 1.8 kc/sec to the primary of the high-voltage transformer T_{205} . The plate voltage of this tube is controlled by the dc amplifier consisting of tubes V_{302} , V_{301} , and V_{306} . This amplifier compares a fraction of the -4-kV output voltage with the negative 250 V supply. Any difference between these voltages is amplified and alters the plate voltage on V_{303} in such a manner as to eliminate the difference. In this way, the -4-kV output is regulated by comparison against the -250-V supply. Consequently, the remaining high voltages are regulated against disturbances that are common to both the positive supply and the -4-kV supply.

Tube V_{305} holds down the plate voltage of V_{303} by depressing the grids of V_{301} and V_{306} when the power is first turned on. As C_{315} is charged through R_{322} , the effect of this tube fades to zero, and the regulating circuit assumes its normal operating conditions. This action delays the application of the accelerating voltage to the electron gun, thus preventing "flare" when the instrument is turned on with the intensity control left at a normal setting.

Twin triode V_{304} is used as a phase-shift oscillator to provide audio-frequency power to the primary of T_{206} . The latter provides isolated filament power to the rectifier tubes.

3. Sweep Generator

The sweep generator is contained in a chassis located immediately behind the electron gun. Its purpose is to supply the positive gate pulse to unblank the gun and to supply the negative-voltage ramp to sweep the beam. The circuit is shown in Diagram 3.

The generator is triggered by a 20-V positive pulse derived from the master pulser (Sec. IV B. 4). This pulse is applied to the grid of V1 through diode D1. Tube V1 and associated circuitry comprise a monostable multivibrator. Positive feedback applied from dynode (5) to grid (3) produces a regenerative change of state when the input pulse overcomes the negative bias applied to the grid through R2. The tube returns again to the nonconducting state when C2 becomes charged through R2. Shortly after regeneration begins, the voltage on the grid exceeds the voltage of the pulse applied through P1, and the tube is disconnected from the input by the blocking of D1. This action enhances the regeneration since the feedback voltage through C2 needs only to drive the grid-circuit impedance and not the impedance of the pulse generator as well. The output pulse is applied to the grid of V2A by means of the pulse transformer T1. The latter serves to invert the pulse and to step up the voltage somewhat. The pulse is differentiated by C4R5 (which has a time constant of 0.135 msec) and also by T1.

Tube V2B is a blocking oscillator. The regeneration is provided by the coupling between plate (9) and grid (7) through transformer T2. The first half V2A drives the blocking oscillator by means of the common plate connection. The output pulse of the blocking oscillator is taken from another winding of T2. Added to this pulse is a portion of the driving pulse from the plate of V2A. This is coupled by means of T3 and serves to sharpen the rise of the pulse received from the blocking oscillator. The width of the pulse from the blocking oscillator is determined by the characteristics of T2, and is approximately 0.1 μ sec. The pulse fed to the grid

of V3 is an approximately square positive pulse with a width of $0.1 \mu\text{sec}$ and height of 100 V. This same pulse serves as the unblanking pulse and is fed to the grid of the electron gun through C8. The pulse drives the grid of V3 to approximately 0 V, causing this tube to draw a current determined mainly by the voltage on its screen grid (1). This is variable by means of a potentiometer located in the hot-top supply and is normally set at +250 V.

Between pulses, capacitor C_s is charged through R_s from a +1500-V supply. During the pulse this capacitor is discharged through the plate circuit of V3 to provide the sweep ramp that is fed to one of the Y-deflection plates of the gun via P3. The value of C_s is chosen for the sweep rate desired, and then R_s is selected so that $R_s C_s$ is about $200 \mu\text{sec}$ —long enough so that R_s may be considered infinite during the discharge of C_s but short enough so that the capacitor will be fully recharged in about one millisecond.

Capacitor C_s is removable so that different sweep rates may be used. It is mounted, together with its charging resistor R_s and a tubular connector for the plate of the tube, on a brass plate which is attached to the chassis with knurled nuts. Several such assemblies, with different values of C_s and R_s , are provided and are known as "sweep plates." The output waveforms are shown in Fig. V-1 (Sec. V C. 3).

The duration of the output pulse of the accelerator is determined by the sweep rate, the deflection factor of the electron gun (expressed as the voltage necessary to move the beam a unit distance on the slit plate), and the width of the slit. The fastest sweep plate provided uses $C_s = 200 \text{ pF}$. The sweep rate of this unit, as measured with a fast oscilloscope having a probe with an input capacitance of 8 pF , is 5 V/nsec . The deflection factor of a typical gun was measured to be 4.1 V/mm . The slit width as measured with an optical comparator is 0.38 mm . The voltage necessary to sweep the beam across the slit is $4.1 \text{ V/mm} \times 0.38 \text{ mm} = 1.55 \text{ V}$, and the pulse duration is $(1.55 \text{ V}) / (5 \text{ V/nsec}) = 0.31 \text{ nsec}$.

However, these values are computed on the assumption that the diameter of the beam is small compared with the width of the slit. Actually the diameter of the beam is 0.25 mm, an appreciable fraction of the slit width. This will cause the output pulse to rise and fall gradually and the widest portion of the pulse will be ~ 0.5 nsec.

4. Main Hot-Top Power Supply

This circuit (Diagram 4) supplies all ac and dc required by the hot-top circuits except the electron-gun filament. The 115-V ac input comes from a 150-kV isolation transformer having a winding ratio of 1:1 and located on the floor of the high-voltage cage at the right of the accelerator bench. This transformer is in turn fed via the HOT-TOP POWER switch and variable transformer on the main control panel.

The principal circuits are three regulated dc supplies having outputs of -250 V, 225 V, and 500 V. The -250-V output is the reference voltage for the 225-V and 500-V supplies. It is a conventional series-regulated supply with V1 serving as the series-connected regulator. A portion of the output is tapped off by R2 and the difference between this voltage and the reference voltage developed across V2 is applied between the grid and cathode of V3. The output of V3 then controls the series regulator V1. The 225-V and 500-V supplies function in a similar manner. Test points and adjustments for the four adjustable dc outputs are mounted on the rear apron of the chassis.

The output of the 500-V supply is observable by means of a meter located on a sloping panel at the lower front of the hot-top and visible from the front of the accelerator. Also on this panel is a meter indicating the voltage of one of the 6.3-V windings of transformer T3. This serves to indicate the correct input voltage to T1, T2, and T3.

From V5 is taken a filtered but unregulated output of +360 V for use in the gun supply and in the 1500-V rf supply. Positioning voltages

for the X and Y plates of the electron gun are obtained from R32, R33, R36, and R37, the voltages to these being derived from the 500-V and -250-V supplies. Voltage dividers R32 and R33 are driven by a single shaft which is rotated by a 1-rpm motor mounted on the rear of the cage structure. The same is true for R36 and R37. The motors are operated by switches on the electron-gun control panel or box.

All power taken from the chassis leaves via the power receptacle PS. Terminals of the receptacle are represented by circles coded according to the circuit they serve and numbered according to stampings on the receptacle. The coding and numbering are matched on the diagrams of the respective load circuits.

The 1500-V supply for the 4X150A sweep tube is mounted on the main supply chassis but is shown separately (Diagram 5). That portion of the circuit on the left of the diagram is another series regulator and provides operating voltage for the rf oscillator of the plug-in unit.

5. Power Supply for Activating the Electron Gun and Operating the Magnet

A single supply furnishes power for the electron gun when its cathode is being activated and then later for the electromagnet which focuses the electron bursts. However, the regulating requirements are different for the two functions. When powering the magnet the supply must furnish a constant current, whereas the cathode activation requires at first a constant voltage and later a limited current. A two-position switch directs the output of the supply to one or the other of the loads and also provides the proper combination of control circuits to satisfy the requirements of each load. Except for one voltage-regulating tube, all active components of the circuit are solid-state devices. In addition to the main power supply, the circuit comprises a direct-coupled amplifier and two auxiliary power supplies furnishing reference voltages (Diagram 6).

Since regulation of the current for the magnet is the simpler of the two, that mode will be considered first with the aid of block diagram 6A. A voltage from the current-control potentiometer is amplified and fed to the series regulating transistor allowing the transistor to pass a current I_L from the power supply, the load (magnet), and the sensing resistor R_s . The voltage E_s , developed across R_s as a result of the passage of current I_L , is connected to oppose the voltage E_c being applied to the amplifier from the control potentiometer. As the current I_L increases, the input to the amplifier decreases as a result of this bucking action of the voltages until there is only a small error signal at the input of the amplifier and voltage E_s is approximately equal to voltage E_c . As the current I_L tries to increase above this point, voltage E_s reduces the error signal, thus reducing the gain of the amplifier and causing the regulating transistor to decrease the flow of load current I_L until a balance is achieved.

This would be sufficient control of the current from the supply except that the output voltage of the supply is 150 V. Because of this, almost all of the normal 115-V ac input would be applied across the series regulating transistor and this would exceed the collector-emitter voltage rating of the transistor. As a means of keeping the output voltage within bounds, the input of the power supply is varied by a magnetic amplifier (saturable reactor) which is controlled by the collector-emitter voltage of the regulating transistor. The current i_c in the control winding of the magnetic amplifier flows through the Zener diode D_2 . If the collector-emitter voltage is smaller than the Zener voltage of diode D_2 , no current i_c flows through the control winding and the input voltage E_1 to the supply is maximum. However, as soon as the voltage across the transistor exceeds the Zener voltage of D_2 , a current i_c will flow and will cause the magnetic amplifier to reduce the voltage E_1 . Through this action a voltage of the order of the Zener voltage of D_2 is maintained across the series transistor.

The Zener diode D_1 protects the transistor against high-voltage transients. Its Zener voltage is somewhat higher than that of D_2 . If for any reason the collector voltage of the transistor rises to a value higher than the Zener voltage of D_2 , the base voltage of the transistor is brought up to collector voltage and the transistor becomes fully conducting. The current I_L becomes large enough so that almost all the voltage occurs across the load. Of course there is no current regulation in such a case.

The amplifier of the current regulator is mounted on a printed circuit board. Its circuit is shown in the upper left-hand corner of Diagram 6. A differential input stage is used to minimize temperature drift. A second, single-ended stage feeds the series regulating transistor Q_4 . The emitter connection of Q_4 may be considered as the ground or reference point.

A negative signal from the control potentiometer to the base of Q_2 increases the collector current so that the collector itself becomes less negative. This causes a reduction of base current in Q_3 and results in less collector current through Q_3 . Thus the voltage at the collector of Q_3 and hence at the base of Q_4 becomes more negative, and this increases the base current of Q_4 . Increasing the base current of Q_4 allows a greater collector current I_L to flow. Thus a negative input to the amplifier results in an increase of load current.

When the switch is turned to the ELECTRON GUN position, three things are accomplished: (1) the supply output is switched from the MAGNET terminals (rear apron) to the ELECTRON GUN terminals (front panel); (2) a voltage regulating circuit is inserted to control the output from the supply; and (3) the current regulator is modified to be current limiting rather than strictly regulating. Diagram 6B is a block diagram of this arrangement. The resistor R_L represents the cathode-anode resistance of the electron gun. To understand the regulation of voltage across R_L , first imagine that the series regulating transistor Q_4 and resistor R_s are shorted

and that the voltage-control potentiometer is set to produce a voltage E_{vc} to act as a bias on diode D_3 . Note that there is a second control winding on the magnetic amplifier. As long as the voltage across R_1 is lower than the bias E_{vc} on the diode D_3 , no current i_{c2} flows in the second control winding and the maximum ac voltage E_1 is applied to the power supply. The output of the supply thus increases and this output appears across R_1 . When the voltage across R_L becomes large enough to buck out E_{vc} , the bias on diode D_3 , a current i_{c2} will flow. This will cause the magnetic amplifier to reduce the ac input to the power supply until a balance is reached.

As the cathode of the electron gun becomes activated, the cathode-anode resistance R_L decreases. The voltage across it will be held constant as the resistance R_L decreases until the current through it (I_L) rises to the desired value. This upper limit of the current I_L is determined by the setting of the current-limit control and is limited in the following manner.

Until the current I_L reaches the limiting value, the voltage E_s across R_s is smaller than the voltage E_c from the control potentiometer. Therefore the series regulating transistor has been receiving enough base current from the amplifier to remain saturated; i.e., there has been no voltage between its emitter and collector. For this reason no current i_c has flowed in the first control winding of the magnetic amplifier and the power supply has been controlled entirely by the voltage regulating section and the second control winding of the magnetic amplifier. Now however, with the current I_L approaching its limiting value, the voltage E_s has reached such a value (relative to E_c) that the amplifier is made to decrease the base current of Q_4 and thus reduce current I_L . As a result, a voltage appears between the emitter and collector of Q_4 . As soon as this voltage exceeds the Zener voltage of D_2 , a current i_{c2} begins to flow. This tends to lower the input and hence the output voltage of the supply. Initially the

voltage regulator tries to oppose this change by reducing i_{c2} , only to cause a further increase in i_{c1} . Soon i_{c2} becomes zero but cannot reverse because of the presence of diode D_3 and the fact that in this region only the current limiter has control of the supply. The current will therefore remain at the desired value even if the output is short circuited.

B. The Detection System

1. The Probe and the Power Supply for the Photomultiplier

The light given off by the irradiated scintillator is picked up by an RCA-1P28 photomultiplier tube located in the light-tight probe box. This tube has an S-5 spectral response, the wavelength of maximum response being $3400 \pm 500 \text{ \AA}$.

The particular tube used here was chosen from a group of tubes of this type because it had a high gain and the smallest transit-time spreading, as evidenced by its production of the shortest electrical pulse when illuminated by scintillations from a given scintillator. The tube is operated and wired into the circuitry in such a manner as to enhance the response to high frequencies. To reduce the inductive effect of long lead wires, the base of the tube is removed, and the bypass capacitors are wired as close to the glass envelope as possible. The glass envelope is supported by being cemented^{*} to a hard-rubber plate.

With the voltages used, it was found that the use of all stages gave a higher gain than was necessary for study of the expected types of scintillating systems. Thus, to further reduce transit-time spreading, only six stages of electron multiplication are used.

Diagram 7 shows the phototube circuitry. Although a total of 2 kV is applied to the probe box, only 1540 V is applied across the tube. The remaining 460 V is lost across the resistors R_1 and R_2 used to protect the power supply in the event of a breakdown in the tube. There is

*The cement used was EC 801, Minnesota Mining & Manufacturing Co.

approximately 185 V across each of the first five stages, 230 V across the sixth stage, and 390 V between the sixth dynode and the seventh dynode (used as the collector).

A push-pull signal is sent directly to the deflection helices of the traveling-wave cathode-ray tube in the EG&G oscilloscope by taking a positive signal from dynode 6 through a blocking capacitor and a negative signal from dynode 7. There is no intermediate amplification.

The circuitry for the power supply for the detector photomultiplier is given in Diagram 8. The supply actually consists of two highly regulated power supplies. The upper unit in the diagram furnishes up to 3 kV but at a low current. The sole purpose of the lower unit is to furnish current for the operation of the voltage-reference tubes. Voltages across these tubes are used as references for the regulators of both supplies. Through the use of a 10-turn potentiometer and three selector switches, the output of the supply is variable from -500 to -3000 V.

2. Oscilloscope

The high-speed oscilloscope used here is a traveling-wave type 2236 manufactured by Edgerton, Germeshausen & Grier, Inc. Since no vertical amplification is provided, the frequency response of the instrument is limited only by the design of the vertical deflection system of the cathode-ray tube. Making the deflection plates in the form of helices rather than a solid plate gives this tube a response extending to 2 kMc/sec.

The specifications, operating instructions, and wiring diagrams for this oscilloscope are found in the manufacturer's manual. However, certain modifications have been made to adapt the instrument for use with the present systems for detection and readout.

The filters have been removed from the inputs and outputs of the deflection helices and the 125- Ω coaxial signal cables from the phototube are connected directly to the helix input pins on the cathode-ray tube.

Beam positioning in both vertical and horizontal directions is controlled by the "Scope-O-Graph" readout system, so all wires providing internal positioning voltages have been removed from the tube. Vertical positioning voltages are supplied by the restorer of the Scope-O-Graph and are applied through a 125- Ω coaxial cable to the output end of the helices. (The characteristic impedance of the helices is 120 Ω .) These cables are terminated at the restorer with 120- Ω resistors (Diagram 12). Of course, the terminations are not perfect, and some small reflections are sent back along the line. The cables are made long enough that the one-way transit time is about 25 nsec, so that the reflections do not interfere with the presentation of the original short pulse on the cathode-ray screen. Some interference is observed with long pulses, but the perturbations are usually small enough to be ignored.

Horizontal positioning voltages come from the "scanner" of the Scope-O-Graph via shielded cables and connectors added to the oscilloscope chassis.

Position No. 1 of the sweep-speed selector is an open position and is not normally used. Position 2 provides the fastest sweep, approximately 12.5 nsec/cm. Position 7 gives the slowest sweep, about 3300 nsec/cm. When the tube face is viewed through the periscope of the perceiver, a reticle is seen. The divisions of this reticle correspond very closely to 1-mm distances on the cathode-ray screen.

3. The UHF Signal Generator; Time Calibration

The UHF signal generator is used to provide a 1-kMc sine wave for time calibration of the oscilloscope sweep and of the Scope-O-Graph tracings. This too is a commercial unit, and the manufacturer's operating and servicing manual is available.

A modification was again necessary to adapt the generator for its intended use. The Scope-O-Graph can read only repetitive signals and the sine wave must appear on the cathode-ray tube as a steady, locked-in pattern. But the trigger circuit of the oscilloscope cannot synchronize with a sinusoidal signal of such a high frequency. The scheme used here is to have the generator shock excited by a pulse from the same source as the pulse that triggers the oscilloscope. The schematic diagram in the signal-generator manual shows how and where these pulses are fed into the oscillator circuit. A synchronized wave train of about 200 cycles of the 1-kMc/sec signal is thus obtained with each sweep of the oscilloscope.

Neither the eye nor the Scope-O-Graph can resolve the 1-kMc/sec sine wave unless the oscilloscope is on one of its two fastest sweep speeds, i.e., unless the sweep-speed selector is at position 2 or 3. The slower sweep speeds can be measured only roughly by insertion of coaxial cables of calibrated length into the trigger line running from the master pulser to the hot-top. The procedure used here is first to trace out the pulse with the Scope-O-Graph in the usual manner. Then disconnect the cable going to the hot-top from the tee at the master pulser and insert the calibrated delay cable. Retrace the leading edge of the pulse. The leading edges of the two traces will then be separated by an amount corresponding to the delay time of the cable. The cascading of several such cables will provide several time markers.

4. The Master Pulser; Pulse Distribution

The master pulser triggers the hot-top sweep circuit, the UHF signal generator, and the sweep circuit of the oscilloscope, and

thus synchronizes the oscilloscope with either the electron bursts from the accelerator or the output of the UHF signal generator. The output of the master pulser consists of repetitive pulses having a rise time of about 0.1 nsec, a duration of 300 nsec, a repetition rate of 60/sec, and an amplitude of up to 100 V. The design is based on that of Garwin.³ The output impedance is 50 Ω . The circuit is shown in Diagram 9.

The unit comprises a power supply, a variable attenuator, a pulse-forming coaxial cable, and a mercury-wetted switch. The forming cable, which is open-ended, becomes charged to a voltage V from the power supply. When this cable is switched into a matching load by the mercury-wetted switch, a pulse having an amplitude $V/2$ and a duration of twice the electrical length of the forming cable is discharged into the load.

The switch capsule used here is commercially available, a type 218A manufactured by the Western Electric Co.

The switch consists of a ferromagnetic reed and a pair of contacts mounted in a glass capsule filled to a pressure of several atmospheres with hydrogen. A pool of mercury keeps the contacts wetted. Mercury wetting of the contacts causes the mechanical break between them to be very "clean," i.e., there is no contact "bounce." The hydrogen filling prevents electrical sparking between the contacts as they separate.

The capsule forms the center conductor of a coaxial stub (the brass tube located on the front panel of the instrument) having a characteristic impedance of roughly 50 Ω . The pulse-forming cable connects to the top of the stub, the load to the bottom. Thus the generator is well matched to the load and the leading edge of the pulse is sharp, fast, and clean.

³ R. Garwin, Rev. Sci. Instr. 21, 903 (1950).

The switch is actuated by magnetic action of the reed. The coil surrounding the switch stub is fed 60 cps ac from a 6.3-V filament winding of the power transformer. The combination of coil and switch used here requires the use of "magnetic bias." This is provided by a horseshoe permanent magnet clamped to a handle fastened to the instrument panel, with the pole faces of the magnet against the coil and facing the center of the coaxial unit.

The switching arrangement at the output of the power supply allows the production of pulses of either polarity and of variable amplitude up to 100 V. Note that the voltage designations on the selector switch indicate the voltage amplitude of the pulse produced rather than the voltage fed to the forming cable. There is also provision for using a precision potentiometer to calibrate the voltage across the divider string.

In the application of the generator to the accelerator system, the pulse-forming cable is a length of RG 8/U which provides a pulse width of about 300 nsec, the polarity is positive, and the amplitude is set to 20 V when triggering the hot-top and to 60 V when exciting the signal generator. The output is divided by the tee shown in Diagram 9A. The division is such that a pulse of $\frac{5}{6}$ V appears at output 1 (bottom) and a pulse of $\frac{1}{6}$ V at output 2 (side-arm) while preserving the 50 Ω impedance.

Output 2 triggers the oscilloscope after passing through a delay line which is variable over a range of 1.5 μ sec. The variable delay line provides convenient control over the time between the start of the sweep of the oscilloscope and the arrival of the pulse from the phototube, i.e., it allows positioning of the scintillation pulse along the base line of the oscilloscope.

Output 1 is fed to the hot-top sweep circuit and to the UHF oscillator. The triggering requirements of these two circuits differ in that the sweep circuit must be triggered by a positive pulse, whereas the oscillator can be shock-excited only by a negative pulse of rather large amplitude. To avoid interchanging cables when one or the other of these circuits is to be triggered, a pulse inverter is used. This unit was originally supplied with the EG&G oscilloscope to transform a single-ended input signal into a push-pull output. The inverter has a single 50- Ω input and two 120- Ω outputs, one having the same polarity as the input, the other being of opposite polarity. Therefore a 50 Ω cable connects the bottom of the tee (output 1) to the pulse inverter, which is located just behind the UHF signal generator. The negative output of the inverter connects to the oscillator input of the UHF signal generator, where it is terminated with a 120- Ω resistor.

A special high-voltage coaxial capacitor transmits the positive pulse from the inverter at ground potential up to the hot-top sweep circuit, which is 70-90 kV negative with respect to ground. The center conductor and dielectric of this capacitor are the remains of a 4-ft length of RG17 coaxial cable from which the vinyl jacket, the braided outer conductor, and a portion of the center conductor have been removed so that the dielectric projects considerably beyond the end of the conductor to ensure adequate high-voltage insulation. The outer conductor is a brass sleeve 10-in. long in the hot-top assembly.

The lower portion of the dielectric-covered center conductor is contained in one of the Lucite rods that support the hot-top assembly above the floor of the cage. This support rod, located directly behind the accelerating column, has been bored axially throughout its entire length. The bottom end of the center conductor attaches to a coaxial connector mounted on the support

rod near its lower end. The bottom end of the bore in this Lucite rod has been threaded to accept a cap screw inserted upward through the floor of the cage. In addition to securing the lower end of the support rod, this specially-made cap screw supports and grounds the lower end of a $\frac{1}{2}$ -W carbon resistor which terminates the coaxial cable extending from the positive output of the pulse inverter to the above-mentioned connector near the bottom of the support rod. The screw has a spring-loaded insert which ensures electrical contact between the upper end of the resistor and the junction of the connector with the center conductor of the coaxial capacitor. This cap screw can easily be removed for checking or changing the terminating resistor.

The dielectric-covered center conductor extends on upward through the hot-top assembly, where a brass sleeve 10 in. long is slipped over the dielectric to serve as the outer electrode of the high-voltage coaxial capacitor. This sleeve connects to the input of the hot-top sweep circuit. The effective capacitance of the coaxial unit is approximately 27 pF. The dielectric extends upward through the top plate of the hot-top assembly and several inches beyond the upper end of the center conductor as protection against arcing between the hot-top and this conductor.

It is seen then, that whenever the master-pulser reed is vibrating, all three units (the oscilloscope, the signal generator, and the hot-top) are being pulsed. However, when the hot-top is being used, the OUTPUT LEVEL of the signal generator is turned to zero; and, when the signal generator is being used, the detector phototube voltage is at zero. Also, different amounts of delay in the trigger line to the oscilloscope are necessary to properly display the signal from one or the other of the units. To display the scintillation pulse, a delay of about 150 nsec is

required; but there is a delay of about 700 nsec before the signal generator is excited. Thus even though both units are being pulsed, neither interferes with the display of the other on the oscilloscope.

The reed, and therefore the pulses, is turned off and on by the RATE switch.

C. The Scope-O-Graph

This method for transcribing oscillograms was described in Argonne National Laboratory Report ANL-5985.¹ The following paragraphs discuss conventional circuitry (photomultipliers power supply etc.), the commercial instruments used, and an accessory (the logarithmic converter), all of which were omitted from the above report. It is recommended therefore that the reader study that report before continuing this discourse. Minor discrepancies may be noted between wiring diagrams found in the report and those of this handbook. Though important from a maintenance standpoint, the changes made in the circuitry will not interfere with the reader's understanding of the system. The diagrams of this handbook are the up-to-date version.

1. Perceiver, Restorer, Scanner

Diagram 10 is the circuit of a cathode-follower circuit for the photomultiplier. Two such circuits (channel 1 and channel 2) are in the perceiver. Power for the cathode followers comes from one of the voltage-divider strings of the pulse amplifier through the connector shown at the right of the diagram. This connector is common to both 6AK5 circuits. The purpose of the cathode followers is to transform the high-impedance output of

the photomultipliers to a lower impedance suitable for transmission over fairly long cables to the pulse amplifiers of the restorer.

The photomultiplier wiring is conventional, and again the high voltage for both tubes comes through a single cable. Tubes having nearly equal gains are used here. Extremely close matching is not necessary.

The circuits for the pulse amplifiers and dc amplifier of the restorer are shown in Diagrams 11 and 12, respectively, and the scanner is shown in Diagram 13. Power supplies for all Scope-O-Graph circuits including the logarithmic converter discussed in the next section, but excluding the high-voltage supply for the photomultiplier tubes, are covered by Diagrams 14-18.

2. Logarithmic Converter

The logarithmic converter produces a voltage which is (approximately) proportional to the logarithm of the restoring voltage developed at the output of the dc amplifier in the restorer and therefore (approximately) a linear function of the logarithm of the deflection "seen" by the perceiver as it scans the waveform displayed on the oscilloscope.

The circuit of the converter, shown in Diagram 19, may be broken down into three circuits. (1) The network of diodes and resistors, comprising the upper half of the diagram, is the log circuit. The conversion is accomplished here. (2) The resistor string connecting the poles of a 24-position switch is the log-test string and is used for alignment of the log circuit. (3) The attenuators at the lower right provide suitable voltages for operating the XY recorder.

The log circuit may be thought of as a series of cascaded voltage dividers, in which biased diodes are incorporated.

The first such divider consists of R_{37} , R_{38} , D_1 , and R_{26} . The voltage from the dc amplifier (restorer) is applied across this string, and the output is taken across D_1 and R_{26} in series. Because of the current flowing through R_{49} , R_{60} , and R_{26} , the diode is blocked by the voltage developed across R_{26} . The resistance of the diode under these conditions is about $10^8 \Omega$, so that the gain of this attenuator is very nearly unity (if the effects of later attenuators are neglected). Each succeeding diode is blocked by a larger bias than the proceeding one. Therefore, when the input voltage is small, the gain of the entire circuit is unity. When the input voltage reaches a value equal to the bias on the first diode, that diode will begin to conduct, and the incremental gain of the network will decrease to a new value. The output will still be a linear function of the input but the slope will be less than unity. As each successive diode cuts in, the incremental gain will change, so that the output follows the input at a slower and slower rate. This behavior is similar to a logarithmic relationship, and by proper adjustment of the bias resistances (circled, even numbered) and the attenuator resistances (circles, odd numbered) the circuit can be made to follow a logarithmic response curve rather closely. It has the additional feature that the output goes to zero when the input goes to zero, so that one may observe the baseline without changing the circuit conditions.

On Fig. IV-1 are plotted portions of the two equations

$$u = y \quad (1)$$

and

$$u = k \log_{10} y, \quad (2)$$

where y is the input voltage to the log circuit, u is the output voltage of the log circuit, and $k = 0.9625/\log_{10} \sqrt{2} = 6.3947 \text{ V}$.

Fig. IV-1. A portion of the designed response of the logarithmic converter plotted along with an idealized logarithmic curve.

Equation (1) describes the initial linear response of the log circuit, i.e., it describes the response of the log circuit at low input voltages. Equation (2) is an idealized logarithmic function chosen for this circuit. It has the property (as do all logarithmic functions) that a series of y values in which successive terms differ by a constant factor (geometric progression) leads to a corresponding series of u values differing by equal increments (arithmetic progression). In this particular case, whenever y increases by a factor of $\sqrt{2}$, u increases by 0.9625 V . One reason for choosing this equation is that although it intersects the line $u = y$, it is nearly tangent to it. (Another reason is that the desired range of y is about 130 V , a reasonable value to be required from the dc amplifier preceding the logarithmic converter.) The job of the log circuit is to break the line $u = y$ at a point where y exceeds $k \log_{10} y$ by a small

percentage, and to produce a new function which is again tangent to Eq. (2). In turn this new line is broken when it begins to stray above the log function. Several such breaks and readjustments of slopes produce a curve of straight-line segments which closely follow the log function.

In order to have the output at zero when the input is zero, the response of the circuit is allowed to remain linear at low input voltages. As can be seen from Fig. IV-1, the linear function joins the logarithmic function at an input of about 2.25 V. (Information contained in inputs below this voltage was considered to be not essential to the work for which the equipment was designed.) At the point indicated by the vertical arrow No. 2, the straight line is about 1% above the logarithmic curve. This corresponds to an input of 3.500 V. The first diode begins to conduct here and adds a constant (determined by the setting of R_{37}) to the right-hand side of Eq. (1) and decreases the slope of the line. By proper adjustment of this resistance, the slope of the line can be made equal to that of the logarithmic curve so that the line crosses the curve twice and again becomes 1% high at arrow No. 4 where the second diode begins to conduct.

This process is repeated with each successive diode. In Fig. IV-1, the numbered vertical lines indicate test points at which the output and input will be tested for conformity. Line No. 1 is at the point of maximum separation of the straight line and the curve. The circuit values determining its location are fixed. Line No. 2 and the other remaining lines are separated by factors of $2^{1/4}$ on the y scale and by increments of 0.48125 V on the u scale. The even-numbered lines indicate the voltages at which a diode cuts in. These voltages are adjustable by the resistances (Diagram 19) having the same numbers as the lines on the figure. The odd-numbered lines indicate the points that are determined by the slope of the straight-line segment. These points are adjusted by the attenuator resistances of the log circuit.

Table B lists the numerical values of the voltages and resistances in the logarithmic converter, according to Eq. (2), at the 23 test points. Column 2 gives the value of y (input voltage). Columns 3 and 4 will be discussed later. Column 7 gives the actual diode bias decided upon. Column 8 is the contact-potential bias of the individual diodes, obtained by extrapolating the curve of I vs V to $I = 0$.

The output of the log circuit is sent to the recorder by way of the attenuator R_{74} - R_{78} , which reduces the signal by a factor of 1350. When switch S is in position No. 1, the signal from the amplifier bypasses the logarithmic circuit and goes directly to the above attenuator through an additional 1:8 attenuator R_{71} , R_{73} . The additional attenuation is provided so that the same oscilloscope deflection will produce a full-scale signal on either the linear or the logarithmic scale.

Capacitors C_1 and C_2 together with resistors R_{74} and R_{75} reduce the amount of 60-cps ripple between the signal and ground.

The logarithmic-test string, together with the power supply and meter M_1 , comprise a calibrated voltage divider which generates the sequence of voltages y_n of Table B. Columns 3 and 4 of that table show the voltages and resistances between adjacent test points. The voltage across R_2 is brought out to special terminals to which an external measuring potentiometer may be connected for calibration purposes. Variable resistor R_{25} is used to make the necessary adjustment during calibration.

When S_1 is in position No. 3 (TEST), the potential developed by the logarithmic-test string is bucked against the input to the log circuit. The latter may be produced by an artificial signal delivered to the integrating condenser in the restorer. By

TABLE B. Numerical values of the voltages in the logarithmic converter at the 23 test points. Column 1 is the number of a test point. Even numbers designate points at which a diode cuts in. Column 2 is the input voltage. Column 3 is the voltage between adjacent test points and Column 4 is the corresponding value of the resistance. Column 5 is the output voltage. Column 7 is the diode bias decided upon for the particular test point.

1	2	3	4	5	6	7	8
n	y_n (V)	$y_n - y_{n-1}$ (V)	R_n (Ω)	u_n (V)	Diode	Total diode bias (V)	Contact potential (V)
1	2.750	2.750	2595	2.807			
2	3.500	0.750	708	3.479	D 1	3.500	0.54
3	4.162	0.662	625	3.960			
4	4.950	0.788	744	4.442	D 2	4.462	0.55
5	5.886	0.936	883	4.923			
6	7.000	1.114	1051	5.404	D 3	5.425	0.55
7	8.324	1.324	1250	5.885			
8	9.900	1.576	1487	6.367	D 4	6.387	0.55
9	11.772	1.872	1767	6.848			
10	14.000	2.228	2103	7.329	D 5	7.350	0.55
11	16.649	2.649	2500	7.810			
12	19.799	3.150	2973	8.292	D 6	8.312	0.56
13	23.545	3.746	3535	8.773			
14	28.000	4.455	4205	9.254	D 7	9.275	0.56
15	33.298	5.298	5000	9.735			
16	39.598	6.300	5946	10.217	D 8	10.237	0.56
17	47.090	7.492	7071	10.698			
18	56.000	8.910	8409	11.179	D 9	11.200	0.56
19	66.596	10.596	10 000	11.660			
20	79.196	12.600	11 890	12.142	D 10	12.162	0.56
21	94.180	14.984	14 140	12.623			
22	112.000	17.820	16 820	13.104	D 11	13.125	0.57
23	133.191	21.191	20 000	13.585			

adjusting the input to the log circuit to give $u = 0$, the input voltage is made equal to the test voltage y_n . When going from one test point to the next, y is multiplied by the factor $2^{1/4}$ so that u should increase by 0.48125 V. In other words, when the input goes through the sequence of voltages y_n given in column 2 of Table B, the output must go through the corresponding voltages u_n given in column 5.

Another requirement of the log circuit is that the output must drive the recorder across one decade on the graph paper when y goes through exactly one decade. From Eq. (1) it follows that when Δy is one decade, $\Delta u = k = 6.3947$ V. Then for two-cycle paper, u must range from 0 at the bottom to 12.7894 V at the top. From Table B one sees that the top of the paper comes between the 21st and 22nd test point. The circuit constants are exactly matched with the paper when the 21st test point is at 96 on the graph paper. Details of the procedure for calibration are given in Sec. V.

3. The Photomultiplier Supply and the X-Y Recorder

The power supply that furnishes the high voltage for the photomultiplier tubes in the perceiver is a commercial unit, Model RE-1603 manufactured by Northeast Scientific Corp. It is used here in a straightforward manner without modification. Small (1/4 in. diameter) coaxial cable carries the output of the supply to the perceiver.

The X-Y recorder is a Model 225 manufactured by Electro Instruments, Inc. The X input is connected to the scanner via a two-conductor shielded cable. A similar cable connects the Y input to the logarithmic converter. In both cases the shields interconnect only chassis grounds and not circuit grounds.

D. High Voltage and Control

1. High-Voltage Power Supply

The high-voltage power supply is a commercial unit, a Model 37H45 built by the NJE Corporation. It is contained in an oil-filled tank and controlled from the main control panel. The manufacturer's manual describes both this high-voltage section and also a control section which is customarily provided with the supply. Since the control section is not used here, that part of the manufacturer's manual may be ignored. The only modifications to the high-voltage section are in the values of the limiting resistors at the output. The modified unit is shown schematically in Diagram 20.

The circuit is a conventional full-wave voltage doubler capable of an output of 150 kV at 5 mA. A separate transformer T_3 is used for the filaments of the rectifier tubes so that they may be warmed up before the high voltage is applied. A shorting relay grounds the output of the supply through a 150-M Ω resistance each time the high-voltage is turned off. This serves to discharge the filter capacitors.

The output is transmitted to the slit plate of the accelerator column by a 76-ft length of RG 17/U coaxial cable. Most of this length is coiled on a shelf at the top of the high-voltage cage. The capacitance of the cable is used as a filter. The long time constant provided by it in combination with the 10^{10} - Ω load resistance serves to smooth the output voltage.

2. Main Control Panel

From the main control panel the operator controls (1) the high-voltage power supply, (2) the input power to the hot-top,

and (3) the voltage to the filament of the electron gun. Meters on this and on an auxiliary panel indicate the voltage and current outputs of the high-voltage supply. The circuit is shown in Diagram 21.

The 115-V ac line is connected to the main control panel through the magnetic contactor and a Sola voltage-regulating transformer, both of which are shown in Diagram 22.

Unregulated 115 V ac is taken from the input to the magnetic contactor and applied to the MAIN switch of the control panel through terminals A and B of the terminal block mounted on the back of the panel. Closing the main switch activates the magnetic contactor and 115 V ac is applied to terminals G and H through the Sola unit. This turns on the filaments of the rectifiers of the high-voltage supply through terminals I and J as well as the white panel light. It also sends power to the input of the ELECTRON-GUN FILAMENT switch. Closing the ELECTRON-GUN FILAMENT switch applies power to the variable transformer and then to the isolation transformer (TI of Diagram 1) from which the filament receives its power. However, in series with the input to this isolation transformer is a switch controlled by the ion-gauge control unit (see Sec. IV E. 2 and Diagram 25), so that power cannot be applied to the filament unless a satisfactory vacuum exists in the accelerator tube.

The HOT-TOP POWER switch is fed on one side directly from terminal G and on the other side from terminal D through the hot-top interlock (Diagram 23). This interlock consists of a receptacle mounted on the bottom edge of the opening of the hot-top cage and a shorted plug mounted on the cage door. Thus the door must be fully closed before the hot-top power can be turned on. Closing the HOT-TOP POWER switch activates the green panel light, the HOT-TOP POWER variable transformer

and, through terminals T and V, a blower which cools the hot-top sweep circuit. Voltage from the variable transformer is fed to the hot-top circuitry through terminals R and S and through the isolation transformer mounted in the high-voltage-supply cage.

The switching arrangement for the high-voltage control is complicated by the interlocking arrangement. Note the double-pole switch made up of the contacts of relay II. Up to this switch, power is from the same source as that for the hot-top power switch (i. e. , through the hot-top interlock) so that the door of the hot-top cage must be closed before power is available to the switch. One end of the relay coil is connected to the "common" input. In series with the relay coil are 5 switches, all of which must be closed before the relay can actuate. (1) A switch controlled by the shaft of the HIGH-VOLTAGE variable transformer requires that the transformer be at zero. (2) Terminals N and O connect to an interlock switch located on the left jamb of the door of the high-voltage cage so the door must be fastened in place. (3) Terminals P and Q connect to the diffusion-pump relay (Diagram 26). The diffusion-pump relay is in turn controlled by the ion-gauge circuit in such a way that the diffusion pump relay is closed (and hence terminals P and Q shorted) only when the pressure in the accelerator column is less than 10^{-4} torr. This safety switch may be bypassed by the VACUUM INTERLOCK toggle, but in normal operation the latter is left open. (4) Relay I must be de-energized so that its contacts are closed. The function of this relay will be described later. (5) Finally the H. V. START button must be pushed. Once relay II is energized it becomes self-holding through the H. V. STOP button. Pushing the H. V. STOP button or opening any of the interlocks mentioned above de-energizes relay II, and thereby turns off the high voltage and grounds the output of the power supply.

The magnitude of the high voltage is indicated by a 0-20 μA meter. This meter is in series with, and at the grounded end of a 10^{10} - Ω resistor connected to the voltage output of the supply. The resistor is located in the high-voltage tank. The current through the resistor is 1 μA for every 10 kV across it. However, the meter has a scale indicating kilovolts rather than microamperes.

The components shown in the upper left-hand corner of Diagram 21 are mounted on a separate auxiliary panel located to the right of the main control panel. The COLUMN CURRENT meter is connected in series with the ground return of the string of resistors that distributes the high voltage across the accelerating electrodes. Since the total resistance of this string is 10^{10} Ω , the current through it will be 1 μA for each 10 kV of applied voltage.*

Also shown in the upper left-hand portion of Diagram 21 are the H. V. SUPPLY CURRENT meter and a SENSITROL overload relay which are connected in series with the rectifier circuit of the high-voltage power supply. The meter, in conjunction with its shunts, gives a reading equal to the total current drain on the supply—including column current, current required by the voltage-indicating circuit, leakage in the transmission cable, and losses due to corona. The overload relay is adjusted by means of a shunt so that it trips if and when the total supply current reaches 5 mA. Tripping the relay turns off the high voltage by causing relay I to become energized and break the circuit through the coil of relay II. When the cause of overload is remedied, the overload relay can be reset by momentarily closing the RESET switch.

* The 50- μA meter has too large a range for this particular application. It was originally installed when a different type of accelerating column was being tried. That column had a much lower resistance than the currently used resistor string.

E. The Vacuum System

1. Vacuum System Proper

The vacuum system comprises the accelerator column and drift tube, a cold trap, a set of water-cooled baffle plates, a 2-in. oil diffusion pump (water cooled) and a mechanical roughing and backing pump.

The cold trap and pumping system are at the back of the structure. A crossover tube connects the drift tube to the cold trap. There are three diaphragm-type valves in the pumping system: the foreline valve at the discharge arm of the diffusion pump, an air-inlet valve near the bottom of the vertical length of the foreline, and a pump valve just below the inlet valve. The arrangement of the latter two valves facilitates the use of a mass-spectrometer leak detector, which can be connected to the air inlet. A fourth valve, a $\frac{1}{8}$ -in. unit, is found in the top of the crossover tube just behind the drift tube. This valve allows the system to be filled with dry nitrogen instead of air when the system is to be brought to atmospheric pressure.*

The glass insulators of the accelerator column are sealed to the metal electrodes with polyvinyl acetate and with vacuum wax. Because of this and the use of rubber O rings, the system must be pumped continuously. During pumping, cold tap water flows through the baffle unit through valves that are provided to shut off the flow through this unit as well as the diffusion pump

*

It is thought that the absorption of oxygen and water vapor by the walls of the system shortens the life of the cathode of the electron gun. Also, since this valve is on the high-vacuum side of the diffusion pump, oil vapors are not carried throughout the system when air is admitted.

when the system is brought to atmospheric pressure. The cold trap is kept at a low temperature through the use of liquid N_2 dispensed by the automatic filling system discussed in Sec. IV E.4. The normal operating pressure in this dynamic system is from 4×10^{-5} to 8×10^{-7} torr.

2. Vacuum Gauges

Three electronic gauges are provided for measuring the pressure in the system. A thermocouple gauge, connected into the crossover tube at a point just behind the drift tube, measures pressure in the main system down to about 10^{-3} torr. A second thermocouple gauge, mounted on the foreline valve, can be used to measure pressure in the foreline.

Both thermocouple gauges are connected electrically to the same control circuit.(Diagram 24). Their filaments are connected in series, and the filament current is indicated on the 0-1.0 A meter. This current is adjustable (to meet the specifications of either gauge) by means of the small knob just to the right of the meter. By means of the selector switch, the output current of either thermocouple gauge can be read on the 0-200 μA meter.

An ionization gauge is also provided to measure lower pressures in the main part of the system. This is a VG-1A ion manometer tube connected to a modified ANL Model 17B control circuit. The combination provides for measuring pressures in the range from 10^{-3} to 10^{-7} torr. The control circuit is shown in Diagram 25. The functioning of this control circuit will be discussed briefly.

That portion of the circuit in the lower left-hand corner of the diagram (T3, T4, V4, V5, and V6) regulates the

filament voltage supplied to the ion gauge in order to maintain a constant 5-mA emission current (grid current). Tubes V7 and V8 and the 0-100 μ A meter comprise an electrometer circuit which indicates the positive-ion current collected at the plate of the ion gauge. The latter current, which consists of the ions formed when electrons flowing from filament to grid collide with gas molecules, is a measure of the gas pressure in the system. The approximate relationship between these quantities is indicated in Table C.

TABLE C. Conversion of the reading on the plate-current meter of the ion gauge to pressure in torr (mm Hg).

Setting of range switch	Pressure for full-scale reading (torr)
100	10^{-3}
30	3×10^{-4}
10	10^{-4}
3	3×10^{-5}
1	10^{-5}
0.3	3×10^{-6}
0.1	10^{-6}

In order to protect the meter and the ionization gauge from possible damage in the event of an abrupt rise of pressure in the system, the circuit involving V9 and the associated relay shown in the upper right-hand corner of the diagram is included. This serves to remove filament voltage from the gauge whenever the 0-100 μ A meter exceeds a full-scale reading, provided that the START-SAFETY switch is in the SAFETY position. At the same

time, it energizes auxiliary relay KL17APB which turns off the diffusion pump and removes the heater voltage from the electron gun of the accelerator column. As will be explained in the following section on Diffusion-Pump Control, the high voltage is also removed from the accelerator column under these circumstances. These are important protective measures against the consequences of the sudden development of a leak in the vacuum system.

When the system is being pumped down from a pressure greater than 10^{-3} torr, the START-SAFETY toggle switch may be placed in the START position so that the diffusion pump can be turned on. After the pressure has dropped below 10^{-3} torr, and it is desired to operate the ionization gauge, this switch should be returned to SAFETY.

For the purpose of degassing the ionization gauge, its grid can be heated by a current delivered via transformer T2. The ac input to the ion-gauge control circuit is left on continuously.

3. Diffusion Pump Control

The relay which is the heart of this circuit has two stable states. A dual-winding electromagnet throws the set of switches to one position or the other, where they will remain without any further current being drawn by the windings. Diagram 26 shows this relay in the "off" or STOP position. The contacts control not only the current to the heater of the diffusion pump but also the high voltage to the accelerator and the diffusion-pump alarm circuit. In turn, the relay coil is controlled by the ionization-gauge circuit as well as by the START and STOP push buttons.

Momentarily pushing the START button applies 115 V ac to the coil winding. This moves the contacts downward (ON position)

and brings about the following conditions. Switch 1 breaks the circuit to the "on" winding of the coil so that continuing to hold the START button has no effect. Switch 2 "arms" the STOP circuit. Switch 3 actuates the alarm circuit which will be discussed later. Switches 4 and 5 apply 115 V ac to the variable transformer which in turn feeds the diffusion-pump heater.* Switch 6 shorts across terminals P and Q of the main control panel so that the high voltage may be applied to the accelerator.

The "off" winding of the relay magnet may be energized by the STOP switch or by the contacts of the relay in the ionization-gauge circuit when that unit is deactivated.

Note the safety circuit energized by switch 4. It includes a variable transformer, a high-voltage transformer, a spark plug, and a relay. This is part of the original design but has not proved dependable in practice. Though the circuit is intact, it is usually left unactivated (by leaving the VACUUM SAFETY switch open).

If the main relay is shifted to the STOP position by action of the ionization-gauge control circuit at a time when the accelerator is in operation, the operator is immediately aware of it because of the loss of high voltage, etc. However, if this happens at a time when the machine is not in operation, many hours or days might pass before the condition would be noticed. The purpose of the alarm circuit is to call attention to the shutdown of the diffusion pump, but only during normal working hours.

For the moment assume that all switches at the input of the bell transformer are closed. If the diffusion-pump relay is "on," switch 3 will be closed so that it shorts out the winding of the

* The normal voltage on the pump heater is 100 V.

buzzer. The output of the transformer is now absorbed by the #82 lamp. When the pump relay moves to "off" and switch 3 is opened, the buzzer winding is energized.

A time switch is in the input to the transformer and is set so that it is closed only during the hours of 8:30 AM to 5:30 PM Monday through Friday. A separate power switch can be used to disable the alarm when the system is being shut down intentionally.

The components of the alarm circuit are mounted on a hardboard panel on the left-hand end of the structure. This panel becomes a sounding board so that operation of the buzzer produces a loud raucous noise.

4. Automatic Filling System for the Cold Trap

The capacity of the cold trap for liquid nitrogen is such that it needs to be refilled only once every 24 hr. This can be done by hand during the week, but an automatic system was needed to do the filling over the weekends.

A 15-liter Dewar is used as the storage tank, and the liquid is pumped from this to the trap by pressurizing the Dewar with nitrogen gas. A time switch initiates the filling cycle and a carbon resistor senses the "full" condition and terminates the cycle.

The control circuit is shown in Diagram 27. Ideally the time switch should provide only an impulse to start the cycle and once this is done, have no other effect on the continuity or termination of the cycle. The usual commercial timer, however, cannot be adjusted to remain "on" for a period less than about 15 min. This drawback is overcome here by teaming the timer with a relay having a time delay of 3 sec.

Consider the first 3 sec of operation. The ac power switch is on continuously. When the timer switch closes, relay RL 2 is energized through the normally-closed contacts of RL 1. This activates the solenoid valve so that the nitrogen gas pressurizes the Dewar. It also activates the sensing circuit by sending power to the transformer. The output of the transformer is rectified, filtered, and regulated at 15 V. With the sensing resistor R4 at room temperature, the collector current I_c of the transistor TR will be between 0.25 and 3.0 mA, depending on the setting of the sensitivity control R3. The pull-in current of RL3 is 1.6-1.8 mA. Hence R3 is adjusted to make $I_c \approx 2$ mA. Relay R3 now becomes energized and closes the "latching" contacts.

Three seconds after the time switch closes, the time-delay relay RL 1 activates and opens the contacts which allowed RL2 to be energized. However, RL2 is "latched" by the contacts of RL3 and the system continues to fill the trap.

The sensing resistor R4 is located inside and near the bottom of a polyethylene funnel which is in the filling opening of the cold trap. After the trap is completely filled, the level of liquid nitrogen will rise up into the funnel and immerse R4. About 1 sec after immersion, the resistance of R4 increases abruptly so that the base current I_b of the transistor is reduced and hence I_c falls to about 0.5 mA. Since the drop-out current of RL3 is about 1.2 mA, this relay de-energizes and the latching contacts open. Relay RL2 now opens and deactivates the gas-pressure solenoid and the sensing circuit.

The entire filling operation has taken about 1 min and, since the "on" time of the time switch is 1 hr., that switch is still closed. However, relay RL1 is still holding its contacts open and will continue to do so until the time switch opens and

allows the thermal unit of RL1 to cool. At that time the circuit will be rearmed and ready for the next filling operation called for by the setting of the timer.

Resistor R_2 limits I_B to a safe value in case the sensor leads are accidentally shorted. Diode D3 short circuits the inductive high-voltage surge of the relay coil, which might otherwise damage the transistor.

The liquid is forced out of the storage Dewar through a fiber tube extending from the bottom of the Dewar up through the top. It is the use of fiber rather than metal tubing that allows four complete fillings of the cold trap with one filling of the Dewar.⁴

All of the components on the output side of the transformer are mounted on a turret-type socket into which relay RL3 is plugged. A symbolic drawing of the wiring of the socket is shown in Diagram 27A.

⁴ E. A. Mroz, "Automatic Filling System for a Liquid-Nitrogen Cold Trap," in Physics Division Summary Report ANL-6146, April-May 1960, p. 22.

V. MAINTENANCE INSTRUCTIONS

A. The Vacuum System

1. Shutting Down the Vacuum System

Turn off the diffusion pump by pushing the **STOP** button on the diffusion-pump panel. The diffusion-pump alarm will sound but can be de-activated by a toggle switch on the alarm panel. A blower may be clamped to the structure and positioned so as to rapidly cool the boiler of the pump.

Bring the cold trap to room temperature. To do this, one must first remove the funnel and pipe through which the trap is filled. Unscrew the thumb nut which fastens the hold-down block, remove the block, and remove the funnel-pipe assembly. Compressed air may be blown into the trap opening through the U-shaped piece of copper tubing found hanging near the trap. Alternatively, the trap may be warmed by blowing warm air from a hair dryer into a bell-ended length of copper tubing inserted in the filling hole.

Disable the automatic filling system for the cold trap by turning off the power switch on the control panel for that system.

Turn off the ion gauge by pushing the **STOP** button on the ionization-gauge control panel.

When the cold trap and the boiler of the diffusion pump have reached room temperature, shut off the valves in the water lines to the pump barrel and to the baffle-plate unit.

Close the FORELINE valve. This is the valve just at the outlet of the diffusion pump.

The mechanical pump is shut off by means of a feed-through switch in the ac cord.

Immediately let air into the mechanical pump and foreline by opening the AIR INLET valve.

The main system is now brought up to atmospheric pressure by opening the BLEEDER valve located in the crossover tube and just behind the drift tube. This valve should be opened slowly to prevent a sudden rush of air which might cause damage to the exit foil. A hose from a tank of dry nitrogen may be connected to the bleeder valve if it is desired to exclude oxygen from the system.

2. Starting Up the Vacuum System

Close the BLEEDER valve and the AIR INLET valve.

Start the mechanical pump and check that the AUXILIARY valve is open.

Set the selector switch of the thermocouple (TC) gauge to FORE. to determine that the mechanical pump is working properly and that the foreline is being evacuated. The TC gauge should quickly reach a meter reading of 200 μ A.

Open the FORELINE valve slowly to prevent shock damage to the exit foil.

When the FORELINE valve is completely open, switch the TC selector to VACUUM. This connects the TC meter to a gauge tube located in the crossover tube at the entrance of the BLEEDER valve. After about 10 min, the TC meter will reach 150 μ A and the diffusion pump may be turned on.

To turn on the diffusion pump, first place the START-SAFETY switch of the ionization-gauge control panel to START; then push the diffusion-pump START button.

Open the water valves to the pump and to the baffle-plate unit. The valve to the baffles is opened a full turn. The valve to the pump is opened about one-eighth of a turn. When the pump boiler comes up to full operating temperature, this valve is adjusted so that the water outlet tubing feels slightly warm to the touch.

About 45 min of pumping is required before the ionization gauge can be turned on. Set the scale selector of the ionization gauge to 100. Push in the ionization gauge START button and hold it for a few seconds. If the PLATE-CURRENT meter remains off scale, the gauge will turn off when the START button is released and further pumping time is needed. When the meter stays on scale and the gauge remains on when the START button is released, check that the grid current is 5 mA. Adjust the GRID-CURRENT control as necessary. Place the START-SAFETY switch to SAFETY. This protects the diffusion pump against an increase in pressure as a result of a leak. Also turn the diffusion-pump alarm switch to ON so that an audible signal is given should the pump be de-activated by the gauge control.

Reassemble the funnel and filler pipe to the opening of the cold trap, being certain that the carbon resistor in the funnel is positioned as close as possible to the bottom of the funnel.

After the system has been reduced to at least 5×10^{-4} torr (a reading of 50 on the ionization-gauge PLATE-CURRENT meter with the scale selector at the 100 position), fill the cold trap by first closing the POWER switch on the automatic-filling-system panel and then pushing in the MANUAL-FILL button on that panel.

Degas the ionization-gauge tube by placing the GAUGE-DEGAS switch on the ionization-gauge control panel to DEGAS for approximately 15 min.

Several hours of pumping will be needed to reduce the pressure in the system to the 3×10^{-5} torr required when the electron gun is to be activated. This figure corresponds to a reading of 30 on the PLATE-CURRENT meter with the range switch in the position marked "1" (Sec. IV E.1).

3. Automatic Filling System for Cold Trap

The 15-liter storage Dewar for the filling system must, itself, be refilled twice a week or every four days. It is well to turn the system's POWER switch off while the storage Dewar is not connected to the system. This prevents wasting gas if the timer should try to initiate a filling cycle while the Dewar is disconnected and will also avoid "burns" to the operator attempting to connect the Dewar while the gas is flowing.

4. The Ionization-Gauge Tube—Removal and Replacement

After a period of time the ionization-gauge manometer tube will blacken, and electrical leakage because of contamination will cause the output of the tube to become erratic. To change the manometer tube, proceed as follows.

Shut down the vacuum system according to Sec. V A. 1.

Remove the clip from the collector ring of the tube.

Disconnect the plug on the power cable.

The stem of the tube is sealed to the vacuum system by an O ring which is compressed against the stem and the stem wall by a knurled pressure nut. The pressure nut is locked in place by the narrow knurled jam nut just above the pressure nut.

Unscrew the jam nut to unlock the pressure nut.

Unscrew the pressure nut a few turns and pull out the tube. In a few instances, the tube may be so long that it will be necessary completely to unscrew the pressure nut and to remove the tube with the nut and the O ring remaining on the tube stem.

Before inserting the new tube, apply a light coating of Dow-Corning high-vacuum grease to the tube stem. Only moderate

pressure need be applied to the pressure nut to effect a vacuum seal. The jam nut should be tight enough to prevent creeping of the pressure nut. USE NO TOOLS; FINGER PRESSURE IS SUFFICIENT.

Start up the vacuum system according to Sec. V A. 2.

5. Leak Detection

Large leaks in the vacuum system can be found with the aid of a Tesla coil. The output of the coil can be connected to one of the accelerating electrodes along the column to cause a discharge glow within the tube. Paint suspected leakage points with acetone or alcohol. The change in the color of the discharge due to entrance into the column of the vapor of the solvent can be seen through the glass insulators.

Use a mass-spectrometer type leak detector to locate small leaks as follows.

Start up the leak detector and connect its input to the air inlet in the foreline of the pumping system of the accelerator.

The diffusion pump and cold trap of the accelerator are left at room temperature (i.e., not operating) so that the accelerator is being pumped only by its mechanical pump.

Open the air-inlet valve of the accelerator and proceed according to the instructions of the manufacturer of the leak detector.

Maximum sensitivity of the detector will be had when the AUXILIARY valve of the accelerator is closed so that the system is being pumped by the detector only.

6. Oil Diffusion Pump

For instructions on cleaning and refilling the oil diffusion pump, see the manufacturer's instruction bulletin on the "Veeco Type EP2" fractionating oil diffusion pump.

B. The Accelerating Column

1. Changing the Electron Gun

Shut down the vacuum system according to Sec. V A. 1.

Open the hot-top cage door and remove any residual charges on the capacitors of the high-voltage supplies by grounding the hot-top (corona rings) and the slit plate with the grounding chain. (The grounding chain is attached to the plastic rod which hangs inside the cage door.)

Remove the top corona ring and the top plate of the hot-top.

Remove the socket from the top of the gun, pull out the sweep lead which extends through a hole in the shield of the gun and lift off the shield.

Unsnap the four remaining leads at the side of the gun.

Remove the 8 flange screws with the special long-handled Allen wrench provided and lift off the gun-flange assembly.

A new gun which has been sealed onto a mounting flange is now taken from the storage dessicator and installed on the column by reversing the above procedure. Put a light coating of Dow-Corning high vacuum grease on the O ring which seals the flange before setting the gun in place. Note the scribed mark on the vertical section of the flange. This mark is in line with the spacing between the X (lower) deflection plates of the gun. The gun is in its proper position when the mark is toward the front of the structure, i.e.,

toward the door of the hot-top cage. Some time may be saved by proceeding with the start-up of the vacuum system (Sec. V A.2) after only four of the flange screws are in place. The installation may then be completed while the system is being evacuated.

When replacing the deflection plate snaps on the side of the gun, check for broken wires.

2. Sealing a New Gun to the Flange; Storage of the Gun

While the vacuum system is pumping down, the gun-flange assembly which was removed should be disassembled and a fresh gun sealed to the flange. This assembly will then be stored for use when the gun just installed on the accelerator has come to the end of its life.

Before removing the gun from the flange, note the alignment of the two units. The scribed mark on the vertical wall of the flange is in line with an imaginary bisector of the space between the lower deflection plates, and an extension of the mark would come between pins 8 and 9 on the base of the gun.

Wipe off any grease remaining on the base of the flange. Set the flange on a clean laboratory-type hot plate. Set the hot plate to a medium heat, and when the wax in the groove of the flange melts, lift the gun straight up so that any strings of wax do not fall onto the walls of the flange.* Add enough small bits of Apiezon W wax to that in the groove of the flange to make up for the wax which has stuck to the glass of the old gun. Carefully clean the lower $\frac{1}{4}$ in. of the glass

*Should there be any wax on the inner or outer walls of the flange, remove the flange from the hot plate and allow it to cool. Clean the wax from the walls with toluene and reheat the piece.

of a new gun with acetone-soaked tissue. Any projections on the edge of the glass should be removed with appropriate glass-grinding equipment. Set the gun into the groove and align it radially as directed in the second paragraph of this section. Check that the wall of the gun is vertically aligned with that of the flange by placing a 6-in. metal straightedge along the flange wall. A ring stand and clamp may be used to hold the alignment until the assembly has cooled and the wax has hardened.

To prevent deterioration of the cathodes by moisture, the new, unused guns are stored in a vacuum dessicator under a partial vacuum.

3. Initial Activation of the Electron-Gun Cathode

The initial activation of the electron gun differs from the routine activation given in Sec. III A.4 mainly in the amount of time spent in bringing the cathode to its activation temperature. The cathode material tends to flake off if its temperature is increased rapidly.

Install the adapter socket between the regular socket and the base of the electron gun.

Set the filament voltage of the gun at 2 V. Increase this by 1 V every 15 min, noting each change in the log book. When the increase from 6 to 7 V is made, apply the collection voltage E_B by turning on the ELECTRON-GUN AND MAGNET power supply and putting its selector switch to ELECTRON GUN. After a few minutes, the cathode current (as indicated on the milliammeter of the ELECTRON-GUN AND MAGNET supply) will rise. The supply will limit this current I_B to 40 mA by reducing E_B . Let the cathode "cook" at 7 V for 3-5 min, and then lower the filament voltage E_f to 6.5 V. The time of change and the values of E_f , E_B , and I_B at the time of change should be recorded in the log book. (The symbols

have the meanings assigned in Sec. III A.4.)

If I_B remains at 40 mA after E_f is at 6.5 V for 5 min, the activation is satisfactory and the gun is ready to be put into operation according to Sec. III A.4.

Should there be no noticeable current I_B produced after a 15-min period at a E_f of 7 V, increase E_f by increments of 0.5 V, waiting about 10 min at each step. An occasional sluggish cathode will need a E_f of 9 V. When such a high voltage is necessary for the initial activation, do not hold it for a long period but reduce it to 7 V as quickly as possible while keeping I_B at 40 mA.

4. Changing the Exit Foil

Shut down the vacuum system according to Sec. V A.1.

Unscrew and remove the light hood.

Remove the three screws that hold the threaded hood ring in place and remove the ring.

Remove the six screws that fasten the snout to the bottom of the drift tube.

Lay the snout, flange downward, on a piece of tissue and with a jeweler's screwdriver remove the six small 0-80 screws holding the nose piece to the snout. Lift out the nose piece.

Remove the old foil by filing across the foil and the projection to which it is soldered with a fine Swiss file. Use care here, filing lightly and holding the file as flat as possible until the foil and the thin layer of solder beneath it are removed. Use the file to clean away excess solder and foil from the outer edge of the projection. Clean the edge of the hole with a sharp, curved surgical blade. Use the blade as a scraper and leave the edge of the hole rounded. This work is best done under a high-powered loupe or other

magnifying glass. Be sure there are no burrs or other sharp edges left on the piece. Blow away all filings and chips.

Prepare a brush which will be used to apply soldering flux by cutting away most of the bristles of a small artist's brush until only about 10-12 bristles remain.

A very satisfactory flux is "Allen's Soldering Salts" mixed according to the directions given on the jar.

From a piece of foil^{*} cut out a section measuring approximately $\frac{3}{16}$ in. square. Handle this section only by a corner with a pair of pointed-end tweezers.

The solder used here is solid wire of 63-37 composition. Prepare a piece about 0.010-0.015 in. square by flattening the wire in a smooth-jaw vise and cutting off a narrow section.

The heat source is a laboratory-type electric hot plate with a graduated heat-control knob.^{**} Place a $\frac{1}{4}$ -in. brass nut ($\frac{1}{4}$ -20 or $\frac{1}{4}$ -28) on the hot plate and set the heat control to 400. Place the nose piece on this nut so that the projection to which the foil is soldered faces upward. Paint a narrow band of flux on the projection near its outer edge. Keep the flux away from the hole. Apply a very small amount of solder from the stick prepared earlier. Spread out the solder with the flux brush until a narrow band near the edge of the projection is tinned with a thin layer of solder.

Do not try to speed up the heating by increasing the hot-plate setting because this would tend to cause burning of the tinning solder while the foil is being prepared and thus to make the foil adhere poorly.

^{*}Nickel foil 0.00004 inch (1 micron) thick, grade C, as supplied by the Chromium Corporation of America, Waterbury, Conn.

^{**}Precision Scientific Co., Cat. No. 61725, or equivalent.

Examine the piece of foil. One side is dull, the other shiny. On the dull side, paint a circle of flux. The portion that will cover the hole must NOT be touched by flux. If this should accidentally be done, the foil must be discarded and a new one prepared.

Using the tweezers, place the foil on the nose piece carefully. It is necessary to position the foil correctly the first time. An attempt to reposition it is most certain to result in contamination of the area covering the hole.

Gently press down the edges of the foil with the rounded, back side of the tweezers. Also brush more flux around the edge of the projection.

Grasp the nut with the tweezers and, with the nose piece still on top, remove the nut to a large mass of metal, such as a vise, where it may cool.

Trim away the excess foil with a razor blade.

The inside surface of the foil can be examined with a loupe. (A good light source for this is a 1.5-V prefocused penlight bulb mounted in a plain socket supported by two stiff wires attached to the terminals of a No. 6 dry cell.) No solder should be visible along the edge of the hole. With the light source at the opposite side of the foil, look for any pinholes.

The Teflon gasket used to seal the nose piece to the snout measures $\frac{5}{32}$ in. in diameter by 0.020 in. thick with a No. 49 hole. Since it is difficult to cut this material cleanly with machine tools, small burrs and filaments will be seen under a magnifier. These must all be carefully trimmed away so that they will not project into the hole to impede the electron beam nor impair the seal.

Remove the used gasket from the snout. Examine the phosphorized surface and with a camel's hair brush, clean away any dirt or loose particles. Insert the new gasket and mount the nose

piece. Draw the fastening screws up evenly, going from one screw to the one diametrically opposite.

(Note: Always use a new gasket when reassembling the nose piece to the snout.)

Fasten the snout back onto the drift tube after first putting a light coating of Dow-Corning high-vacuum grease on the O ring that seals the junction.

Start up the vacuum system according to Sec. V A. 2.

Mount the threaded hood ring in place against the snout but do not tighten the screws completely. Thread the light hood on the ring. This is a triple thread, and some patience is required to start it. Screw the hood all the way up and tighten the screws attaching the ring to the snout. This procedure of fastening the ring is necessary because of the small clearance between the inside diameter of the threaded portion of the hood and the outside diameter of the snout. With the hood screwed all the way up, the ring becomes centered.

C. The Hot-Top Circuits

1. The Main Hot-Top Power Supply

Test points and adjustable controls for all of the regulated voltages furnished by this supply are located on the rear apron of the supply's chassis. The 500-V output is also indicated on a meter mounted on a sloping panel at the front of the hot-top.

The supply can be tested while it is in place in the hot-top. A shorted ac plug is available for bypassing the cage door interlock so that the door can be left open while power is being applied to the supply. FOR SAFETY disable the 24-kV supply that furnishes voltages to the electron gun. Do this by removing tube V303, a 6AU5 located on the inverted chassis to the right of the 24-kV supply. This

tube is clearly marked. ALSO ground the hot-top by hanging the grounding chain on one of the corona rings.

An important point to bear in mind when adjusting the voltage outputs is that the -250-V output is the reference for the regulators of the other voltages. Therefore, trouble shooting of the supply should begin with tests for the malfunctioning or excessive loading of the -250-V section.

Adjustment of the 1500-V output of the rf plug-in unit is had by adjusting the trimmer capacitor C_{16} through a hole in the top of the rf unit.

To remove the chassis to the bench for testing:

Remove the top corona ring and the top plate of the hot-top.

From the bottom of the hot-top, remove the two screws which hold the chassis to the floor of the hot-top.

With an Allen wrench of appropriate size disconnect the two plastic rods that drive the positioning controls at the back of the chassis. Slide the chassis along the floor to pull out the control shafts from the rods and to pull out the input (banana) plugs.

Disconnect the main output connector at the left front corner of the chassis and the 1500-V lead from the rf plug-in unit.

Pull out the rf unit and lift out the supply chassis.

An ac cord with appropriate connectors is available for connecting the supply directly to the ac line.

2. The 24-kV Power Supply

An electrostatic voltmeter having 10-, 20-, and 30-kV ranges is available for checking the output of this supply. A control marked H.V. ADJ. on the oscillator chassis (the inverted chassis to

the right of 24-kV unit) adjusts the output. It is adjusted so that there is 20 kV at the slit plate, and nominal voltages of 13.3 kV and 6.6 kV at the intermediate electrodes.

In testing this unit, it is again desirable to bypass the cage-door interlock with the shorted ac plug so that the door can be left open. The hot-top should be grounded with the grounding chain, BUT NOTE that the 20-kV point (the slit plate) is grounded through the 150-kV supply. Thus, with the hot-top grounded, the output of the 24-kV supply is short-circuited. To remove this short, merely unplug from the slit plate the lead coming from the high-voltage cage.
Failure to do this results in certain damage to components within the 24-kV supply case when the power is applied.

3. The Sweep Generator

Loss of the beam or sweep at the slit plate is often caused by malfunctioning of the sweep generator. Fig. V-1 shows the waveforms at various stages of the generator as well as the two output waveforms, the unblanking pulse, and the sweep ramp.

To operate the generator for checking of the output waveforms:

Bypass the hot-top cage-door interlock with the shorted ac plug.

Disable the 24-kV power supply by removing V303 from the oscillator chassis (the inverted chassis next to the 24-kV supply case).

Ground the hot-top by hanging the grounding chain on one of the corona rings.

Apply hot-top power.

Set the master-pulser into operation.

Fig. V-1. Waveforms of the sweep generator. These were measured with a Tektronix 545A oscilloscope having a type CA plug-in pre-amplifier and using a 10X attenuator probe having a capacitance of 8 pF. The amplitude of the sweep ramp will depend upon the particular sweep plate installed in the generator.

To look at the sweep ramp, connect a fast oscilloscope through a 10X attenuator probe to the sweep lead. This is the lead that connects to the side of the electron gun through a hole in the shield of the gun.

To look at the unblanking pulse, connect the oscilloscope probe to the lead coming from pin 3 of the electron-gun socket. This lead joins a 100-k Ω resistor on the terminal board just behind the gun and the probe can be connected to this junction.

Screen voltage for the 4X150A sweep tube is adjustable from, and measured at, the rear apron of the main hot-top power supply. It is nominally 250 V but is adjusted so that the output sweep ramp is straight and makes a voltage excursion of 800 V when the 5×10^{-10} sec. sweep plate is in place.

To operate the generator on the bench requires that the main hot-top power supply also be taken from the hot-top to the bench. A special cable for interconnecting the two chassis and a blower-hose assembly for cooling the 4X150A are available.

D. The Scope-O-Graph

1. The Perceiver

The perceiver case need not normally be removed from the oscilloscope for servicing. On occasion, when it must be removed, first withdraw the microscope barrel which sits loosely in the periscope tube.

For inspection of the interior of the case, remove the panel on the right-hand side. Always be certain that the voltage to the photomultiplier tubes is off before removing any panel from the perceiver case.

Two separate panels form the bottom of the case. All of the mirror assembly is mounted on the rear panel, and the electronics (including all tubes) are mounted on the forward (long) panel.

For servicing of the electronics, the forward panel may be removed without disturbing any other part of the case. Remove the cable connectors and hold the panel in place by hand until the screws are completely removed. Tilt the forward end of the panel downward, and then move it downward and forward until the upper phototube clears the housing. If the paint causes the panel to stick, pry gently only along the front edge of the panel.

The rear bottom panel cannot be removed while the forward panel is in place.

The front-surface mirrors used in the perceiver are easily damaged by careless handling. Dust is best removed by blowing with dry air or by dusting with a camel's hair brush.⁵ The mirrors are ruined if they are wiped with tissue.

2. The Scanner

To replace the rubber drive belt:

Locate the yoke on which the rearward of the two driven potentiometers is mounted. Remove the two round-head brass screws and nuts that fasten the yoke to the chassis. Rotate the shafts so that the pin of the coupling between the potentiometers is up. Move the yoke upward and toward the rear of the chassis and slip the belt over the end of the shaft.

Disengage the driving clutch by pulling the AUTO-MANUAL knob outward. Using a narrow-bladed screwdriver, push the white Teflon insert back against its tensioning spring. This will leave enough space for removal of the belt.

⁵See "Method to Clean Precision Optics," Bulletin 9024, Edmunds Scientific Corp., Barrington, N. J.

The belt is a standard rubber or neoprene O ring measuring $5\frac{1}{4}$ in. O.D. $\times$ $\frac{1}{8}$ in.

3. The DC Amplifier

Table D gives voltage readings at various points in the circuit under the following conditions.

A load consisting of a $20\text{ K } \Omega$, 10 W resistor is connected to output terminals P4 and P5. A Simpson volt-ohmmeter measures the output across this load. The input of the amplifier is driven by a voltage source, such as a measuring potentiometer, plugged into jack P9. The JACK SELECTOR switch is set to G and the BAL. SPEED SEL. to any position other than TEST. Adjust the potentiometer by comparison with its standard cell, switch to EMF, and turn the dial to zero. Bring the amplifier output to zero by adjusting the AMP. ZERO control.

The output should be the full 135 V when the input is 0.4425 V.

The B- terminal (under the chassis) is labeled.

4. The Logarithmic Converter

The following procedure is used to make sure that the log circuit is in proper alignment to produce a logarithmic output.

- a). At the scanner chassis, disconnect the leads which go to the X input of the X-Y recorder. Plug these leads into the tees at the LOG. CONVERTER output of the dc amplifier (Fig. V-2).

TABLE D. Voltages measured with a vacuum-tube voltmeter at various points in the dc amplifier. The letters refer to tubes labeled A, B, C, D, and E; subscripts refer to their pin numbers. In addition, a measurement from A₂ to TP (see diagram) is less than 0.5 V.

Test point	Dc voltage relative to B-	
	For output = 0 V (V)	For output = 135 V (V)
B+	545	545
A ₂	82	82.5
A ₃₋₈	90	90
A ₁	221	218
A ₆	219	222
B ₁	178	225
B ₆	175	142
B ₃₋₈	77	77
C ₇	62	62
C ₃₋₈	71	67
C ₁	229	333
C ₆	229	168
D ₁₋₆ ; E ₁₋₆	455	450
D ₃₋₈	239	183
E ₃₋₈	239	333

Fig. V-2. Interconnections of the dc amplifier, the logarithmic converter, and the X-Y recorder when testing for alignment of the log circuit.

- b). Measure the LOG SUPPLY voltage by connecting a precision measuring potentiometer into the test points on the rear apron of the chassis of the logarithmic converter. The voltage between these points should be 0.411 V. If necessary, adjust the SUPPLY ADJ. control on the front panel.
- c). In a similar manner measure the voltage at the LOG ADJ. TEST points. Adjust the LOG ADJ. control for 0.711 V here.
- d). Place 2-cycle semi-log paper (K&E 359-62L) on the X-Y recorder, close the shorting switch at the Y input of the recorder, set the SCAN DIAL to zero, and

adjust the X and Y controls of the recorder to bring the pen to the lower left-hand corner of the graph. Release the shorting switch.

- e). Set the BAL. SPEED SEL. to TEST and adjust the AMP. ZERO control to bring the recorder pen to the above zero point.
- f). Set the amplifier JACK switch to F.
- g). Set the log TEST POINT switches to position 21.
- h). Set the BAL. SPEED SEL. to any position other than TEST and plug the battery-box connector into the test jack. (Note that if the BSS switch is turned to TEST with the JACK SEL. at F, a direct short is placed across the batteries.)
- i). Set the FUNCTION switch of the log circuit to TEST and immediately:
- j). Adjust the battery-box voltage to bring meter M1 to zero, using first the COARSE and then the FINE positions of the M1 SENSITIVITY switch.
- k). Set the FUNCTION switch of the log circuit to LOG. The pen should now be at 96 ± 0.5 division on the Y scale of the graph. If it is not at 96, check all zero adjustments according to steps (d) and (e) after first disconnecting the battery-box plug. Repeat steps (h) to (j). If the pen still does not read 96, adjust the Y CALIBRATE of the recorder to bring the pen to exactly 96.
- l). Set the PEN-STOP switch of the recorder to PEN and trace a curve, starting at the top of the graph, by slowly adjusting the battery-box voltage. Upon reaching zero, retrace the curve, going upward. Fig. V-3 is an example of such a curve. The

Fig. V-3. Response of the logarithmic converter when the log circuit is in proper alignment.

ordinate of this curve is called R and the abscissa v. The values of v are proportional to the logarithm of the horizontal displacement of the pen.

m). Plot R versus v on linear graph paper as in Fig. V-4.

This plot will be a straight line through zero if the log circuit is in good alignment. Slight curving of this line can be corrected by adjusting only control #21. If the line is concave downward, adjust the #21 control to make this point higher. If the line is concave upward, set this point lower. Repeat the entire procedure from step (d) on. Of course, each time that the #21 control is readjusted, the Y CALIBRATE of the recorder must be adjusted at step (k).

If the foregoing indicates the need for a complete realignment of the log circuit, proceed as follows:

- 1) Set the Y-AXIS SENSITIVITY switch to 100 mV/in.
- 2) Place 250-mm linear graph paper (K&E 359-14L) on the recorder.
- 3) Disconnect the leads at the Y INPUT of the recorder and connect to this input a voltage source adjustable from 0 to 1 V. Connect a precision measuring potentiometer to measure this source.
- 4) Calibrate the X-Y recorder by adjusting the Y CALIBRATE so that the pen is at 245 mm on the graph with a Y input of 0.9575 V and at zero with a Y input of 0 V.
- 5) Remove the voltage source, reconnect the leads from the log circuit to the Y INPUT of the recorder and reset the Y sensitivity switch to 1 mV/in.

Fig. V-4. Straight line that results when the response of the properly aligned log circuit is replotted on a linear graph.

- 6) Recheck the LOG SUPPLY and LOG ADJ. TEST voltages.
- 7) Recheck all zero adjustments.
- 8) Set the log TEST POINT switches to test point 2, the log FUNCTION switch to TEST, and the BAL. SP. SEL. at any position other than TEST.
- 9) Plug the battery-box plug into the test jack after first adjusting the voltage of the box to nearly zero.
- 10) Adjust the battery-box voltage to bring meter M1 to zero. The recorder pen should now indicate 65 divisions on the graph. If it is not at 65 divisions, adjust #2 control to bring the pen to that position.
- 11) Switch to test point 3 and bring M1 to zero. The recorder should now read $65 + 9 = 74$ divisions.
- 12) Proceed through the remainder of the test string in a similar manner. Each succeeding test point should increase the recorder reading by 9 divisions. At any point where a deviation occurs, adjust the corresponding aligning control. Test point 22 should read 245 divisions. Do not adjust control #23.
- 13) There is some interaction among the controls so that it is necessary to make several runs through the test string, starting at test point 2 and ending at point 21, until no further adjustments are needed.

Should proper alignment be found impossible, the Y CALIBRATION of the recorder may be changed slightly and the alignment procedure repeated.

The final indication of proper alignment will be the straight line obtained by the test procedure described in steps (a) to (m).

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