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Construction and Calibration of a Flying-Spot Microscope for Nuclear Emulsion Plates.

by

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ABSTRACT

A flying spot microscope has been designed, constructed and calibrated for studying nuclear events in nuclear emulsions. The instrument has seven major units as follows:
(i) Synchronizing Generator, (ii) Flying Spot Scanner,
(iii) Optical System, (iv) XY stage, (v) Video Chain,
(vi) Monitor for visual presentation, and (vii) a Line Selector for digitization in one direction at the image plane. Detailed descriptions of these units are given. The calibration procedures are outlined and numerical calibrations for the instrument are given.

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INTRODUCTION

The flying spot microscope was originally developed by J. Z. Young and F. Roberts[1] for bacteria research in biology. This device has also been used to count and measure sizes of particles such as dust and blood cells. P.O'B. Montgomery and W. A. Bonner[2] have further developed the flying spot microscope, using ultra-violet radiation, to selectively irradiate living cells at high intensity, as well as to scan the same cells at low intensity to observe any resultant cell changes.

In high energy physics it has been suggested, by J. G. McEwen and J. A. Hébert,[3] that the flying spot microscope technique could be used to examine emulsion plates for track detection and counting, as well as for the detection of nuclear stars.

In recent years the problems inherent in position measurements for spark and bubble chamber events have been thoroughly studied. This led originally to manual film scanning and digitizing machines, followed by a new generation of high speed, high accuracy automatic film digitizing machines. Two examples are: the CERN Mark II H.P.D.[4] machine for bubble chamber film, and SAMM[5] an automatic digitizing machine for spark chamber film. When bubble chambers were initially proposed, the digitizing aspect was foreseen and supported with the result that fast and accurate digitizing machines were developed. As well, the availability of the proven principles of digitizing film, combined with high speed computers, later spurred the rebirth of the spark chamber as a high energy physics detector.

Nuclear emulsions are losing their former position as the foremost of the high energy physics detectors, primarily because of the large time involved in manually digitizing the nuclear events within the emulsion, compared to the automatic digitizing times for other detectors such as the bubble chamber and the spark chamber.

However the nuclear emulsion does have one large advantage over the previously mentioned film digitizers. This advantage is that the developed grains in the emulsion are fixed in a three dimensional medium compared to the two dimensional view with which the film digitizers are presented. In order to make up for this difficulty the film digitizers use two, three or even four film frames, each showing the same event, but from different angles, so that the computers, after receiving the digitized pairs of coordinates from each film frame, can reconstruct the event in three dimensions. This reconstructed three dimensional system now allows the computer to analyse the kinematics of the event in our normal physics language, which is, of course, based on the Cartesian coordinate system. A further difficulty with the film digitizers is that tracks, shown on the two dimensional film, which appear to be intersecting each other, may actually be separated by large distances. This is one of the most difficult problems for the computer to resolve, especially (a) when two tracks on one two-dimensional view cross each other at small angles, or (b) when a track having light ionization is crossed by a track having heavier ionization. Here the human scanner of a nuclear emulsion has a decided advantage when using an optical microscope having a small depth of field, since he can readily discriminate between tracks at different depths within the emulsion.

Some representative figures for bubble chamber film and spark chambers are given below:

1) 30 inch hydrogen bubble chamber at B.N.L. digitized by a CERN MARK II H.P.D.

Film format - 70 mm film; the information is confined to a circular area of about 50 mm in diameter.

Scanning is done by a spot of light which moves in a straight line, at constant velocity, with a line length of 53 mm. The least count is 1.6 microns in the scan line direction. This corresponds to bubble centre locations accurate to approximately 14 microns in the bubble chamber.

Scanning is accomplished in a perpendicular direction by moving a hydraulic stage to which the film is clamped. The least count in the stage position digitizers is 2.0 microns; this corresponds to bubble centre locations accurate to approximately 29 microns in the bubble chamber.

2) For spark chamber film digitization, using a manually operated machine similar to a Vanguard, one can obtain spark centre positions to an accuracy of approximately 1.0 mm for a spark chamber with dimensions of 35 cm by 45 cm.

Our aim was to design and construct a flying spot microscope so that the emulsion volume could be scanned by a two dimensional horizontal plane, which could be moved vertically. It was hoped that the resolution would be approximately two microns over a horizontal plane with dimensions in the order of 250 by 250 microns. Finally we wanted to develop a method of making meaningful measurements, in the image plane, using this flying spot microscope.

Basic Principles of the Flying Spot Microscope.

The system block diagram is shown in Fig. I. A brief explanation of the overall system follows:- (Fig. 1, see p. 78).

The light source is placed above the eyepiece so that the light rays proceed through the microscope in the reverse of the usual direction. The source of radiant energy is a cathode ray tube with a small scanning spot having high and uniform brightness. This cathode ray tube has a short persistence phosphor screen. [i.e. See D. G. Fink[6]]. The scanning spot moves over the surface of the cathode ray tube screen tracing out a scanning pattern. This scanning pattern is a large number of closely spaced parallel lines. The microscope objective produces an extremely small image of the scanning spot and focusses this image, and the reduced size pattern, within the depth of the emulsion to be examined. The radiant energy passing through the emulsion is directed onto the photocathode of a photomultiplier by means of a condensing lens system. The magnitude of the photocathode current is linearly related to the radiant energy reaching the photocathode, and therefore depends on the emulsion absorption for the radiant energy used. Thus the photomultiplier anode current varies as the absorption of the emulsion, and since the image of the scanning spot moves along a definite pattern with respect to time, the photomultiplier anode current waveform, also varying with time, can be related to the pattern on the flying spot scanner cathode ray tube. Therefore the photomultiplier anode current output gives a geometrical mapping of the absorption (or transmission) of the area of the emulsion scanned by the flying spot image. The developed grains in a nuclear emulsion cause an increase in absorption over the background of emulsion absorption. The output of the photomultiplier is suitably amplified and modulates the brightness of a second cathode ray tube which is scanned in synchronism with the flying spot scanned cathode ray tube. This second cathode ray tube has a long persistence phosphor so that the visual presentation can be accepted by the eye to give a complete absorption (or transmission) picture of the area of the emulsion being scanned. The display unit (i.e. the second cathode ray tube mentioned above) is a commercial TV monitor.

The scanned plane can be defined as an XY plane, with the X direction from left to right (on the monitor) and with the Y direction from top to bottom (on the monitor). There are 501 horizontal, or Y, lines which make up the visual picture.

The operator can digitize in the Y direction by using the "line selector" to relate image positions to calibrated "line numbers" as follows:

(i) Out of 501 lines in the picture, one can be made black. Each of the 501 lines in the picture has its own line number. Therefore the black line has a particular line number which can be found by examining the positions of four rotary switches on the line selector.

(ii) The operator can change the Y position of the black line through the same four rotary switches.

(iii) Line numbers can be calibrated against a stage micrometer resulting in a function which gives distance versus line numbers.

i.e. $S = S(Y)$ where S = distance in microns,
Y = line number.

(iv) Therefore the distance between two images at line numbers Y_1 and Y_2 is:

$$L_{1,2} = S_1 - S_2 = S(Y_1) - S(Y_2)$$

where $L_{1,2}$ = distance between image 1 and image 2 in microns.

The emulsion plate is mounted on a servo driven, XY dovetail stage which was constructed in the Physics department workshop. This stage allows one to examine large areas within a single emulsion plate. In the following sections, flying spot scanner becomes F.S.S., and cathode ray tube becomes C.R.T.

Development of the Optical System.

The original design, as shown in Fig. 4 part A, had an aerial camera lens (with an f number of 4.0 and a focal length of 24 inches) supported at its focal length below the F.S.S. C.R.T. Therefore a spot of light generated at the C.R.T. phosphor would result in a parallel beam of light emerging from the camera lens. A portion of this parallel beam of light is intercepted by the eyepiece lens system of the microscope. This light is then converged to a sharply focussed spot below the objective lens. (i.e. Within the depth of the emulsion). The light diverging from this spot is converted to a parallel beam of light by the microscope condenser system, and this parallel beam of light illuminates a considerable area of the photomultiplier photocathode. Note that this system uses the microscope optical elements in their proper manner. The result, after careful alignment, was a very small photomultiplier signal which had an extremely small signal-to-noise ratio. The cause of the low signal-to-noise ratio was simply that very little light passed through the optical system. The microscope optics in particular were designed for the light spectrum which the human eye can comprehend, whereas the spectrum of the P 16 phosphor (in the F.S.S. C.R.T.) peaks in the ultra violet wavelengths. Thus only a small percentage of the light from the phosphor is available to carry information to the photomultiplier. This optical design was not satisfactory and led to the following system.

The second optical design, as shown in Fig. 4 part B, had the primary requirement that more light had to be available at the photocathode to get a better signal-to-noise ratio. The aerial camera lens was an unknown quantity as far as its ability to pass ultra violet light was concerned. Therefore it was removed and the assumption was made that the light rays, from the P 16 phosphor, intercepted by the eyepiece lens system would be nearly parallel. Note that the F.S.S. C.R.T. face plate is approximately 82 cm above the microscope eyepiece, and the eyepiece aperture is in the order of 1 cm in diameter. The system was set up and an improvement in the signal-to-noise ratio was quite apparent; however, there was still room for improvement in this direction.

The third optical design had the same objective, i.e. more light at the photocathode of the photomultiplier, but more drastic means were taken to accomplish this end. First the eyepiece system was removed, since less glass in the system would mean more light at the photocathode. It was realized that this would force the objective to work in unusual conditions. (i.e. An objective microscope lens normally produces an image, for the eyepiece lens, at an image distance from 160 to 180 mm, whereas the distance from the P 16 phosphor to the microscope objective lens is 82 cm plus approximately 18 cm.) One result of this arrangement was that the objective lens has a different magnification. This optical system did produce a better signal-to-noise ratio than previously, and led to the removal of the microscope condenser lens system in hopes that an even better signal-to-noise ratio would result. Visual inspection of the monitor C.R.T. showed that no significant change in signal-to-noise ratio occurred for this last change. The cause was simply that a very large proportion of the sharply diverging cone of rays below the focussed spot in the emulsion was scattered by the photomultiplier support, before striking the photocathode. One method of improvement would be to raise the photomultiplier so that it would intercept a larger cone of light. The limitations here are (i) the requirement of a light shield to keep unwanted room light out of the photomultiplier, and (ii) the mechanical restrictions due to the stage holder for the emulsion plates. The method used to get more light to the photomultiplier follows. (i) A cone of silver foil was placed inside the light shield, as high as possible, to scatter the light downwards. (ii) A cylindrical light duct of silver foil was then used below the cone to further direct the light, by multiple reflections, down to the photomultiplier. With this final modification, there was again an appreciable increase in the signal-to-noise ratio. This arrangement is shown in Fig. 4 part C.

N.B. The signal-to-noise evaluations were made by eye, simply by estimating the amount of "snow" on the monitor C.R.T., with respect to the picture details caused by a nuclear emulsion plate. One method of getting quantitative signal-to-noise data would be to measure the average photomultiplier anode current during the horizontal sweep of the F.S.S. C.R.T., but this would have required a nuclear emulsion plate with no developed grains, and such a plate was not available at that time. The anode current mentioned above could then be used to find the appropriate signal-to-noise ratio.

Description of the Electronics associated with the Optical System.

Referring to the System Block Diagram, Fig. 1, the following parts of the scanner will be discussed: Monitor System and Synchronizing Generator, Flying Spot Scanner, and the Video Chain System.

The Monitor System.

The monitor block diagram is shown in Fig. 7. The horizontal and vertical outputs from the synchronizing generator are used to create a raster on the commercial TV set which is used as a monitor. The horizontal and vertical outputs give appropriate signals to trigger the horizontal and vertical sawtooth generators in the flying spot scanner. These signals are also combined to form a blanking signal which is used (i) in the flying spot generator, and (ii) in the video chain. (See Fig. 1 System Block Diagram). Finally the video signal from the video chain is used to modulate the intensity on the monitor C.R.T. resulting in a visual representation of the developed grain density at the F.S.S. focal plane within the emulsion.

Synchronizing Generator.

This generator supplies timing pulses to trigger the horizontal and vertical sweep generators in (i) the F.S.S. and (ii) the Monitor.

There are two channels and one feedback loop as shown in Fig. 8. Assume that the multivibrator runs at 31.500 kcps. when the feedback loop is opened by disconnecting the D.C. amplifier output signal line.

The horizontal channel is comprised of the multivibrator, a flip-flop which gives an output at 15,750 pulses per second (pps.), a one-shot which gives the proper mark-to-space ratio, and an output driver stage. The output is at a negative voltage level (-6 v.D.C.) for approximately 11 microseconds, (i.e. during horizontal retrace) and is at ground for approximately 52.5 microseconds.

The vertical channel starts with the same multivibrator output. This signal is reduced to 4,500 pps. by a divide-by-seven unit made up of three flip-flops using suitable feedback. This output is further divided by units of five, five and three, resulting in respective output rates of 900 pps., 180 pps., and 60 pps. (Each of these divisions is made by suitable feedback connections around flip-flops). The mark-to-space ratio for the 60 pps. output is controlled by a gating circuit such that the vertical retrace time is an integral number of horizontal periods. The vertical retrace time is exactly 12 horizontal periods. The feedback loop around the vertical channel is completed by a frequency discriminator and a D.C. amplifier. The output of the phase discriminator is a voltage whose amplitude is proportional to the difference in <u>phase</u> between the 60 cps. line voltage and the 60 pps. vertical output. The phase discriminator output voltage also varies in <u>sign</u> depending on whether the vertical output is leading or lagging the 60 cps. line. Note also that the phase discriminator makes its comparison periodically that is during the vertical retrace interval. Thus the discriminator output changes during the vertical retrace interval, and then remains constant until the next retrace interval, at which time another comparison is made. This output is fed into the D.C. amplifier and then into the multivibrator such that the vertical output is locked or synchronized to the line frequency.

The total division ratio from the multivibrator to the vertical output is 7 x 5 x 5 x 3 or 525, while the division ratio from the multivibrator to the horizontal output is 2. These two outputs are the triggering waveforms which will give 525 line, interlaced rasters, simultaneously on both the F.S.S. C.R.T., and on the monitor C.R.T.

A short summary of the interlaced scanning technique used is given below:

Odd Line Method.

1) Total number of lines in one frame (i.e. one complete scanning pattern) is 525.

2) There are two fields, each of 262 1/2 lines, in one frame. One field is made up of all the odd numbered lines, while the second field is made up of all the even numbered lines. Each field has 12 inactive lines (i.e. lines having no video information) which are used for vertical retrace. Thus there are 250 1/2 active lines in each field, or 501 active lines in one frame.

3) Time between the beginning of one scanning line (horizontal and the next is 63.5 microseconds.)

4) Active scanning time along each line is 52.1 microseconds. (Plus 0.6 or minus 0.0 microseconds).

5. Time between the beginning of one field and the next is 16,667 microseconds. Thus the field rate is 60 fields per second, and the frame rate is 30 frames per second.

For further information see Reference 6.

Detailed Description of Synchronizing Generator.

Figure 42 gives the detailed circuit. The logical units used are contained on two printed circuit boards (P. C. Board No. 1, and P. C. Board No. 2), and on 3 identical printed circuit cards manufactured by Computer Control Corporation Inc., Framingham, Massachusetts, U.S.A. Each of the 3 identical printed circuit cards contains 4 complimentary type flip-flops with enough inputs to enable one to arrange division ratios of 2, 3, 4, 5, 6, 8, 10, 12 and 16, by the use of external jumpers on the card socket pins. The self-contained, regulated power supplies are shown in the upper right hand corner of the drawing.

The counter which produces the 525 lines for each frame is shown at the bottom of the diagram. The eleven flip-flops comprising the counter have their outputs numbered from I to XI.

(The barred Roman numerials refer to the inverted outputs for each flip-flop). The master oscillator output is inverted in Nand No. 21, and then enters the vertical counter chain at pin 22 of flip-flop I. The input rate is at 31,500 pulsed per second, and the periodic time corresponds to exactly one half of one line, that is 31.75 microseconds. Flip-flops I, II, and III and Nand gate No. 11 are connected so that flip-flop III gives one pulse at its output for seven pulses entering flip-flop I. The output pulse rate at flip-flop III is 4,500 pulses per second. Ignoring Nand gates No. 12 and No. 13, let us now examine flip-flops IV, V, and VI. These are interconnected so that only one pulse is produced at the output (VI) for each five pulses which enter flip-flop IV at its pin 34. Therefore the output pulse rate at VI is at a rate of 900 pulses per second. Flip-Flops VII, VIII and IX are wired identically to IV, V, and VI, so that the output of IX is at a pulse rate of 180 pulses per second. Finally, flip-flops X and XI are interconnected so that XI has one pulse at its output for each three input pulses to pin 34 of flip-flop X. Therefore the output of flip-flop XI gives one pulse for each 525 pulses at the input of flip-flop I. Note that no resetting of this counter is necessary, i.e. after 525 pulses it repeats, exactly the same pulse sequences in all the eleven flip-flops. Output pulses from XI occur at a rate of 60 pulses per second.

The vertical retrace flip-flop is located on the diagram in the lower right hand corner. Assume that the Set output is at O v.d.c. When the counter output (XI) produces a positive edge at the Set input, this flip-flop changes state, so that its Set output goes to -6 v.D.C. This occurs at a count of 525, which can also be called a count of O(zero). Let us now consider Nand gate No. 12. Its four inputs, III, IV, V, and $\overline{VI}$ will produce at its output one positive pulse for each 24 pulses which enter the counter at the input of flip-flop I. Therefore after 24 pulses the output of Nand No. 12 will reset the vertical retrace flip-flop. This means that at a count of 24 the Set output of the vertical retrace flip-flop will return from -6 v.D.C. to O v.D.C. The further output pulses of N and No. 12 (at counts of 48, 72, 96, ... 504) have no further action on the vertical retrace flip-flop. Since each input pulse to the counter chain corresponds to exactly one half of one horizontal line, one has a vertical output pulse which lasts a time of exactly 12 horizontal lines, and reoccurring every 262 1/2 lines. The vertical output is matched to the RG 62A/U cable by emitter follower (E.F.) No. 11, and is used at the monitor and the flying spot scanner.

Nand No. 13, with inputs from flip-flop V and the Set output of the vertical retrace flip-flop, gives an output which begins at count O and lasts until count 16. (i.e. A time corresponding to 8 full lines). This pulse is the sample pulse input to the phase discriminator. During this interval the discriminator compares the phase of the 60 pulses per second sample pulse to the 60 cps. sine waves from the 115 v.A.C. line. The phase error output signal is fed to the master oscillator, with the proper polarity, such that this oscillator is synchronized to the 60 cps., 115 v.A.C. line frequency. i.e. The vertical output pulses occur at a 60 pulse per second rate, locked to the A.C. line frequency. Very small transients can be produced at the output of the phase discriminator at the end of the sample pulse. However these variations are not seen in the raster line structure since they occur during a time corresponding to the last 4 lines out of the 12 lines in each vertical output pulse. (i.e. During the vertical output pulse the flying spot scanner C.R.T. spot is off).

The horizontal output pulses are generated as follows: The output of Nand gate No. 21 (in the upper left hand corner) is applied to the complementary input of the line flip-flop. This line flip-flop gives one output pulse for each two input pulses; therefore it gives one output pulse for each line of the scanning pattern. These output pulses are sent to the line retrace one-shot which produces (at its Assertion output) an output pulse which goes to -6 v.D.C. for the first 10 micro-seconds of each line. (The first 10 microseconds is the horizontal retrace time, while the 53.5 microseconds is the active time for each horizontal line). The vertical output is matched to the coaxial cable by emitter follower (E.F.) No. 22, and is used at the monitor, the video chain, and the flying spot scanner.

The last function of the synchronizing generator is the creation of a blanking waveform. The blanking waveform is a logical combination of the vertical and horizontal outputs resulting in a waveform having level of 0 v.D.C. during the active portion of each line, and having a level of -6 v.D.C. during both the horizontal retrace and vertical output intervals. This is accomplished by Nand gate No. 22, and emitter follower No. 21 matches this blanking waveform to the coaxial cable. This waveform is used in the flying spot scanner to turn the C.R.T. spot off and on.

Line Selector.

The line selector produces a negative output pulse during the active portion for one particular line out of 525 lines in the total scanning pattern. This will produce a black, horizontal line on the monitor C.R.T. Detailed circuit at Fig. 43.

The selector switches, 1, 2, 3 and 4 use input pulses, both normal and inverted, from the eleven flip-flops in the counter chain. The outputs from these switches (lines 1 to 11 on the line selector fold-out) are used as inputs to a 12 input

OR gate whose output goes to pin 22 (the complementary input) of the line selector flip-flop. Let us consider the output of this OR gate, assuming that the input from the assertion output of the DM-20 (or line retrace one shot) is disconnected. During the first field in a frame, there are 525 pulses (each corresponding to 1/2 of one line) fed into the synch. generator counter chain. There is a negative pulse, having a duration of 1/2 line, at the output of the OR gate, and this pulse will commence at a 1/2 line interval corresponding to a number N. The value of N is specified as the sum of the numbers N_1, N_2, N_3 and N_4, where the subscripts refer to the switch numbers, and the values are shown, on the line selector drawing, opposite each switch position. Note that N can be any value from 0 to 524; however these numbers refer to 1/2 line intervals whereas one wants them to refer to whole line intervals.

Now let us consider the waveform of the assertion output of the DM-20 (i.e. the line reset one-shot in the synch. generator). In every line the output is at -6 v.D.C. for the first 10 microseconds and is at 0 v.D.C. for the remaining 53.5 microseconds of each full line. In the first field of one frame, the negative pulse at the assertion output of the DM-20 will be coincident only with the negative going edge of the even numbered pulses from the OR gate output. Therefore if one connects the assertion output of the DM-20 to the 12 input OR gate, one will get an output pulse only during the retrace time for any even numbered line, selected by the 4 rotary switches. (i.e. Only during the first field of one frame).

The same circuit allows a pulse output for the odd numbered lines, only during the second field in each frame, i.e. the retrace pulse is coincident only with the odd numbered pulses from the 4 rotary switch outputs). The positive going edge of the output pulse from the 12 input OR gate will change the state of the line selector flip-flop so that the reset output will go from 0 v.D.C. to -6 v.D.C. (i.e. This happens at the start of the active portion of the line selected). At the end of this same line, the negation output of the DM-20 will change the line selector flip-flop reset output from -6 v.D.C. to 0 v.D.C. Further pulses from the negation output of the DM-20 have no effect until another pulse from the OR gate changes the state of this flip-flop.

Therefore this circuit allows one to generate a negative pulse for any of the 525 lines in the scanning raster, and this line selector output pulse is used to make one horizontal line black on the monitor C.R.T.

Monitor.

A Miratel Television Monitor Model No. T17MP is used to present the visual display to the operator. Some of the technical specifications are outlined below:

1) The C.R.T. provides screen dimensions of 14 by 10 1/2 inches. The phosphor used is type P4.

2) Linearity is 2% or better in both directions.

3) Video frequency response is plus or minus 1 db. to 12 megacycles, with low frequency tilt less than 10 percent using 50-50 duty cycle, 60 c.p.s. square waves.

4) Video input can be from 0.25 to 4.0 volts peak-to-peak. Black is negative.

This unit is completely transistorized except for the C.R.T. and the high voltage rectifiers.

Description of Flying Spot Scanner Block Diagram.

See Fig. 9.

The three input waveforms; vertical drive, horizontal drive, and blanking come from Fig. 8, the Synchronizing Generator Block Diagram.

Vertical Sweep Generator

This unit is described in the following instruction book;

Preliminary Instruction Manual for Monochrome Scanner Model TA 150 A.

Allen B. Dumont Lab. Inc.

Television Transmitter Division.

Clifton, New Jersey.

Horizontal Sweep Generator

This unit is also described in the above reference.

Blanking Amplifier

This unit too is described in the above reference.

High Voltage Power Supply

This commercial unit is manufactured by the:

Spellman High Voltage Company,
Bronx 69, New York.

The specifications for this unit are:

Model RG 30

Regulated output has positive polarity.

Regulated output is variable from 15 to 30 KV.

Output regulation is better than 0.5% from no load to full load.

Output current from 0 to 1.0 ma.

Regulated Focus output from 4 to 6 KV.

The high voltage power supply is controlled by the following unit.

Sweep Safety Circuits

If no sweep safety circuits were incorporated in the F.S.S., bad phosphor burns would appear on the F.S.S. C.R.T. whenever the H.V.P.S. was operating during failure of one or both sweep waveforms. There is a great danger here, especially when turning on the equipment, turning off the equipment, and during any component failure in either sweep generator or drive circuits.

A sampling resistor of small value is inserted in series with each sweep output transformer secondary. Thus a voltage waveform is available which is proportional to that particular sweep current. This resistor is followed by: a transformer, a rectifier, and a short time constant parallel RC filter. A D.C. voltage is developed across the RC filter which is proportional, roughly, to the peak value of the sweep current in the appropriate yoke winding. This voltage, together with an adjustable D.C. bias voltage, is applied to a D.C. transistorized discriminator so that two output states are available. One state corresponds to the normal output deflection current being present in the appropriate yoke winding, while the other state corresponds to either a reduced or zero yoke deflection current. Note that different time constants are required for the horizontal and vertical sweep channels. The time constant of each filter must be longer than the time for one complete sweep for that particular channel.

Each discriminator controls two relays which (i) cut off the H.V.P.S. and (ii) indicate a low or zero yoke current by means of a light on the control panel. In each channel, the first relay energises the second relay. When the second relay changes its state, it locks itself on so that even a momentary low yoke current will cut off the H.V.P.S. and indicate this mode of operation by means of the appropriate light. A reset switch on the control panel allows one to unlatch the second relay; so that if the trouble was a transient, the H.V.P.S. will be turned on, or if the trouble was legitimate, the H.V.P.S. will be cut off again.

By using this type of circuitry the phosphor screen of the F.S.S. C.R.T. should be saved from burns due to the coincidence of insufficient sweep yoke current(s) and the presence of the F.S.S. high voltage.

The circuit used is shown in Fig. 36.

Description of Video Chain Block Diagram. (See Fig. 10)

H.V.P.S. for Photomultiplier.

This is a commercial unit manufactured by Nuclear Research Corporation, Philadelphia, Pennsylvania. The specifications needed in this application are; (1) well regulated output D.C. voltage, (2) small output voltage drift with time, (3) variable output voltage, so that the photomultiplier current gain can be changed. This unit has the following characteristics:

Continuously variable: (300 to 2,500) v.D.C.
(0 to 1) ma.

Line stabilization: plus or minus 1% line change gives an output change, at 2,500 v.D.C. of less than plus or minus 0.01%, with a 1.0 ma. load.

Load stabilization: output voltage change is less than plus or minus 0.5% from 0 to 2,000 v.D.C. for a 1.0 ma. load.

Ripple: peak value is less than 0.1 volt for an output voltage of 2,500 v.D.C.

This H.V.P.S. for the photomultiplier can be shut off by the following unit.

Safety Circuit in Photomultiplier Holder.

The photomultiplier holder provides a rigid mounting base for the photomultiplier, provides magnetic and electrical shielding for the photomultiplier tube, and houses the dynode resistive divider chain. In addition a safety circuit is provided which operates a relay when the photomultiplier average anode current exceeds 5 ma. This relay activates a second relay which shuts down the photomultiplier H.V.P.S. and indicates this mode of operation by means of an indicator light on the control panel. Figure 31 gives the detailed circuit.

Photomultiplier.

The photomultiplier used in this equipment is a Dumont 6292. Some reasons for this choice follows; (i) relative spectral response is S 11 which extends to both higher wavelengths and lower wavelengths than the P 16 phosphor relative response, (ii) large value of photocathode luminous sensitivity, (iii) large current gain (i.e. 10 dynodes), (iv) low noise characteristics.

The overall relative spectral response curve, obtained by multiplying the S 11 photomultiplier relative response curve by the P 16 phosphor relative response curve, is shown in Fig. 5.

Preamplifier for Photomultiplier Tube.

The requirements for this unit are: (i) low noise, (ii) constant voltage gain over a wide frequency range, (iii) linearity of output with respect to input signals, and (iv) low output impedance.

The design uses two Nuvistor tetrode tubes for low noise and low microphonic operation. The voltage gain has an average value of 52.5 from 200 kcs. to 10.0 Mcs., is substantially flat to 7.0 Mcs., and falls off to 46.0 at 10.0 Mcs. The voltage gain values are given with an RG 62A/U cable, terminated in 100 ohms, connected to the output terminal.

N.B. All video, and Blanking waveforms are passed from one unit to another by means of RG 62A/U cable.

The wide frequency range is obtained by using shunt peaked high frequency circuits of standard form. The linearity from input to output is good up to an output voltage of 1.0 v. r.m.s. with the same output termination as above. The output impedance is low due to the use of a double triode in a White Cathode Follower type of circuit. The output impedance of this preamplifier is designed to be 100 ohms, and therefore gives a good impedance match to the above mentioned cable. Fig. 32 gives a detailed schematic.

Phosphor Correction Unit.

The phosphor used in the flying spot C.R.T. is a P 16 type. (The F.S.S. C.R.T. is a 5ZP16 tube manufactured by R.C.A.).

When an area on the phosphor has not been swept by the electron beam for a long time, its brightness is zero. Now if the electron beam strikes this area, the brightness output increases to 100%, practically instantaneously. The phosphor excitation is practically instantaneous, but its decay, or relative brightness versus time after excitation is removed, (see Fig. 11) is in the form of an exponential series. This curve can be represented mathematically by the following expression:

$$L(t) = ae^{-\beta t} + be^{-\alpha t}$$

where: $L(t)$ is the relative brightness as a function of time after excitation is removed.

t is time after excitation is removed, in microseconds.

a is a constant, (85.0%).

b is a constant, (15.0%).

β is a constant, 1/0.023 microseconds.

α is a constant, 1/0.18 microseconds.

N.B. $L(0) = 100\%$ when $t = 0$ microseconds.

If one considers that the C.R.T. phosphor is excited by a focussed beam of constant energy electrons, moving with constant velocity across the screen, and if one assumes that the same number of electrons strike the phosphor, per unit time, then the constant area under the beam, at any time, will have a relative brightness of 100%. This also assumes that the phosphor has a uniform light output, under these conditions, over the whole useful area of the C.R.T. phosphor screen.

From the phosphor decay expression, L(t), one can see that the light emitted by any particular area on the screen, which has been swept by the electron beam, dies off with time according to L(t). Therefore, if the electron beam moves at constant velocity across the screen, the light output may be considered to have a shape <u>along the line</u> given by the formula L(t).

Now consider that the spot of light from the screen is focussed on a plane which has white (transparent) and black (opaque) areas, as in Fig. 12 part (a). When the spot is focussed on the black area, no light gets to the photomultiplier. The direction of the spot movement is perpendicular to the black-to-white interface. When the focussed spot moves from the black to the white area, as in Fig. 12 part (b), the brightness seen by the photomultiplier corresponds only to the brightness from the phosphor area being struck by the electron beam. As the focussed spot moves further into the white area, see Fig. 12 part (c), the <u>total</u> brightness seen by the photomultiplier is

(i) the brightness due to the new position of the focussed spot, plus (ii) the brightness from the previous position of the focussed spot. Note that (ii) the brightness of the previous position of the focussed spot is decaying with time as L(t), while (i) the brightness of the new position of the focussed spot is exactly the same in Fig. 12 part (c) as in Fig. 12 part (b). Thus the brightness input to the photomultiplier, as a function of time, is the integral, with respect to time, of the phosphor brightness output for the F.S.S. C.R.T. being used.

What is needed is some form of equalization so that the voltage produced after equalization will give an accurate representation with respect to time of the positions of black and white areas which have been illuminated by the flying spot of light produced by the flying spot scanner.

The fact that the persistence characteristic curve for the P 16 is a sum of two exponentials simplifies the electronic details of the equalization.

It can be shown that two equalization circuits can provide the needed equalization if the circuits take the form, see Reference 7, shown in Fig. 13. N.B. In Network #1, one assumption is used, i.e. that $R < R_1$ in order that the frequency amplitude response can increase sufficiently with frequency, over the frequency range used in the video signal. This condition was fulfilled by using $R = \frac{1}{100} R_1$.

The necessary equilization conditions for the flying spot of light to traverse a black-to-white or white-to-black boundary are:

$$L(t) = ae^{-\beta t} + be^{-\alpha t}$$

$$= \frac{R_3}{(R_2 + R_3)(R_1C_1 - R_3C_2)} \left[\frac{R_2}{R_3} \; e^{-\frac{t}{R_3C_2}} - \left[\frac{(R_2 + R_3)C_2}{R_1C_1} - 1 \right] e^{-\frac{t}{R_1C_1}} \right]$$

A block diagram of the phosphor correction unit is shown in Fig. 14.

The calculated values used are:

R = 120 ohms.

R_1 = 12,000 ohms.

C_1 = 15. micro micro farad.

R_2 = 680 ohms.

C_2 = 97. micro micro farad.

R_3 = 240 ohms.

The resistance values used were 10% components, so that some means of optimizing the values of C_1 and C_2 was needed. The following method was used.

The amplitude response with respect to frequency was calculated for each network separately, then the two response curves were multiplied point by point giving an overall response curve which assumes no interaction between the two networks. Two graphs were prepared; one with amplitude response of network #2 versus frequency, and the second with the overall amplitude response versus frequency.

With a constant amplitude, variable frequency signal applied at the first grid of the isolation amplifier 6 A K 5, the value of C_2 was adjusted until a good fit was obtained for the amplitude versus frequency response of this 6 A K 5 and network #2, compared to the first graph. The input signal was then moved to the input of network #1, and the value of C_1 was varied until the measured overall amplitude response was optimized with respect to the second graph.

The final result for overall amplitude response versus frequency is shown in Fig. 15.

The overall voltage gain can be varied from zero to two, and this unit is useful up to a frequency of 4.0 megacycles as seen from Fig. 15. Fig. 33 gives the detailed schematics.

Gamma Correction Unit.

The curve of brightness output versus cathode volts input (i.e. cathode drive conditions used) is not linear for the 17AVP4A C.R.T. used in the monitor. However the curves of the photomultiplier anode current versus input brightness are linear. Thus some form of compensation must be used in order to obtain a linear relationship between the light brightness input to the photomultiplier, and the light brightness output from the C.R.T. monitor screen.

There is one very convenient characteristic of the video voltage signal from the photomultiplier anode resistor, which is very useful. Since the F.S.S. C.R.T. is blanked off (i.e. has no light output) during the horizontal retrace time following each line scanned, there is a resultant black level inherent in the video waveform. See Fig. 16.

The screen brightness of the 17AVP4A can be described by the following formula:

$B = k(es)^{\gamma_1}$ where B is screen brightness,

k is a constant,

(es) is the video signal (volts) from raster cutoff,

γ_1 is a constant.

N.B. "Raster cutoff" is the cathode voltage for cutoff, or for zero screen brightness (i.e. at the "black level").

Using the graphical presentation as shown in Fig. 17 (i.e. log B versus log es), one can calculate the value of the constant γ_1. In this case, γ_1 is 2.77.

Since small values of es result in low screen brightness (i.e. near blacks) and since γ_1 is positive, it can be easily seen that the near blacks are compressed far more than the near whites. By varying the "setup" (or bias voltage for the 17AVP4A) and the overall video system gain, one can obtain a whole family of overall brightness characteristics; however, none of these curves will be linear. In order to get a linear brightness input to brightness output curve, one must take the γ_1th root of the video signal before the video signal is applied to the monitor C.R.T.

The "rooter" or Gamma Corrector equation is:

$$es = k'(b)^{1/\gamma_2}$$

where: k' is a constant,

b is the brightness input at the photo-multiplier, and

γ_2 is a positive constant.

N.B. The constant k' represents the video gain from the photo-multiplier light input to the video voltage output applied to the Gamma Corrector.

$$B = kk'(b)^{\gamma_1(1/\gamma_2)}$$

Now if $K = kk'$, and if $\gamma_2 = \gamma_1$, then

$$B = K(b).$$

And it can be seen that the result is the required linear relationship between the brightness input (b) and the brightness output (b).

The particular type of Gamma Corrector used follows the ideas of B. M. Oliver in Reference 8. A brief description follows:

The block diagram is given in Fig. 18.

The input video signal generator, after having its "black level" restored by the clamp circuit, drives a linear current generator. This video current goes into a nonlinear impedance (one half of a 2C51 dual triode vacuum tube) resulting in an output video voltage (the rooted signal) which is matched to the output cable by a White Cathode Follower output stage.

The plate current versus grid current curve for a triode can be closely approximated by a power law relation. Fig. 19 gives the characteristic curve if one plots the cathode current versus cathode to grid voltage for the 2C51 with 150 v.D.C. from plate to cathode, and minus 7 v.D.C. for the grid with respect to the cathode.

The power law equation is:

$$I = c(E)^{3.3}$$

where: I is the cathode current,

E is the cathode to grid voltage,

and c is a constant.

Now if I is the independent variable, and if E is the dependent variable, then the cathode to grid voltage (E) will be the 3.3rd root of the cathode current (I). Since we only require the 2.77th root, suitable circuitry changes must be made. The methods used are given in Reference 8.

One more characteristic of such a rooter should be mentioned, the bandwidth decreases as the cathode impedance of the rooter increases. If one looks at the curve in Fig. 19, then the cathode impedance is equal to E/1, and this value is high for small cathode currents, (i.e. video signals near black) and is low for large cathode currents (i.e. video signals near white). Hence there is less bandwidth for a black signal than for a white signal. In the design used, there is adequate bandwidth for the black and white video signals obtained from the emulsion scanning process.

Experimental results for Vout versus Vin are plotted on Fig. 20. Using a line of best fit, one can calculate a slope of 1/2.15. Consider the effect of adding a constant voltage increment (called "setup") to each value of Vout, and then plotting (Vout plus "setup") versus (Vin). The slope of the new line of best fit will be smaller, since the left end will be raised more than the right end for the line of best fit. A particular example is shown (using the circles) on Fig. 20. Here one can see that by using a "setup" of 40 millivolts, one can obtain a power of 1/2.77 which, when combined with a value of gamma of 2.77 for the monitor C.R.T. gives an overall gamma of 1.00. Assuming an overall system gamma of 1.00, then a graphical idea of the usefulness of the Gamma Corrector Unit can be found from Fig. 21.

Note that "setup voltage" refers to a D.C. voltage which is added to the video output of the Gamma Corrector Unit so that the log log graph is linear.

The amount of "setup" used is controlled by the Pedestal Inserter and Clipping Unit.

A detailed circuit drawing is shown in Fig. 34.

Pedestal Inserter and Clipper Unit.

This unit follows the γ corrector unit and provides control over the amount of "setup" voltage used, so that the overall system γ can be changed over a small range.

Depending on the absorption within the emulsion being scanned, one may have high contrast ratio picture information or low contrast ratio picture information.

(Contrast ratio is defined, in this section as: maximum brightness during the sweep time, divided by minimum brightness during the sweep time, where these terms are applied to the light input to the photomultiplier. Note that the absolute minimum brightness does not occur during the sweep, but does occur during the retrace time).

Since the photomultiplier has a linear relationship between light input and current output, and since the output current produces an output voltage if an anode load resistor is used, the photomultiplier output signal (video signal) can also be described by a voltage contrast ratio.

The black level is obtained during horizontal retrace, where the black level refers to the video voltage output at the anode of the photomultiplier (i.e. the F.S.S. C.R.T. is blanked off during horizontal retrace).

The low contrast ratio video signal appears as in Fig. 22(a), while the high contrast ratio video signal appears as in Fig. 22(b).

The low contrast level video signal is caused by an emulsion which absorbs much of the light available from the F.S.S., while the high contrast ratio video signal is obtained when an emulsion absorbs less of the available light from the F.S.S.

Note that in Fig. 22(a) and (b) the black level at the anode of the photomultiplier is constant for both the high and low contrast ratio pictures.

If the video signal is now amplified by an A.C. coupled amplifier, the average value for video signals having low contrast ratio and high contrast ratio would be as shown in Fig. 23. There would be equal areas above and below the average D.C. value as shown by the shading. In an A.C. coupled circuit one always has a D.C. operating point about which the A.C. signal varies. Therefore if the average D.C. value of the above waveforms is the D.C. operating point of the monitor C.R.T., then one can see that the "black level" will appear <u>more black</u> for high contrast ratio video signals and <u>less black</u> (i.e. a lighter shade of grey than black) for low contrast ratio video signals. Also, the white level will be <u>more white</u> (i.e. brighter) for high contrast ratio signals than for low contrast ratio video signals. One must have some standard, and the "black level" is the obvious choice. The circuitry must now be arranged such that the "black level" on the video waveform gives a constant black visual output from the monitor C.R.T. <u>no matter what value one has for the contrast ratio.</u>

In the section describing the γ corrector Unit, it can be seen from Fig. 20 that a "setup voltage" must be added to the output of the corrector to obtain a power law relationship. This term "setup voltage" is a constant voltage added to the video signal.

The video input has the black level clamped by clamp circuit #1 to a D.C. reference voltage at the grid of mixer #1. See Fig. 24. This also fixes the D.C. voltage for the black level at the plate of mixer #1 (see Fig. 25a). During the retrace time (i.e. time during which the black level is found in the video signal) a pedestal is generated and is added to the video signal present at the plate of mixer #1 as at Fig. 25b. This waveform is A.C. coupled to the input of mixer #2 where clamping, via clamp circuit #2, establishes a D.C. reference voltage level as in Fig. 25c. At the output of mixer #2, a portion of the pedestal is removed by the clipping level circuit, as in Fig. 25d, so that the output video signal appears as in Fig. 25e. The video portion of the signal is amplified linearly, while the setup voltage (see Fig. 25d) is added. This gives an overall power law relationship from the input of the γ Correction Unit to the output of the Pedestal Inserter and Clipper Unit. Note also that the amount of Setup voltage can be controlled by adjustments to the Clipping Level Circuit in the Pedestal Inserter and Clipper Unit. The circuit details are shown in Fig. 35.

XY Stage System.

This system consists of a lower stage (X direction) which carries an upper stage (Y direction). Emulsion plates can be mounted on removeable frames which can be fastened to the Y stage. The stage is shown in Fig. 3.

The X stage is constrained to move, in a straight line, over a maximum distance of 30 cm by a dovetail arrangement. The leadscrew was designed to move the X stage 635 microns for one revolution, and was produced in the university machine shop. This leadscrew is driven by a 400 cps. servo motor which is geared down first by a factor of six, using spur gears, and finally by a factor of 100, using a wormgear arrangement. By varying the speed and direction of the X servo motor, the X leadscrews angular velocity (or the X stage velocity) can be varied from zero to maximum in either the plus or minus X stage direction. The bottom portion of the Y dovetail, the Y leadscrew (similar to the X leadscrew), the Y servo motor, and its geartrain are all mounted on the moveable part of the X stage. The moveable part of the Y stage is constrained, by a second dovetail, to move at right angles to the X stage motion. (Maximum Y stage travel is 10 cm). Control of the velocity of the Y stage is similar to that described above for the X stage. Maximum stage velocities are approximately 85 microns/sec.

In this manner we have obtained an XY stage which will position and move an emulsion plate anywhere within an area of 30 by 10 cm in the XY plane.

X and Y Velocity Servo Systems and Stage Control Box.

If the X and Y servos have constant velocities, each controlled by the operator, then the XY stage can be moved at any angle in the XY plane. In order to have full control over the XY stage, one must be able to control each leadscrew, by means of its velocity servo, for the following conditions:

(i) When the stage is not moving the servo amplifiers should not consume power.

(ii) The servo velocity should be controllable over a range from full velocity to approximately one tenth of full velocity.

(iii) The servo must be able to drive its appropriate stage in either direction.

(iv) It should be possible to set the servo to run at a constant velocity, when its appropriate stage must be moved over a large distance.

Since the XY stage Control Box will be mentioned in later sections, its description will be given here. A photograph of the control box is shown in Fig. 26. The control box combines the two velocity servo input controls in one lever. When this lever is moved to the right or left of its centre position, the X servo moves the X stage such that the visual presentation on the monitor moves respectively left or right. (i.e. It appears to the observer that he is moving, within the emulsion, to his right or to his left). The further one moves the lever from its centre position, the greater the X servo velocity, and also the greater the X stage velocity. The same lever, when moved away or toward the operator, affects the Y stage so that the visual presentation on the monitor moves down or up. (i.e. This makes the observer feel that he is moving away from or toward any fixed point within the emulsion). Again, the further one moves the lever from its centre position, the greater the Y servo velocity, and also the greater the Y stage velocity. If the lever on the control box is moved at an angle, then the X stage will have an appropriate velocity, while simultaneously the Y stage will also have its own appropriate velocity. The result will be an angular movement of the upper stage with respect to the XY coordinate system.

A block diagram for one stage velocity servo is shown in Fig. 27. The second stage velocity servo is identical. The four conditions which each stage velocity servo must meet are accomplished as below.

(i) The lever on the control box, is mounted directly on a shaft which restricts the lever to fore and aft motions. This shaft is free to rotate, about its long axis, within a frame which can be tilted from side to side. The frame rotates about a shaft whose axis is perpendicular to the first shaft, thus allowing the lever to move from side to side. Each shaft is connected to a rotary switch which opens a circuit when the lever is within 5 degrees from the vertical. One rotary switch goes to the X servo and can force this servo to stop, thus consuming a minimum of power.

A similar rotary switch on the other control box shaft can force the Y servo to stop, as well.

(ii) Each of these two shafts is connected to a potentiometer. Each potentiometer produces a D.C. output voltage which is proportional to the X or Y component of the angle between the vertical and the control box lever position. These two D.C. lines serve as inputs to the X and Y velocity servos.

(iii) A second rotary switch on each control box shaft changes the phase of the signal to one of the two output amplifiers for each velocity servo motor. This changes the direction of rotation of the appropriate leadscrews.

(iv) The X and Y servos will run at a constant velocity if the control box lever is moved at some angle with respect to the vertical. Each servo has an electronic tachometer, which has a variable frequency input, caused by the light chopper disc in the gear train, and has a D.C. output voltage which is approximately linear with respect to the disc r.p.m. The D.C. output from the tachometer is compared to the D.C. input from the control box, and the difference signal is converted to 400 c.p.s. by the electronic chopper. Servo output amplifier #2 produces a variable amplitude 400 c.p.s. output voltage. Servo amplifier #1 produces the constant amplitude 400 c.p.s. current in the reference winding of the servo motor. In this way the servo output velocity remains constant with respect to the D.C. input signal generated by the control box lever position.

Fig. 28 shows a plot of stage velocity versus control box lever position for either the X or Y direction of stage movement. In this figure, the non-linearity is due to the electronic tachometer.

Detailed wiring diagrams for the XY stage system follow: Fig. 37, 38, 39, 40, and 41.

Calibration Procedures for the System.

Linearity and Size Set-Up Procedures.

1) The F.S.S. yoke was adjusted so that the Y direction of the F.S.S. C.R.T. sweep was parallel to the Y stage motion.

2) The above procedure will also align the direction of the X sweep on the F.S.S. C.R.T. to be parallel to the direction of the X stage motion.

3) A glass backed, contact print of graph paper having a 1/8" square grid was prepared beforehand. This is called the "grid plate".

The grid plate is mounted so that its emulsion side is against the flat face plate of the F.S.S. C.R.T. The focus adjustment of the F.S.S. C.R.T. was adjusted so that the grid came into focus on the monitor C.R.T.

4) Adjust the vertical and horizontal size controls so that the width over height ratio of the raster on the F.S.S. C.R.T. is 4/3, where the raster has as large an area as possible. (i.e. This is limited by the horizontal and vertical deflection generators).

5) Display the video waveform on an oscilloscope which has its sweep triggered at the horizontal rate. Adjust the horizontal linearity controls on the F.S.S. so that the video markers caused by the vertical bars on the grid plate are as equally spaced as possible. This will optimize the horizontal sweep linearity of the F.S.S.

6) Display the video waveform on an oscilloscope which has its sweep triggered at the vertical rate. Adjust the vertical linearity controls on the F.S.S. so that the video markers caused by the horizontal bars on the grid plate are as equally spaced as possible. This will optimize the vertical sweep linearity of the F.S.S.

7) Check the new ratio of width over height to find out if it is 4/3. If not, reduce the appropriate size control setting until the ratio of 4/3 is obtained.

8) Repeat steps 5) and 6) until 7) is correct.

This will give optimum X and Y dimensions for the F.S.S. C.R.T. raster, corresponding to the limitations of sweep, size and sweep linearity for the deflection amplifiers used in the F.S.S.

9) The ratio of width over height for the monitor C.R.T. is now adjusted to 4/3. This is done for the largest possible area on the monitor C.R.T.

10) Adjust the monitor C.R.T. horizontal linearity controls so that the vertical bars caused by the grid plate are as evenly spaced as possible.

11) Adjust the monitor C.R.T. vertical linearity controls so that the vertical bars are as evenly spaced as possible.

12) Check the resultant ratio of width over height on the monitor C.R.T. to find if it equals 4/3. If not, reduce the appropriate monitor size control setting until the ratio of 4/3 is obtained.

13) Repeat steps 10) and 11) until 12) is correct.

This will give optimum X and Y dimensions for the monitor C.R.T. raster corresponding to the limitations of sweep size and sweep linearity for the deflection amplifiers used in the monitor unit.

14) Remove the grid plate from the face of the F.S.S. C.R.T.

Method of Calibration of Spot Size for the F.S.S. C.R.T. using SMPTE Resolution Slide.

The Society of Motion Picture and Television Engineers (SMPTE) have a standard black and white wedge type of resolution slide. A photograph of this resolution slide is shown in Fig. 29. There are four sets of wedges on this slide; two horizontal sets of wedges to determine the vertical resolution, and two sets of vertical wedges to determine the horizontal resolution of any type of optical display.

Each set of vertical wedges has nineteen black wedges alternating with eighteen white (transparent) wedges. The wedges are very narrow near the centre of the resolution slide, and are wider as one looks toward the top or bottom of the slide. Each wedge has straight edges on both sides. Near the centre of the slide there is a short horizontal line marked off with the number "500". There are other horizontal lines marked off by "400", "300", and "250". If a horizontal sweep passes across the vertical wedge at "300", and if the wedges on the monitor have distinct edges opposite "300", then one would say that the system has a resolution of 300 "lines" at this point in the picture. Three hundred "lines" would correspond to 300 equally spaced, black and white alternate elements along the horizontal sweep direction.

One evaluates the number of lines, for horizontal resolution, by looking at the vertical wedges and determining the maximum number opposite the point where the black and white wedge pattern has not quite broken up into an indistinct grey smear. The vertical resolution is similarly determined by using the horizontal wedge patterns.

One can find the horizontal resolution in terms of distances as follows. Suppose the horizontal resolution was found to be 300 lines, and the horizontal sweep length was 600 microns. The horizontal resolution would be 600/300 or 2.0 microns.

A resolution slide for the flying spot microscope was prepared in the following manner. First a contact print was made of a standard 35 mm SMPTE resolution slide. This was then enlarged until it covered an area similar to the raster on the F.S.S. C.R.T. A second contact print was made of this enlargement, and the glass backed emulsion was developed and mounted so that it could be placed in contact with the flat face plate of the F.S.S. C.R.T.

This enlarged resolution slide was used to find the F.S.S. C.R.T. spot size as follows.

1. Calibrate the enlarged resolution slide using a stage type of optical microscope.

2. Mount the resolution slide so that its emulsion is against the flat face of the F.S.S. C.R.T.

3. Focus the F.S.S. so that the wedge patterns are in good focus on the monitor C.R.T.

4. Determine the horizontal and vertical resolutions, in numbers of lines.

5. Determine the useful sweep lengths at the F.S.S. C.R.T. screen for both the vertical and horizontal directions.

6. Calculate the F.S.S. C.R.T. spot size (i.e. both vertical and horizontal components) in microns.

Discussion on Video Bandwidth and the SMPTE Resolution Slide.

In this discussion one assumes the resolution slide to be made up of alternately black and transparent equal width vertical strips. Assume that N of these strips correspond to the length that the F.S.S. C.R.T. flying spot scans in each horizontal line. Since the active portion of each horizontal line occupies 53.5 microseconds, one finds (53.5/N) microseconds as the time corresponding to the passage of the flying spot over each black and each transparent strip. If the spot diameter is infinitely small compared to the width of each strip, then the photomultiplier anode current would be a perfect square wave, with a period of (2 x 53.5/N) microseconds. If one increases the number of strips, and keeps the spot diameter constant, the current square wave will have a smaller periodic time, and will also suffer a loss in its harmonic content. That is to say, the square waves will lose their fast rise times and will begin to resemble sine waves. However, as long as the strip widths are equal to or greater than the spot diameter, the current waveform will reach a "black level" and a "white level". If the strip widths become <u>smaller</u> than the spot diameter, the current waveforms will <u>not</u> reach the "black" and "white" levels, but will have maxima and minima between these levels.

The effects of bandwith can be illustrated from the following example. Assume that N = 200. Therefore the square wave period is 0.535 microseconds. These square waves have a fundamental frequency of 1.87 megacycles.

1) A bandwidth of 18.7 megacycles would give good results for a spot size small with respect to line width. Also the maxima and minima would reach both black and white levels.

2) If the spot size equals the strip width, a bandwith of 18.7 megacycles has no advantage over a bandwidth of 1.87 megacycles, since there is very little harmonic content. Again the maxima and minima will reach both black and white levels for the 1.87 megacycles.

3) If the spot size is larger than the strip width, any bandwidth of greater than (D/2 x 53.5 microseconds) is not

utilized. N.B. "D" is the ratio of scan length to spot diameter. Here, however, the maxima and minima will <u>not</u> reach the black and white levels. This is true no matter how <u>high</u> the bandwidth, as long as it is larger than (D/2 x 53.5 microseconds).

4) Note that case 2) with a bandwidth <u>less</u> than 1.87 megacycles will appear to be equivalent to case 3).

Therefore if the bandwidth is too low, the effect will be to make the scanning spot appear larger in diameter than it actually is.

Assuming a round spot, what value of bandwidth would be appropriate for the flying spot microscope? Assume that one wants to examine an area 400 by 400 microns with a spot of diameter equal to 2 microns. Ignoring the demagnification factor from F.S.S. C.R.T. to focal plane, the bandwith is:

$$\frac{400 \text{ microns}/2 \text{ microns}}{2 \times 53.5 \text{ microseconds}} = 1.87 \text{ megacycles.}$$

One should treat this value as a lower limit, and a safety factor of 2 results in a design bandwidth of 3.74 megacycles.

Calibration of the Enlarged Resolution Slide.

The stage microscope (E. Leitz Wetzlar) was calibrated so that 1 division of the eyepiece graticule equalled 11.15 microns in the plane of the object.

Eyepiece: Periplan 10 X

E. Leitz Wetzlar

Objective: 10:1

A 0.25

E. Leitz Wetzlar.

Horizontal width of enlarged resolution slide (inside border):

63.8 ± 0.5 mm.

Vertical Height of enlarged resolution slide (inside border):

48.1 ± 0.5 mm

Width/Height should equal 4/3

Width/Height = 63.8/48.1 = 1.33

Determination of Width of Horizontal Elements at 300 Lines.

Black Wedge Number	Eyepiece Divisions	Black Element Width	White Element Width
		Eyepiece Divisions	
1	9.0 30.0	21.0	
2	42.0 62.0	20.0	12.0
3	75.0 10.0 31.0	21.0	13.0
4	42.5 63.5	21.0	11.5
5	10.0 76.5 30.0	20.0	13.0
6	42.5 63.5	21.0	12.5
7	76.0 10.0 30.5	20.5	12.5
8	43.0 63.0	20.0	12.5
9	10.0 75.5 31.0	21.0	12.5
10	43.0 63.0	20.0	12.0

Black Wedge Number	Eyepiece Divisions		Black Element Width	White Element Width
			Eyepiece Divisions	
11	75.0	10.0 30.5	20.5	12.0
12	43.0 63.5		20.5	12.5
13	10.0 30.0	75.5	20.0	12.0
14	42.5 62.5		20.0	12.5
15	75.0	10.5 31.0	20.5	12.5
16		42.5 62.0	19.5	11.5
17	10.0 29.0	76.0	19.0	14.0
18	41.5 60.5		19.0	12.5
19	74.0	40.0 61.5	21.5	13.5

Average Horizontal Black Element Width at 300

= ((19.0 x 2) + (19.5 x 1) + (20.0 x 6) + (20.5 x 4)

+ (21.0 x 5) + (21.5 x 1)) x 11.15/19

= 227. microns.

Average Horizontal White Element Width at 300

= ((11.5 x 2) + (12.0 x 4) + (12.5 x 8) + (13.0 x 2)

+ (13.5 x 1) + (14.0 x 1)) x 11.15/18

= 139. microns.

Average Width of One Horizontal Element at 300

= (227 + 139)/2

= 183. microns.

Number of Horizontal Elements at 300

= 63.8/0.183

= 349

N.B. This value is large by 16%; however a similar calibration on Enlarged Resolution Slide No. 1, gave a similar result, i.e. 16% too high in the horizontal direction.

Therefore the actual number of equal length horizontal elements is 16% larger than specified on the slide, at 300 lines.

Determination of Height of Vertical Elements at 300 Lines.

Black Wedge Number	Eyepiece Divisions	Black Element Height	White Element Height
		Eyepiece Divisions	
1	10.0 30.5	20.5	
2	44.5 63.0	18.5	14.0
3	76.0 10.0 27.0	17.5	13.0
4	42.0 61.0	19.0	14.5
5	73.0 10.0 92.0	19.0	12.0
6	24.0 42.5	18.5	14.0
7	56.0 74.5	18.5	13.5
8	87.5 10.0 29.5	19.5	13.0
9	43.0 62.0	19.0	13.5

Black Wedge Number	Eyepiece Divisions	Black Element Height	White Element Height
		Eyepiece Divisions	
10	74.0 10.0 93.5	19.5	12.0
11	22.0 42.5	20.5	12.0
12	55.0 73.0	18.5	12.5
13	87.0 10.0 29.5	19.5	13.5
14	42.0 63.0	21.0	12.5
15	75.0 10.0 93.5	18.5	12.0
16	23.0 43.5	20.5	13.0
17	55.0 74.5	19.5	11.5
18	87.0 20.0 39.0	19.0	12.5
19	52.0 71.0	19.0	12.0

Average Black Element Height at 300

= ((17.5 x 1) + (18.5 x 5) + (19.0 x 5) + (19.5 x 4)

+ (20.0 x 1) + (20.5 x 3)) x 11.15/19

= 214. microns.

Average White Element Height at 300

= ((11.5 x 1) + (12.0 x 5) + (12.5 x 3) + (13.0 x 3)

+ (13.5 x 3) + (14.0 x 2) + (14.5 x 1)) x 11.15/18

= 199. microns.

Average Width of One Vertical Element at 300

= (214 + 199)/2

= 207 microns.

Number of Vertical Elements at 300

= 48.1/0.207

= 232.

Note that the height of the resolution slide is smaller than its width by a factor of 3/4. One wants the length of a vertical element to be equal to the length of a horizontal element; therefore one must multiply the above value by 4/3 and after that compare to 300.

232 x 4/3 = 309.

Therefore the actual number of equal length vertical elements is 3% larger than specified on the slide, at 300 lines.

Calibration of the Flying Spot Microscope.

(1) Scanning Geometry and Magnification.

The overall magnification can be defined as:

See Fig. 6.

$M = Mo(Mg)$ where M is overall magnification,

Mo is optical magnification,

Mg is geometrical magnification.

One can also see that by using the X direction only, (i.e. linear magnification), one has:

$Mo = x/a$ optical magnification.

$Mg = X/x$ geometrical magnification.

Therefore,

$$M = x/a(X/x)$$

$$M = X/a$$

In order to have linearity in the XY plane scanned within the emulsion, one must have the same ratio of x/y and X/Y. This is accomplished by suitable adjustments in the two sets of scanning sweep generators (i.e. for the F.S.S. C.R.T., and for the monitor C.R.T.). In this way, a circle scanned within the emulsion would appear as a circle on the monitor C.R.T., and not as an ellipse.

(2) "Useful Area Scanned" at Monitor C.R.T. and at F.S.S. C.R.T.

Since the total area of the picture on the monitor C.R.T. does not have good linearity, one should confine the calibration to the "useful area scanned": i.e. to that portion of the total area scanned which does have good linearity.

The dimensions of the "useful area scanned" were determined as follows:

i) First complete the "Linearity and Size Set-up Procedure".

ii) Install the "grid plate" so that its emulsion side is against the F.S.S. C.R.T. face.

iii) View the monitor C.R.T. screen and decide in which regions the intersecting vertical and horizontal bars produce squares, as compared to the regions where rectangles are produced. Wherever the visual presentation shows rectangles there is linearity distortion, and wherever the patterns are square there is good linearity. (This evaluates both horizontal and vertical linearity since the grid plate is made of two sets of parallel lines, with one set of lines perpendicular to the other set.

iv) The results are evaluated below, with reference to Fig. 6.

1) Width of "Useful Area Scanned" on Monitor 30 1/2 squares on grid plate = 10" $\pm \frac{1}{16}$ inches wide.

2) Height of "Useful Area Scanned" on Monitor screen = 24 squares on grid plate = $3\frac{1}{8}$" $\pm \frac{1}{16}$ inches high.

The errors were evaluated to be, plus or minus $\frac{1}{4}$ square at each edge, making the width = $30\frac{1}{2}$ plus or minus $\frac{1}{2}$ square, and the height = 24 plus or minus $\frac{1}{2}$ square.

One can also calculate the corresponding "useful area scanned" on the flying spot screen raster, since the grid plate, which produces the vertical and horizontal bars on the monitor C.R.T. screen, is mounted against the face of the F.S.S. C.R.T. The vertical and horizontal line spacings on the grid plate are $\frac{1}{16}$ inch, so that the raster dimensions are $(30.5 \times \frac{1}{16})$ by $(24 \times \frac{1}{16})$ inches. (Useful area only).

3) Width of "Useful Area Scanned" at the F.S.S. C.R.T. raster = 1.91 inches.

4) Height of "Useful Area Scanned" at the F.S.S. C.R.T. raster = 1.50 inches.

(3) Resolution of F.S.S. C.R.T. Spot Size in "Lines".

i) Install the Enlarged Resolution Slide so that its emulsion side is against the face of the F.S.S. C.R.T.

ii) Focus the F.S.S. C.R.T. with no emulsion plate under the objective lens, but with two glass slides, with a thickness of 1.25 mm under the objective lens.

(a) Use oil if an oil immersion objective is being used.

(b) Do not use oil if low power objectives are being used.

iii) Normalize the video voltage, at the output of the photomultiplier preamplifier to 3.0 volts P-P by adjusting the photomultiplier high voltage power supply.

iv) Determine the resolution, in numbers of "lines", for the various lenses used with the F.S.S. microscope, using the image on the monitor screen.

1) Observed Resolution in "Lines" versus Lenses.

Manufactured by	Lens Identification: Magnification	Aperture	Air	Oil	Resolution in "Lines" from Monitor Screen Image: Vertical	Horizontal
		-				
E.L.W.	10:1	-	X		325 ± 25	375 ± 25
Prior	25:1	0.50	X		300 ± 25	350 ± 25
E.L.W.	53:1	0.95		X	275 ± 25	325 ± 25
E.L.W.	100:1	1.30		X	275 ± 25	325 ± 25

2) Corrections to the Observed Resolution Values.

Correction No. 1.

From the section entitled "Calibration of the Enlarged Resolution Slide", one knows that the resolution values on the slide are 16% too low in the horizontal direction, and 3% too low in the vertical direction. Therefore the horizontal resolution values must be multiplied by 1.16, and the vertical resolution values must be multiplied by 1.03.

Correction No. 2.

Only a portion of the image of the enlarged resolution slide is shown on the monitor C.R.T. screen. Therefore the resolution values must be diminished as shown below.

Dimensions of "Useful Area Scanned" at F.S.S. C.R.T. are:

1.91 inches in the horizontal direction.

1.50 inches in the vertical direction, see (2) previously.

Dimensions of Enlarged Resolution Slide No. 3 are:

63.8 mm (or 2.51 inches) in the horizontal direction.

481 mm (or 1.89 inches) in the vertical direction.

Therefore the horizontal resolution values must be multiplied by 1.91/2.51, while the vertical resolution values must be multiplied by 1.50/1.89.

3) Corrected Resolution Values for F.S.S. C.R.T. Spot Size.

Lenses Used	Vertical Resolution	Horizontal Resolution
10:1	266 ± 20 "lines"	331 ± 22 "lines"
25:1	245 ± 20 "lines"	310 ± 22 "lines"
53:1	225 ± 20 "lines"	287 ± 22 "lines"
100:1	225 ± 20 "lines"	287 ± 22 "lines"

4) Dimensions of "Useful Area Scanned" at the Focal Plane.

i) Remove the Enlarged Resolution Slide from the face of the F.S.S. C.R.T.

ii) Install a microscope stage graticule on the XY Stage so that the lines appear horizontal on the monitor screen.

iii) Adjust the F.S.S. microscope so that the visual presentation on the monitor screen shows the graticule in focus.

iv) Use oil on the graticule only when an oil immersion lens is being used.

v) Record line numbers for (i) the top and (ii) bottom edges of the useful area scanned. Record line numbers on the centres of the two closest graticule marks, to both top and bottom edges. From this data one can interpolate to obtain ordinates for the top and bottom edges of the useful area scanned.

vi) Calculate the height of the "useful area scanned" at the focal plane for each lens used.

vii) Calculate the width of the "useful area scanned" at the focal plane for each lens used, since the ratio of width over height for the "useful area scanned" is known for the raster at the face of the F.S.S. C.R.T.

i.e. Width = Height x (ratio of width over height, at the raster, on the F.S.S. C.R.T.).

= Height x (1.91 inches/1.50 inches).

= Height x 1.273.

Calculations for Height and Width of "Useful Area Scanned" in the Focal Plane.

Lens Markings as before. Magnification	Calculated Graticule Markings: Top	Calculated Graticule Markings: Bottom	Remarks	Height Calculated	Width Calculated
10:1	1,760 ± 3μ	1,154 ± 4μ	air	606 ± 7μ	772 ± 37μ
25:1	1,671 ± 1.3μ	1,365 ± 1.5μ	air	306 ± 2.8μ	390 ± 18μ
53:1	197 ± 0.5μ	72 ± 0.6μ	oil	125 ± 1.1μ	157 ± 7μ
100:1	73.5 ± 0.3μ	9.2 ± 0.4μ	oil	64.3 ± 0.7	82 ± 4μ

(5) Calculation of Linear Magnification: Focal Plane to Monitor Screen.

(a) Vertical Linear Magnification = $\frac{\text{(Height on Monitor Screen)}}{\text{(Height at Focal Plane)}}$

N.B. Both values are for the "Useful Area Scanned"

(b) Horizontal Linear Magnification: defined similarly.

Linear Magnification versus Lenses: Focal Plane to Monitor Screen.

Lens Markings as before. Magnification.	Vertical Linear Magnification.	Horizontal Linear Magnification.
10:1	340 ± 7	329 ± 18
25:1	675 ± 12	653 ± 35
53:1	1,650 ± 28	1,620 ± 80
100:1	3,210 ± 61	3,100 ± 170

(6) Calculation of Linear Magnification: Focal Plane to F.S.S. C.R.T. Raster.

(a) Vertical Linear Magnification = $\frac{\text{(Height on F.S.S. C.R.T.)}}{\text{(Height at Focal Plane)}}$

N.B. Both values are for the "Useful Area Scanned"

(b) Horizontal Linear Magnification: defined similarly.

Linear Magnification versus Lenses: Focal Plane to F.S.S. C.R.T.

Lens Markings as before	Vertical Linear Magnification	Horizontal Linear Magnification
10:1	62.9 ± 1.1	62.8 ± 3.4
25:1	125. ± 2.	125. ± 7.
53:1	305. ± 5.	309. ± 16.
100:1	593. ± 10.	592. ± 33.

(7) Geometrical Calculation of Flying Spot Size at the Focal Plane.

First, one can calculate the size of the flying spot at the screen of the flying spot scanner, since the enlarged resolution slide was placed as close as possible to the screen of the F.S.S. C.R.T.

i.e. Vertical Spot Size at F.S.S. = $\frac{\text{(Height at F.S.S. C.R.T.)}}{\text{(Vertical Resolution in Lines)}}$

N.B. The height is for the Useful Area Scanned.

Horizontal Spot Size at F.S.S.: defined similarly.

Flying Spot Size at Flying Spot Scanner C.R.T.

Lenses Used	Vertical Spot Size	Horizontal Spot Size
10:1	143μ ± 14	147μ ± 12
25:1	155μ ± 16	157μ ± 14
53:1	169μ ± 18	169μ ± 16
100:1	169μ ± 18	169μ ± 16

Now one can define the flying spot size, at the focal plane, in terms of geometrical optics as:

$$\frac{\text{Spot Size at F.S.S. C.R.T.}}{\text{Linear Magnification: Focal Plane to F.S.S. C.R.T.}}$$

Again, there are both vertical and horizontal values to be used in the numerator, and the denominator.

Flying Spot Size at Focal Plane versus Lenses.

Lenses Used	Vertical Spot Size in microns	Horizontal Spot Size in microns
10:1	2.28 ± 0.26	2.34 ± 0.32
25:1	1.24 ± 0.14	1.26 ± 0.18
53:1	0.55 ± 0.06	0.55 ± 0.08
100:1	0.29 ± 0.03	0.29 ± 0.04

(8) Discussion of Focal Plane, Flying Spot Size Calculations.

From the calculated spot size, at the focal plane, one sees that the scanning spot size varies with the magnification per objective. Using the simple idea of demagnification of the F.S.S. C.R.T. spot size, one obtains scanning spot sizes of 1.25, 0.55, and 0.29 microns, for the following objectives, 25:1, 53:1 and 100:1.

Resolution in the ordinary microscope is produced by interference between adjacent particles when both are illuminated by coherent light. In the flying spot microscope the lenses are used only to produce a minute spot of light. Now, assume that one has a scanning spot whose size is smaller than or equal to the particles that one wishes to detect. (Representative developed grain sizes are 0.5 to 0.7 microns). With such a spot, resolution depends on scanning different particles at different times. It is only when the scanning spot size is larger than the particle size that one will find uncertainties in detected particle positions. Even in this latter case, a knowledge of the characteristics of the scanning spot, and the particles to be detected, can lead to techniques for obtaining good position information.

(9) Vertical Calibration Using the Line Selector.

i) Mount the microscope stage graticule on the XY stage so that the lines are horizontal on the monitor.

ii) Mount a vertical fiducial line on the monitor screen half way across the width of the useful area scanned.

iii) Use oil on the stage graticule only if an oil immersion objective is used.

iv) Adjust the F.S. microscope so that the monitor visual presentation is in focus.

v) Locate the black line (i.e. due to the action of the line selector) on each side of each graticule image, and record these line numbers.

vi) Record the graticule markings at the same time that step v) is performed.

vii) Calculate the line number for the centre of each graticule image (i.e. L_i).

viii) Calculate the difference between successive graticule centre line numbers. ($K = L_1 - L_2$).

ix) Calculate $C_i = K_i/10$ microns for each value of K.

x) Calculate the line numbers (M_i) half way between successive values of L_i.

xi) Plot ix) versus x) as in Fig. 30 to evaluate the vertical linearity at the vertical fiducial line.

Data for Fig. 30

Lens Used is the E. Leitz Wetzlar, 53:1, use oil.

Graticule Used, B. & L. with spacings of 10 microns.

	Line Numbers at the Graticule Line Edges.	Line Numbers at Graticule Line Centres.	K	C = K/10μ	N_i
1	166 ± 1 174	170 ± 1	33 ± 2	3.3	186.5
2	200 206	203	29	2.9	217.5
3	229 235	232	27	2.7	245.5
4	256 262	259	28	2.8	273.
5	284 290	287	27	2.7	300.5
6	311 317	314	28	2.8	328.
7	339 345	342	26½	2.65	355.25

Line Numbers at the Graticule Line Edges		Line Numbers at Graticule Line Centres	K	C = K/10μ	M_i
8	366 371	368	28	2.8	382.5
9	394 399	396.5	26½	2.65	409.75
10	421 425	423	27	2.7	436.5
11	447 553	450	29½	2.95	464.75
12	476 483	479½			

CONCLUSIONS

This flying spot microscope, designed, constructed, and calibrated at this university, has the following characteristics.

(1) A large display which can be seen by more than one person at a time. This is particularly useful for illustrating lectures.

(2) The brightness of the visual display can be easily controlled, so that large groups or a single person can be accommodated.

(3) One can vary the contrast electronically.

(4) An XY stage allows one to work over large areas in a particular nuclear emulsion plate.

In addition to the above characteristics, the line selector gives quantitative data in the vertical direction at the centre of the useful scan area. Note that there is no parallax between the black line, selected by the "line selector", and the visual information on the monitor screen.

The line selector will allow one to make the following types of measurements, useful in the study of high energy physics. (The following measurements require the track to be positioned so that it appears to be vertical on the monitor).

1. Grain density measurements, along a track.

2. Gap length measurements, along a track.

3. Blob length measurements, along a track.

As well, one can obtain:

4. Track width measurements, as a function of track length. (This measurement would require the track to appear to be horizontal on the monitor).

It is readily apparent that this flying spot microscope is a source of voltage (or current) waveforms which can yield position information along each horizontal line. Such horizontal position information combined with the vertical position information (from the line selector) would yield XY coordinates at the image plane. These coordinates can then be related to xy coordinates within the emulsion.

Another direction for further development is in the design of the optical system. More light would result in a better signal-to-noise ratio; while special optics may produce better resolution.

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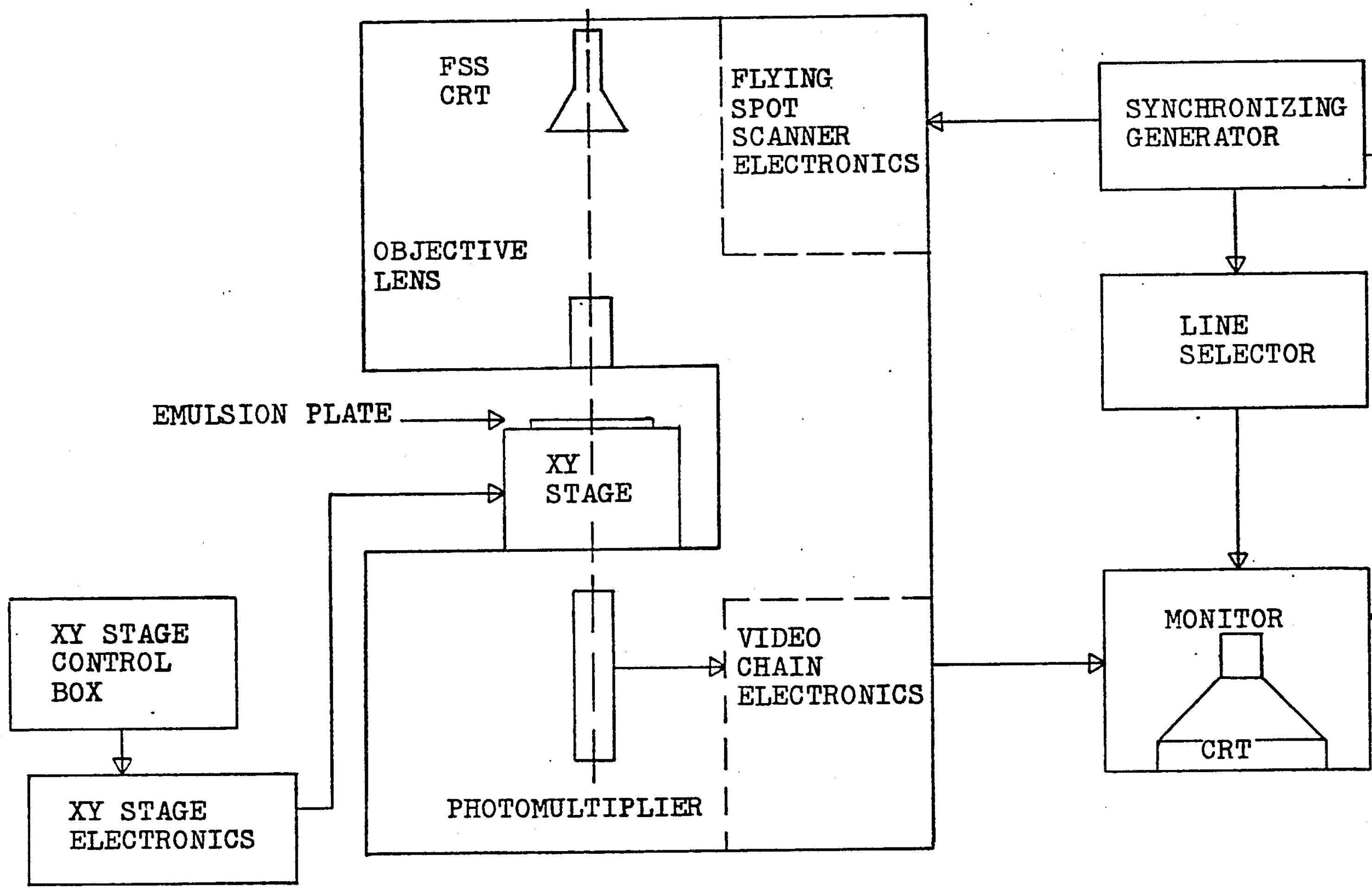


FIG. 1 SYSTEM BLOCK DIAGRAM.

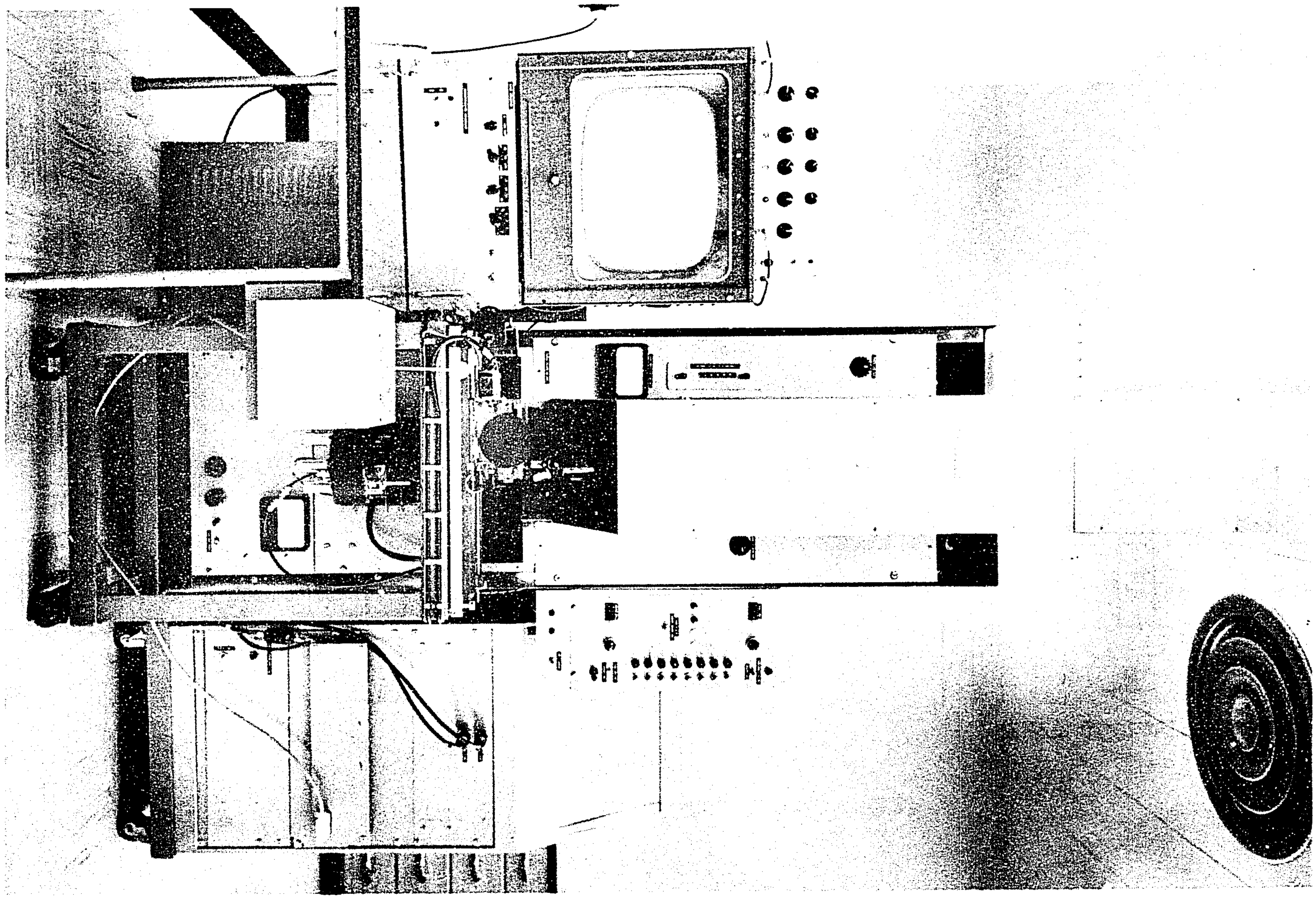


Fig. 2 Photograph of the Scanner.

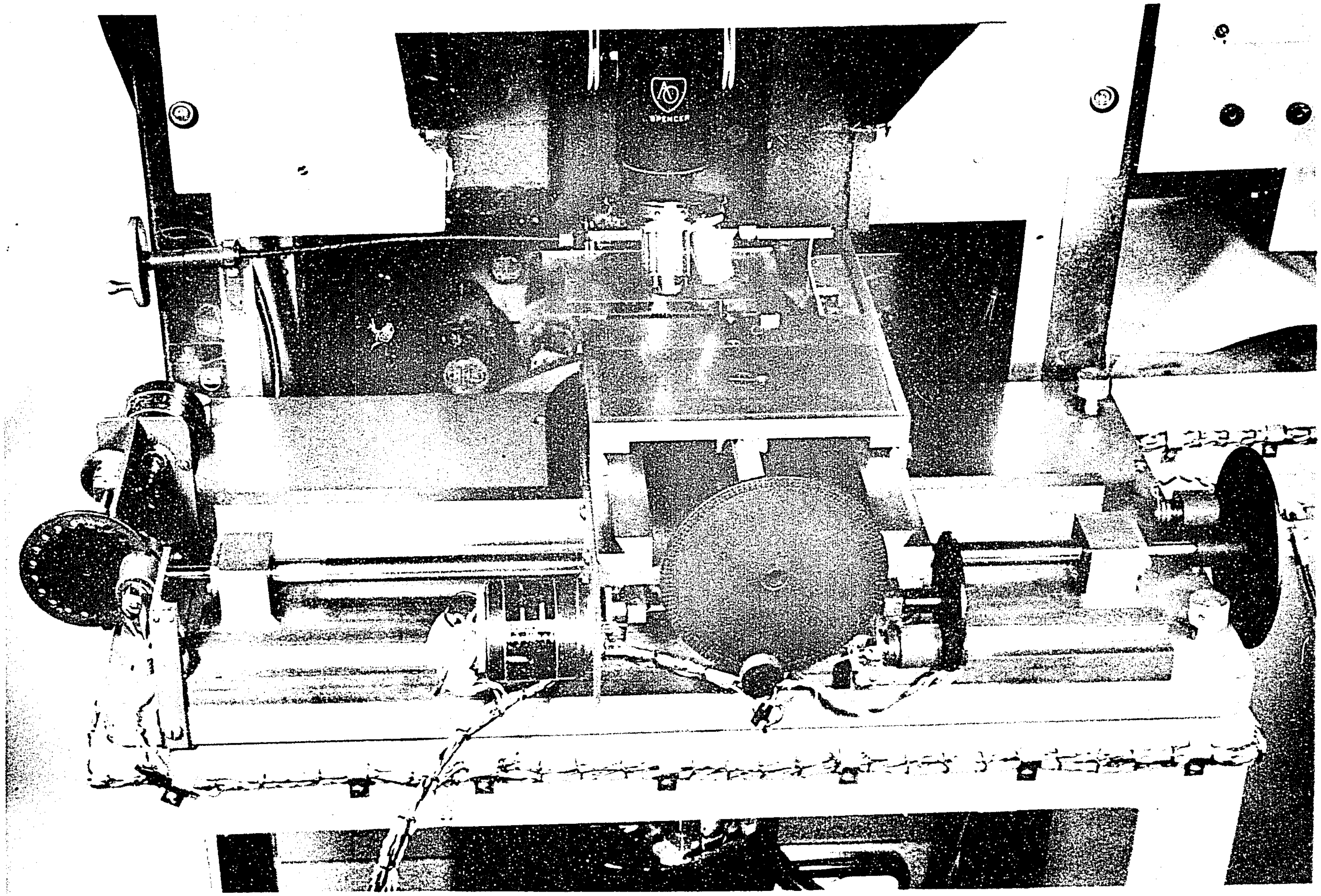


Fig. 3 Photograph of the Stage

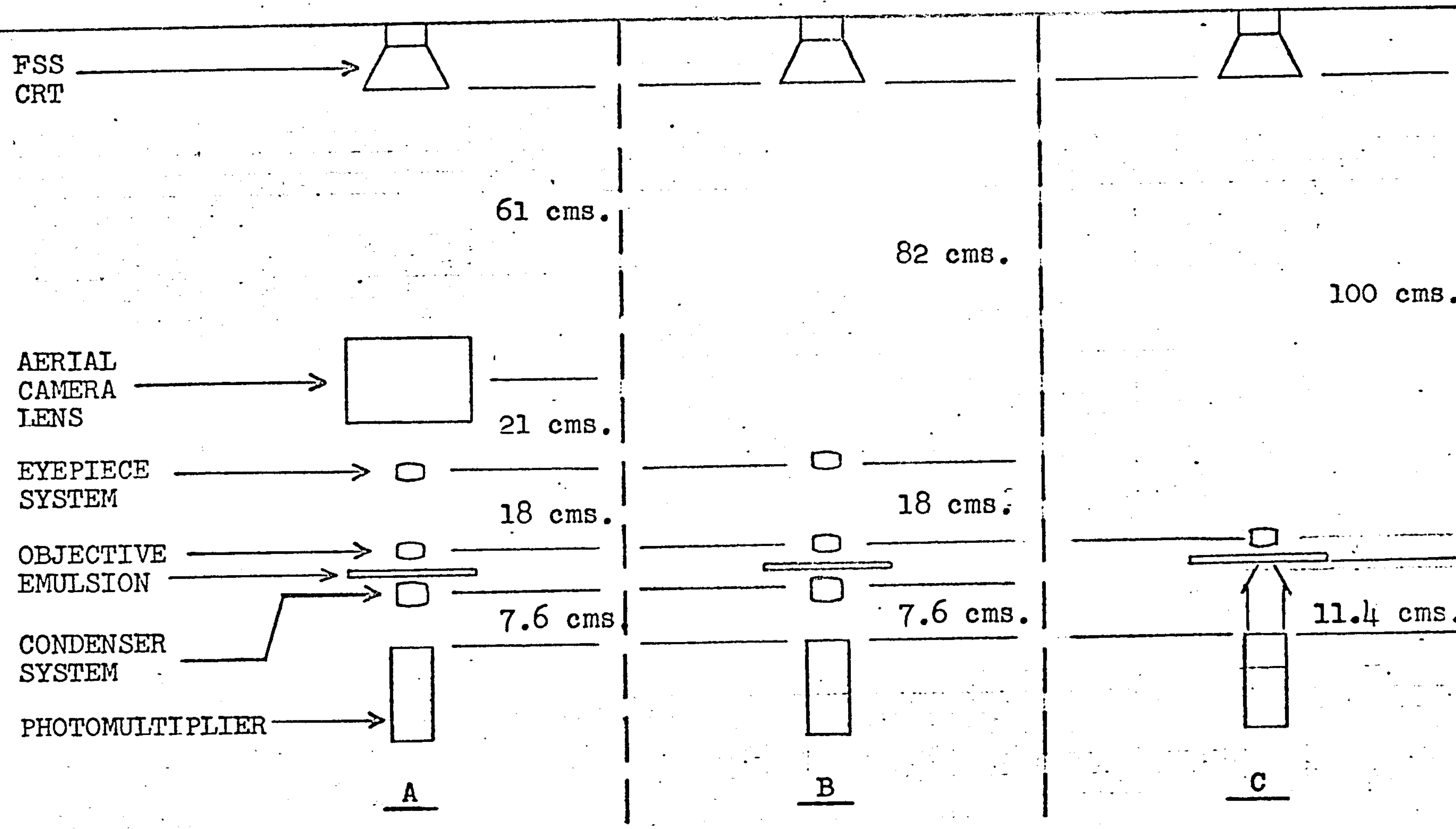


Fig. 4 OPTICAL SYSTEM DEVELOPEMENT

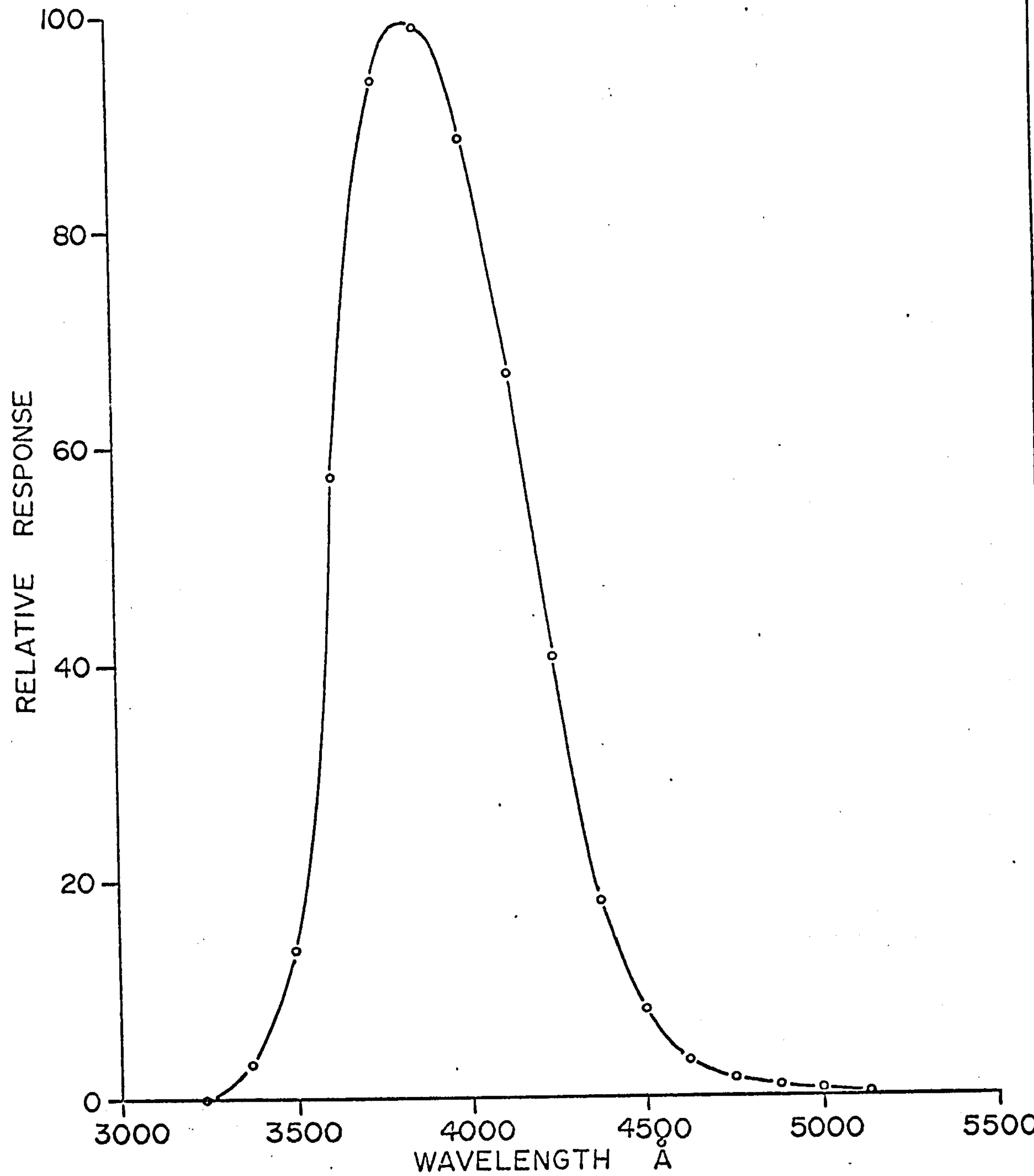


FIG. 5 OVERAL SPECTRAL RESPONSE OF
P16 PHOSPHOR AND 6292 PHOTOMULTIPLIER

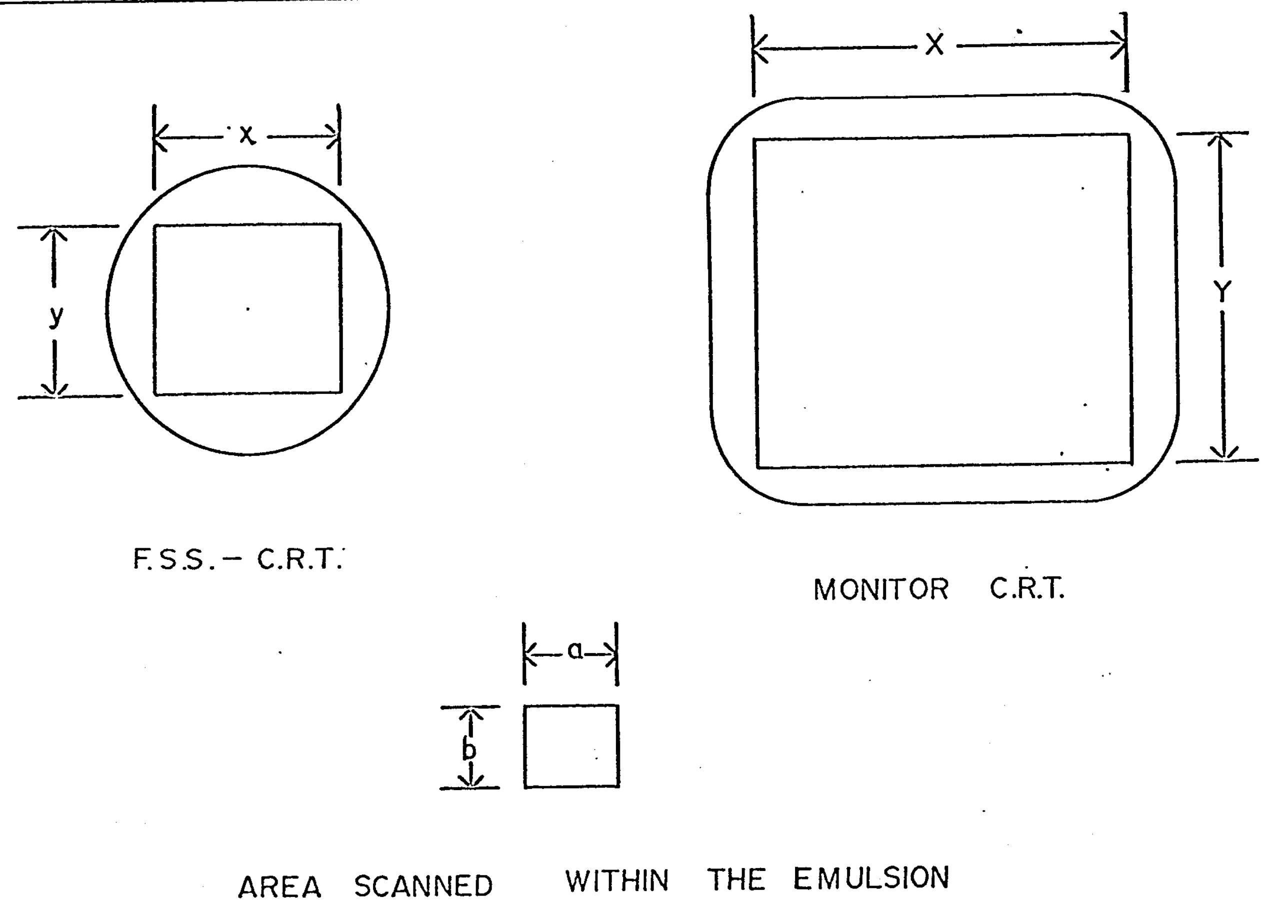


FIG. 6 SCANNING GEOMETRY

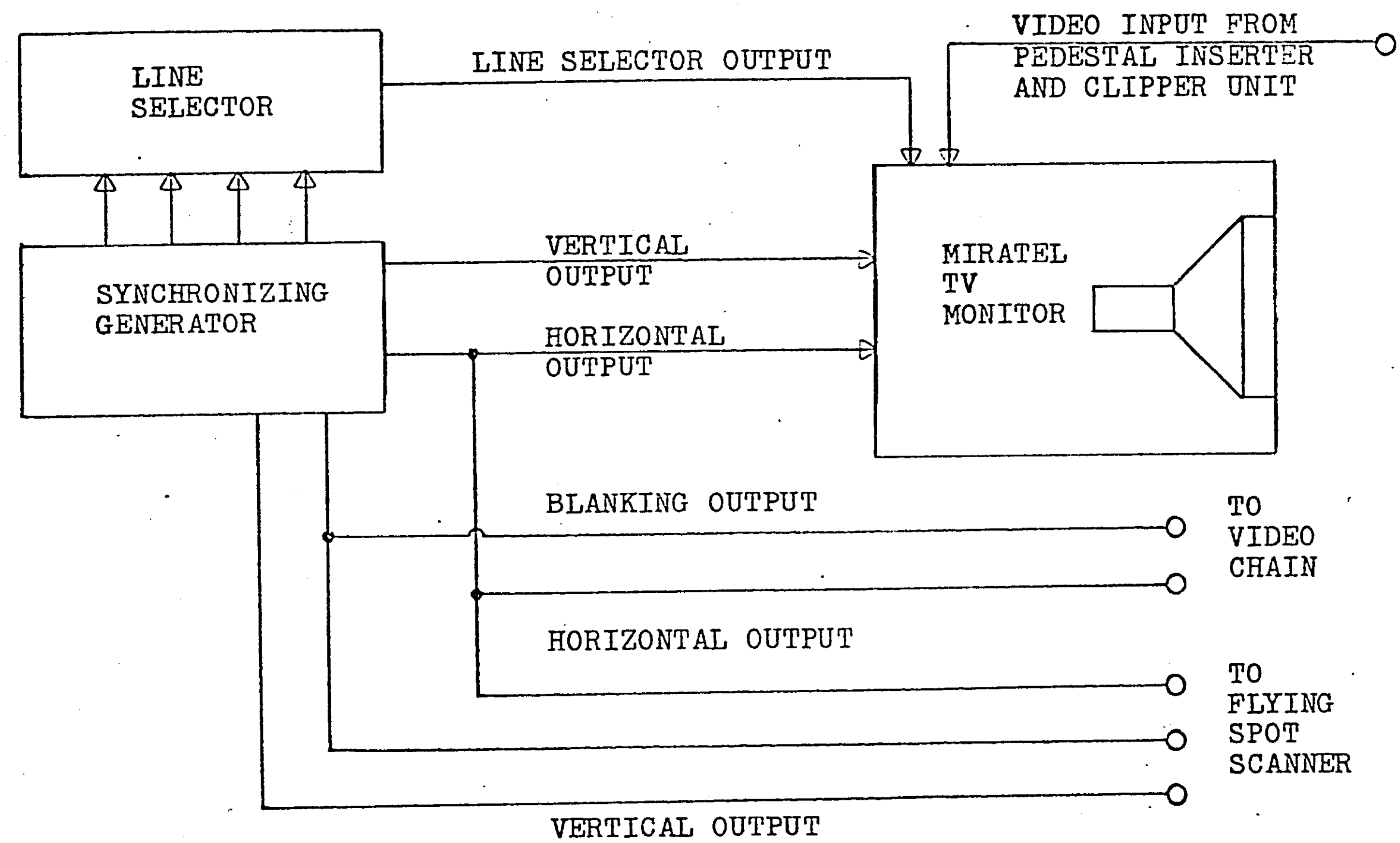


FIG. 7 MONITOR BLOCK DIAGRAM

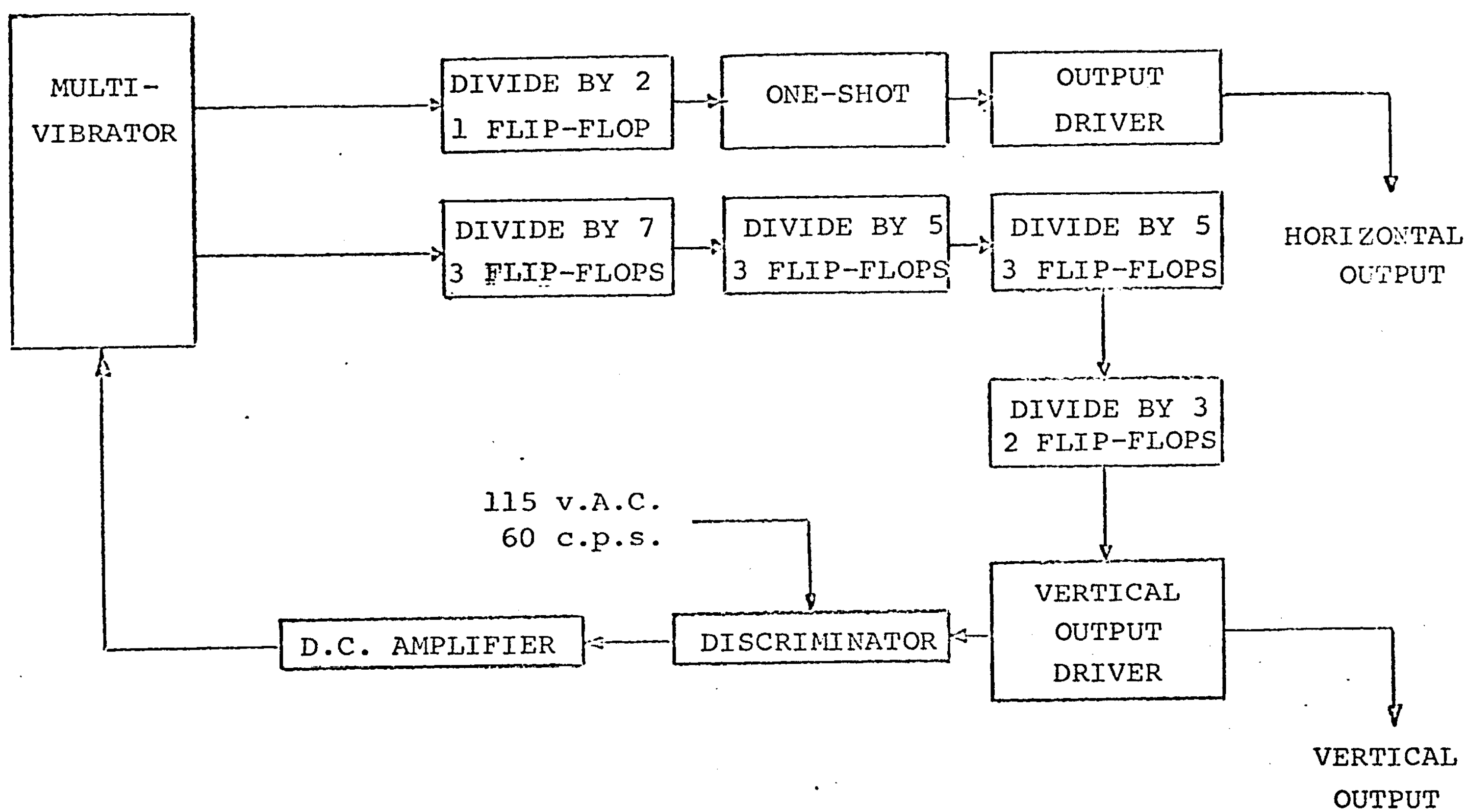


Fig. 8 SYNCHRONIZATION GENERATOR

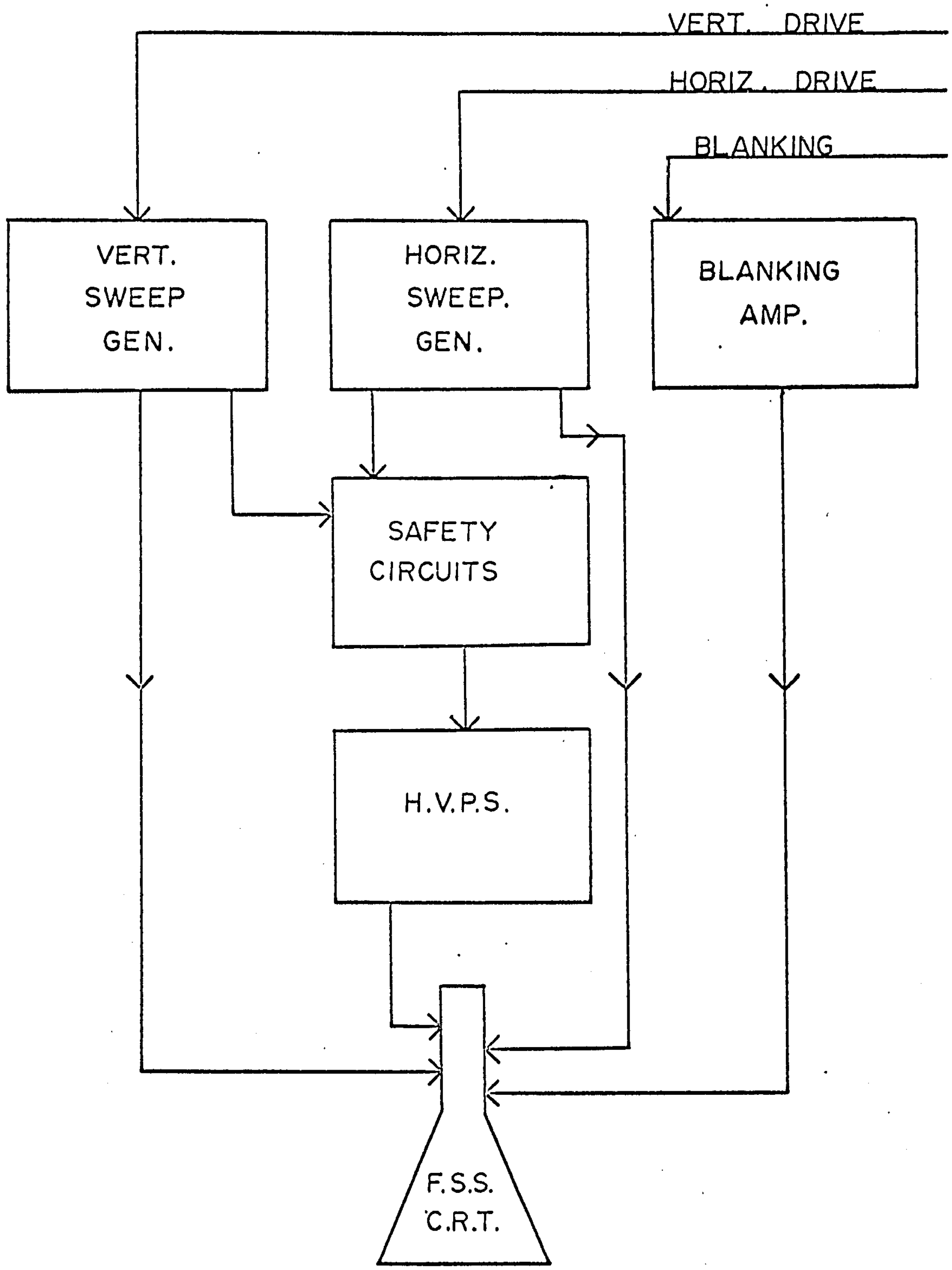


FIG. 9 F.S.S. BLOCK DIAGRAM.

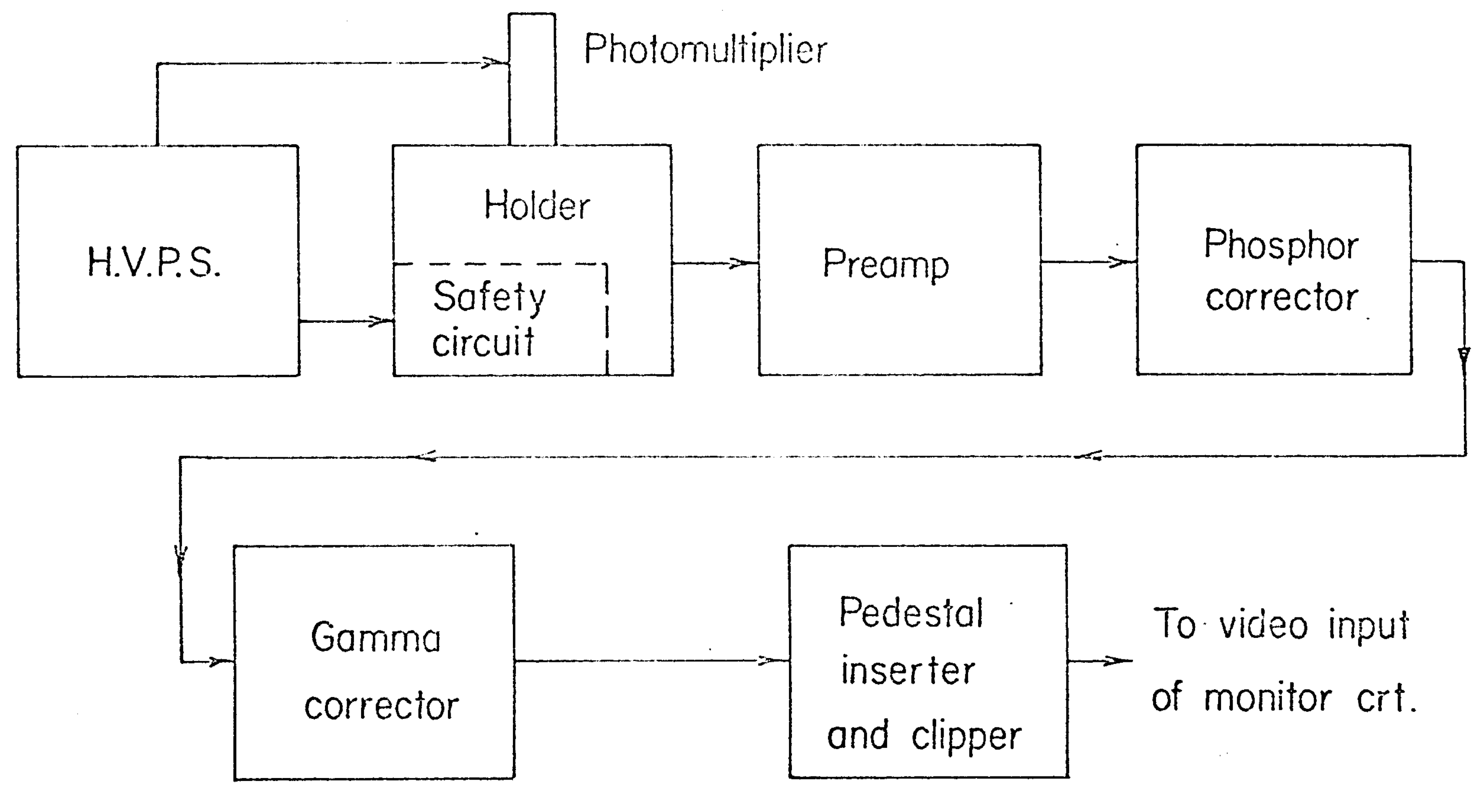


Fig. 10 Video chain block diagram.

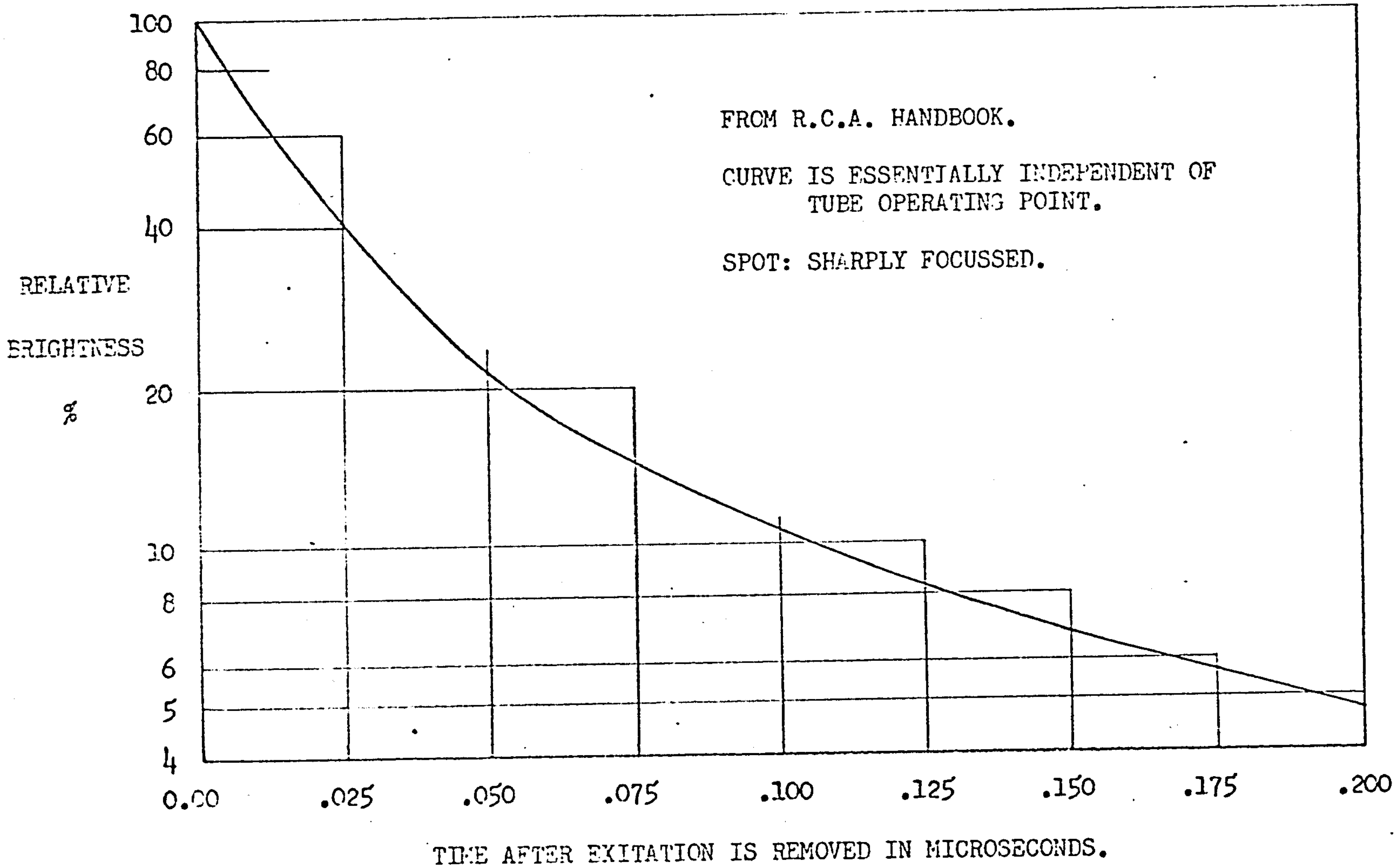
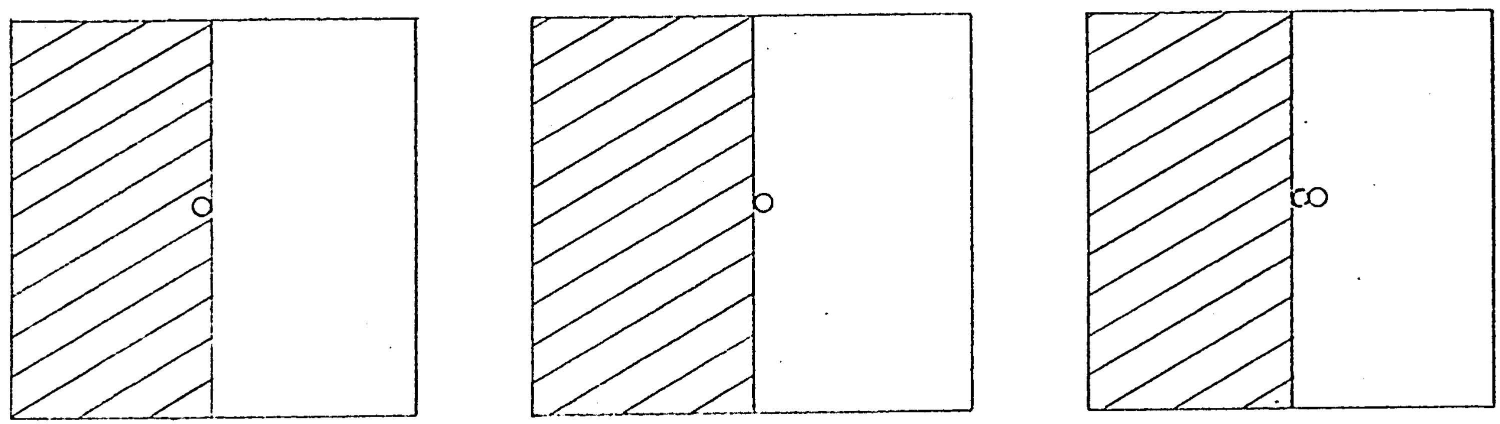


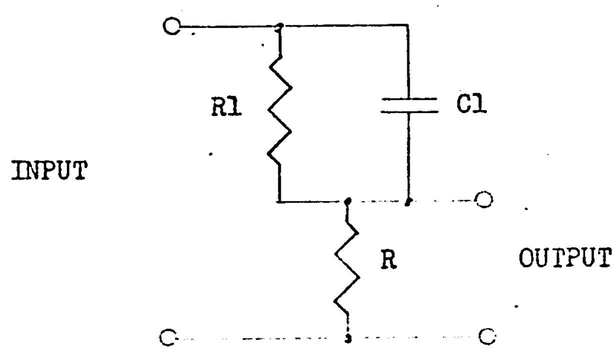
Fig. 11 P16 PHOSPHOR BRIGHTNESS CHARACTERISTIC.



PART (a) PART (b) PART (c)

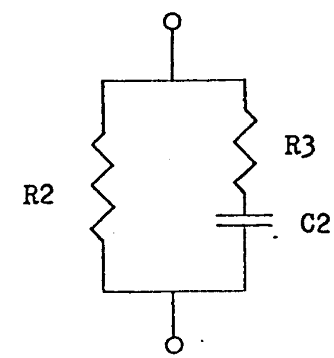
THE SOLID CIRCLE CORRESPONDS TO THE AREA ILLUMINATED BY THE FLYING SPOT OF LIGHT.

Fig. 12 INPUTS FOR PHOSPHOR CORRECTION EXPLANATION



IN GRID CIRCUIT OF 6Ak5

NETWORK # 1



IN PLATE CIRCUIT OF 6AK5

NETWORK # 2

Fig. 13 PHOSPHOR CORRECTION CIRCUITS

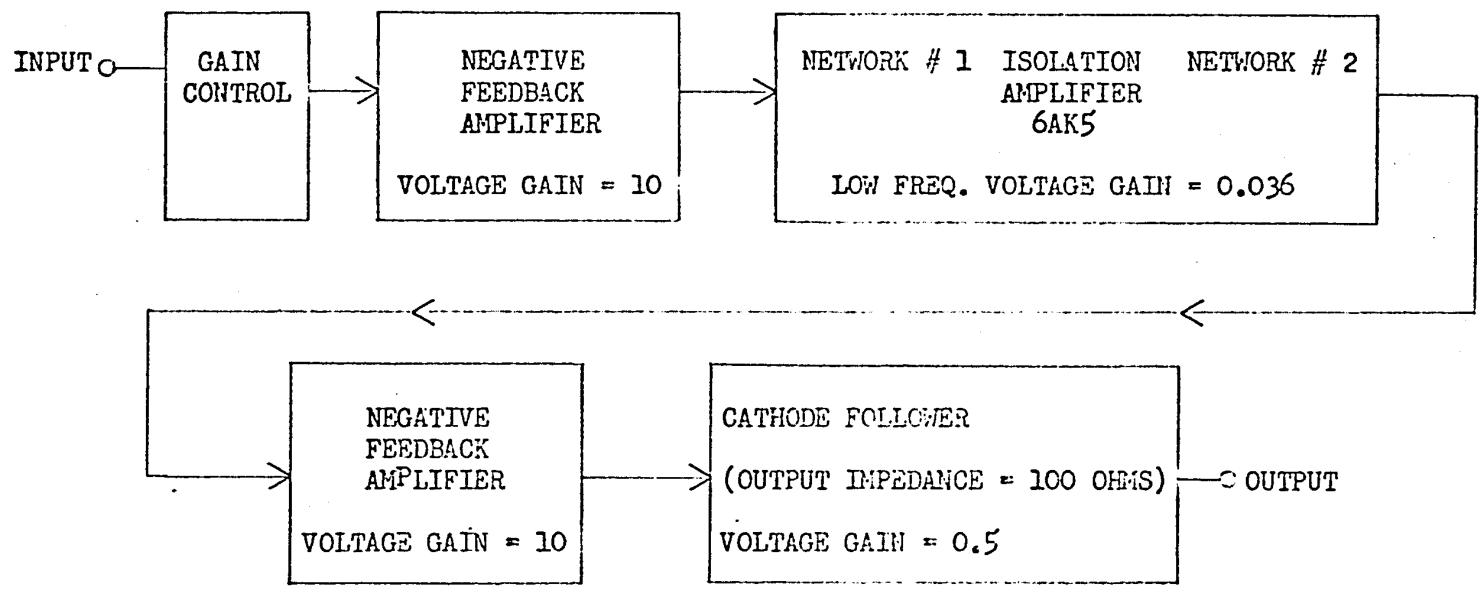


Fig. 14 PHOSPHOR CORRECTOR BLOCK DIAGRAM

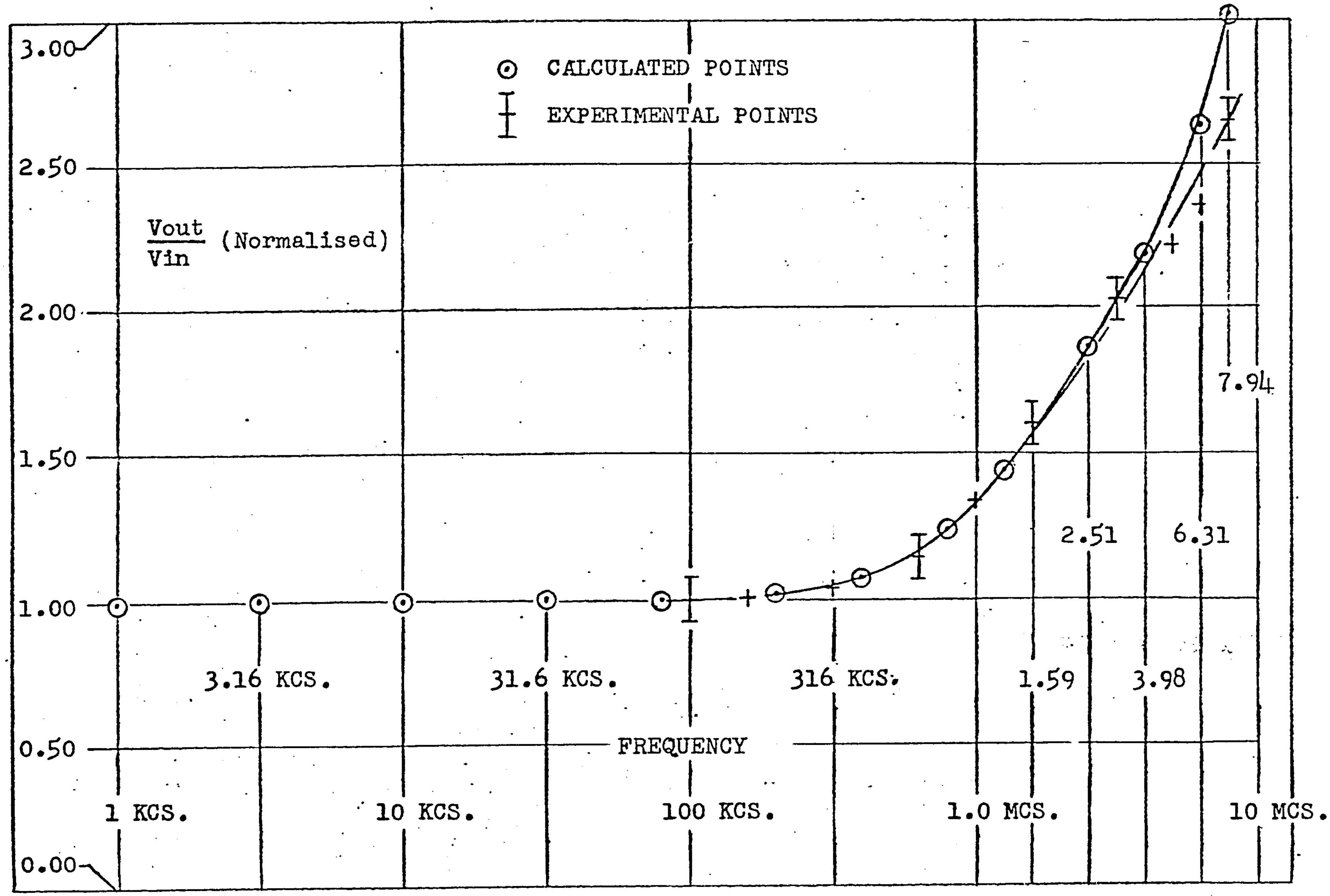


FIG. 15 PHOSPHOR CORRECTOR FREQUENCY RESPONSE

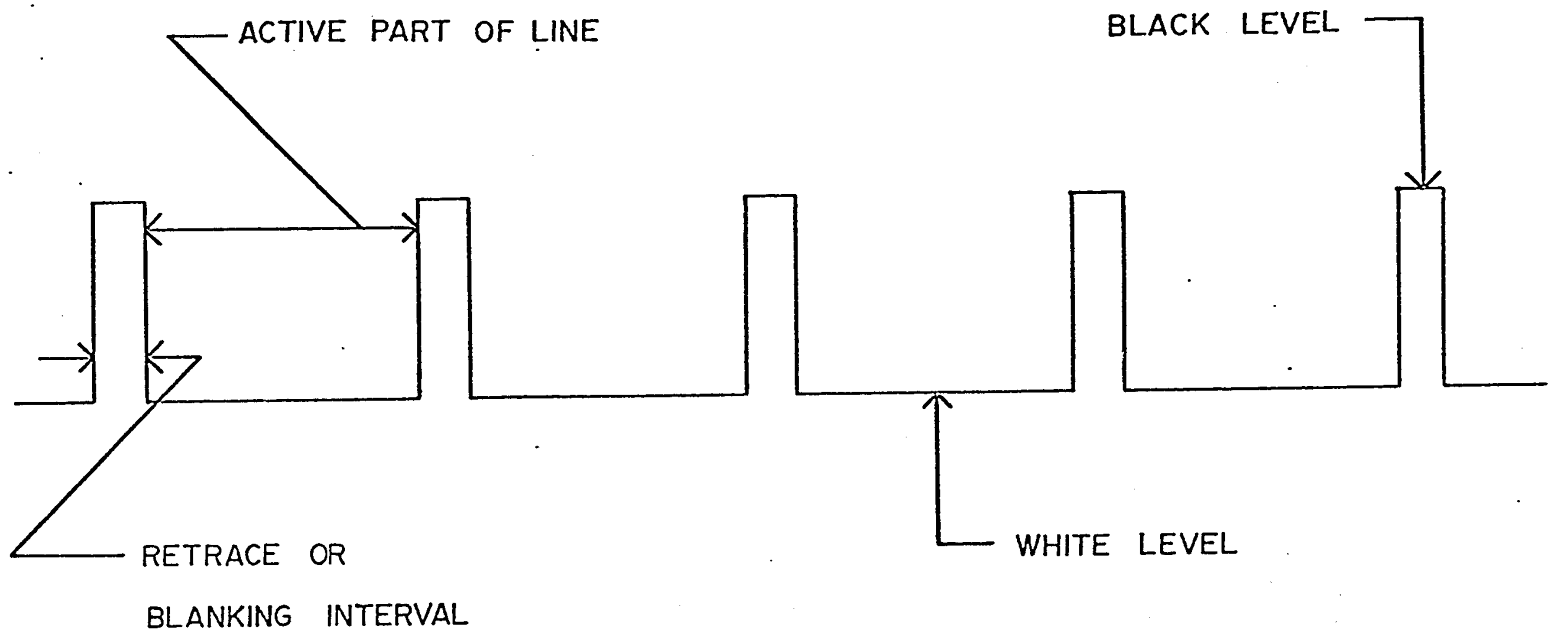


FIG. 16 VIDEO WAVEFORM DETAILS.

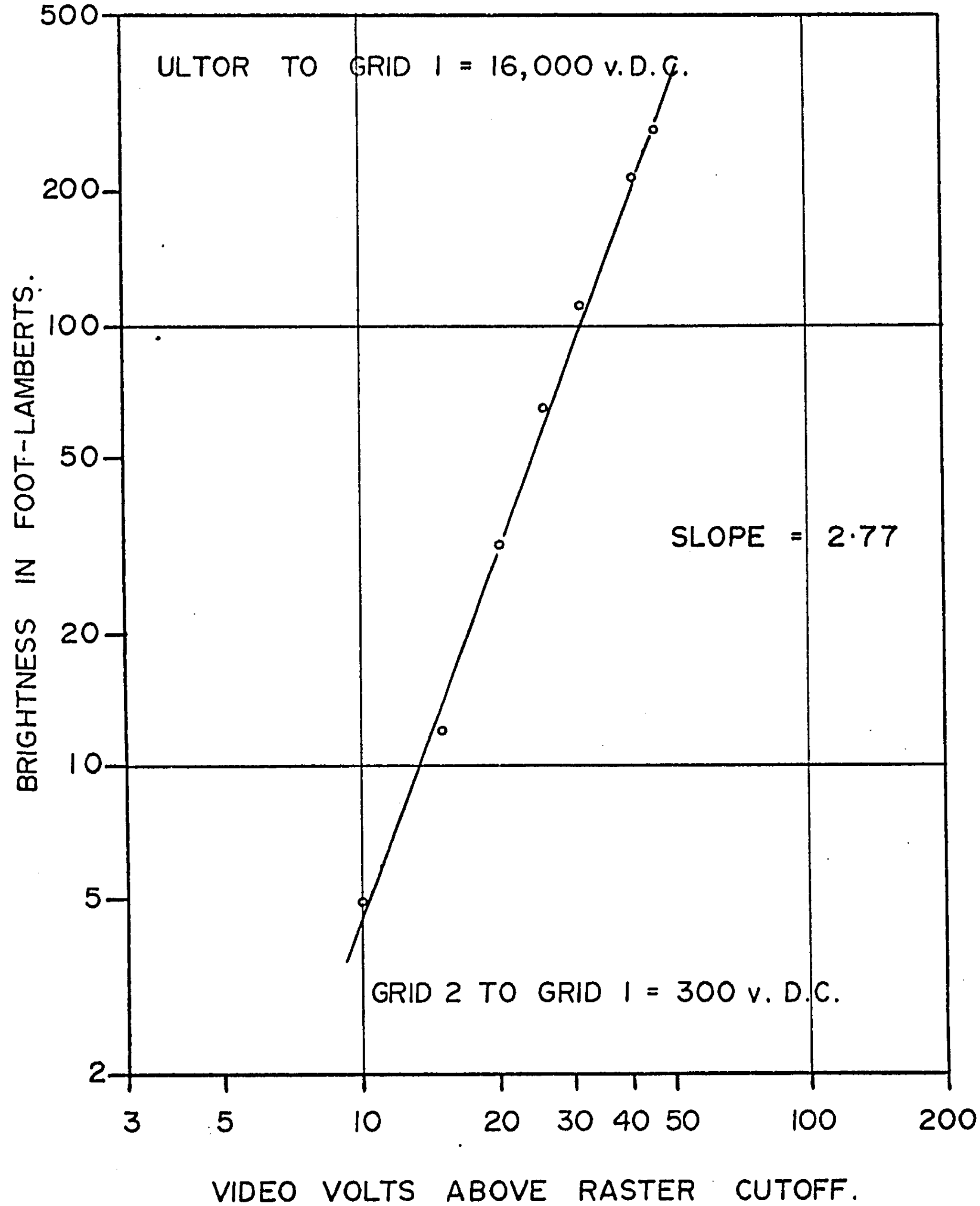


FIG. 17 17AVP4-A CATHODE DRIVE CHARACTERISTICS

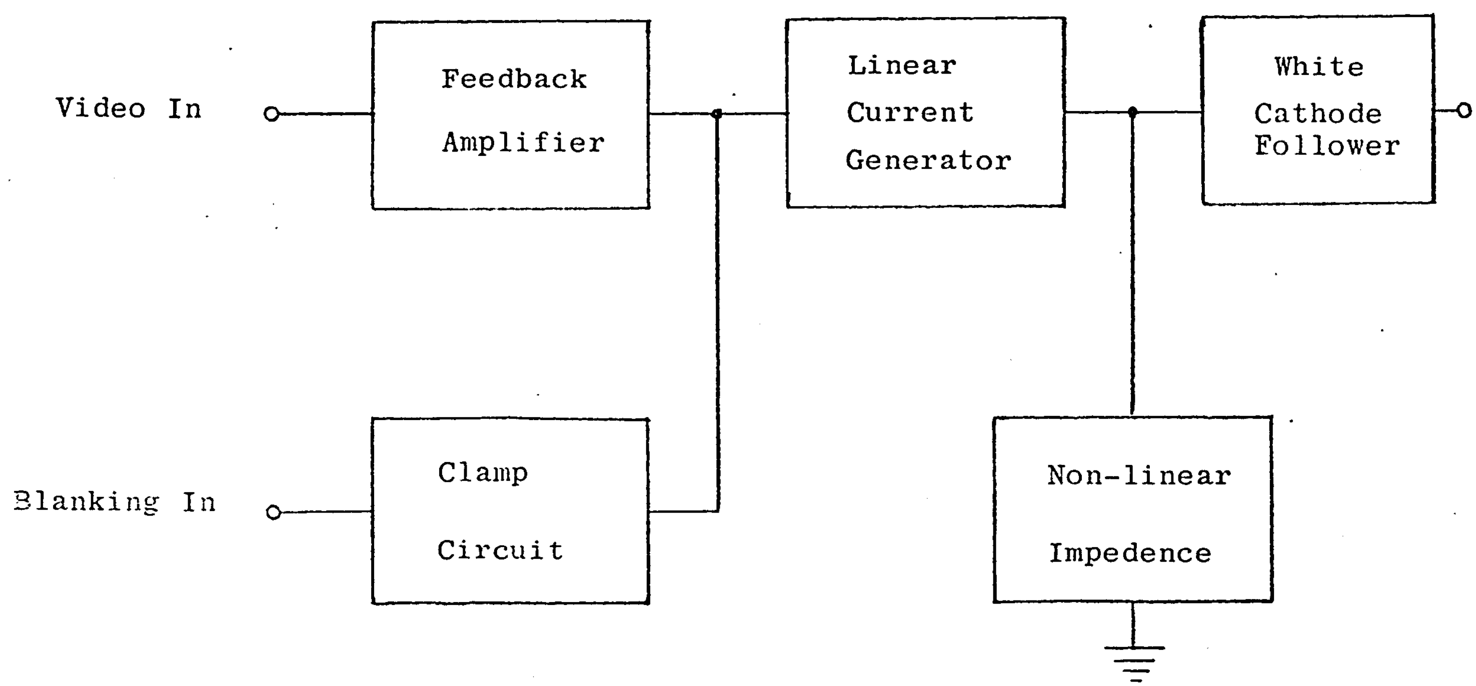


Fig. 18 GAMMA CORRECTOR BLOCK DIAGRAM

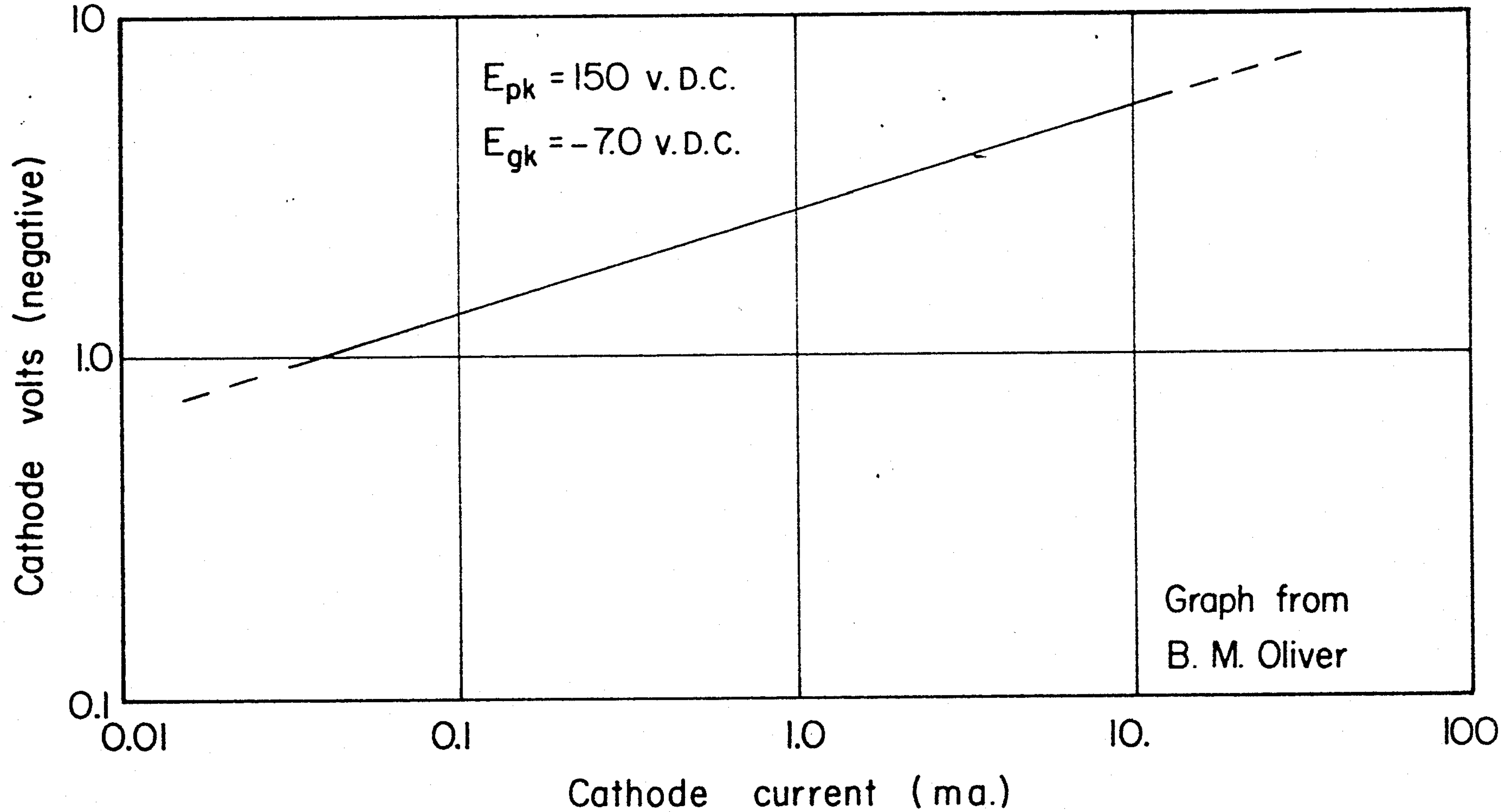


Fig. 19 Characteristic curve for 2C51.

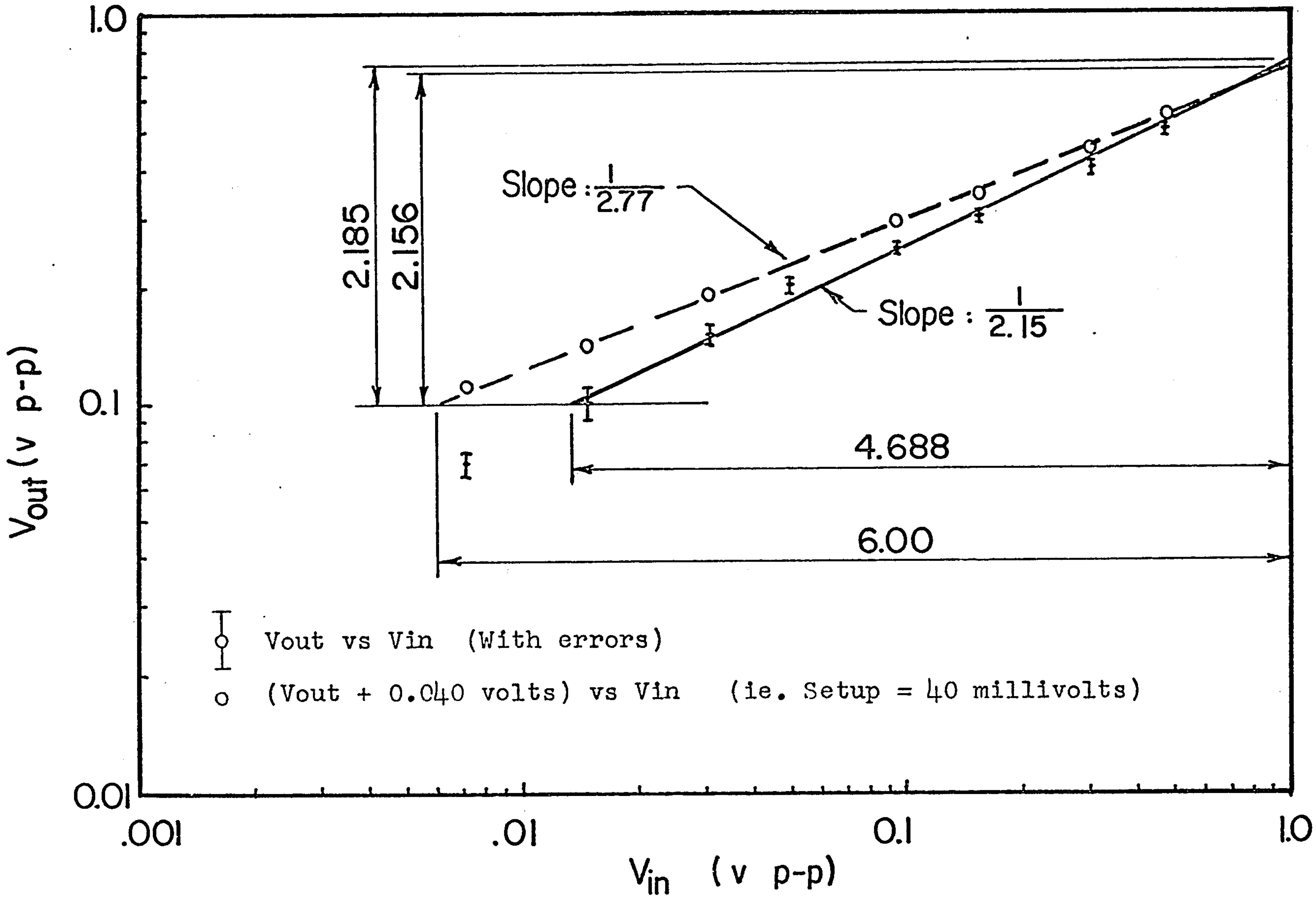


Fig. 20 Gamma corrector characteristic curve.

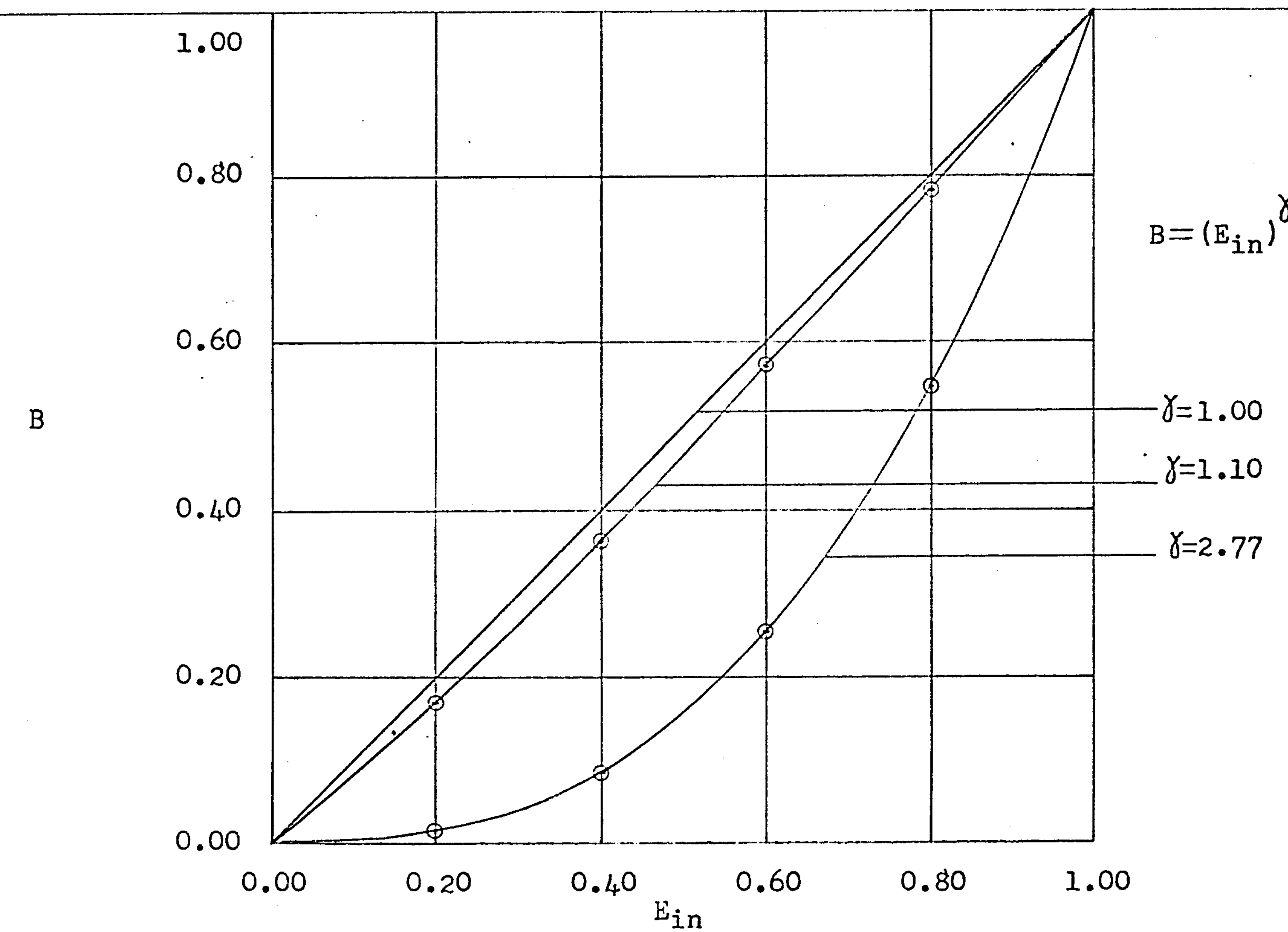
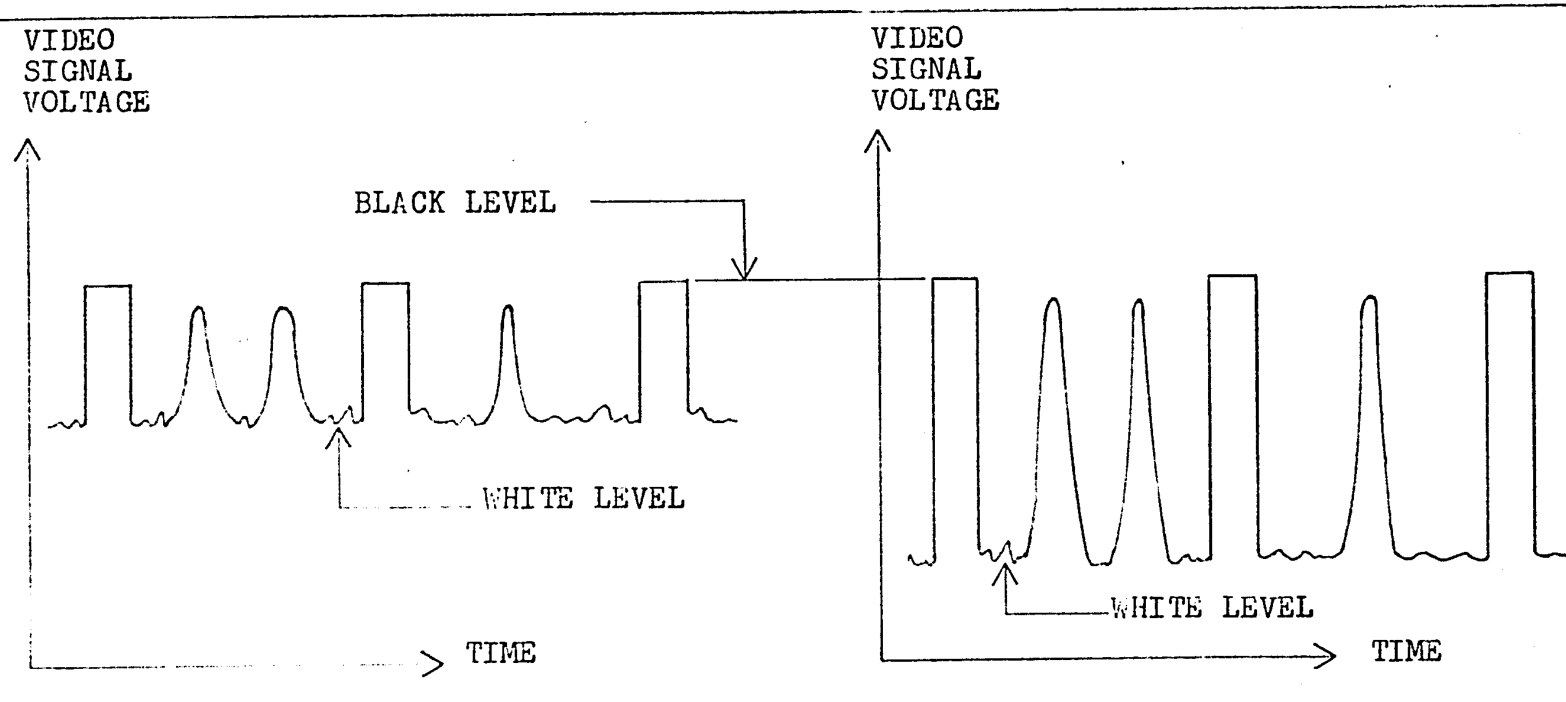


Fig. 21 COMPARISON OF GAMMA CORRECTOR CHARACTERISTIC CURVES



(a)
LOW CONTRAST RATIO VIDEO SIGNAL

(b)
HIGH CONTRAST RATIO VIDEO SIGNAL

Fig. 22   LOW AND HIGH CONTRAST RATIO VIDEO SIGNALS

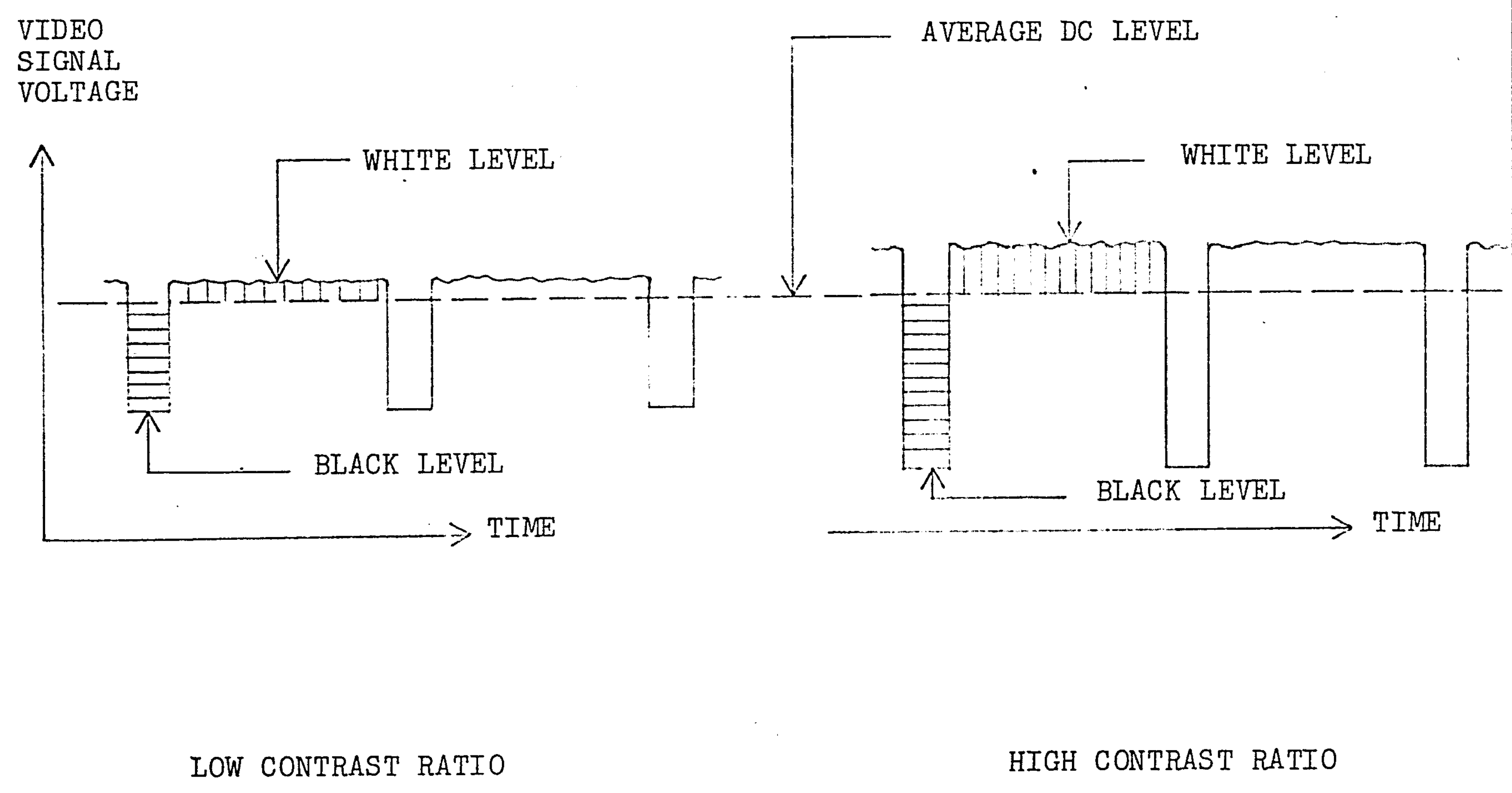


Fig. 23 VIDEO SIGNALS AFTER AC AMPLIFICATION

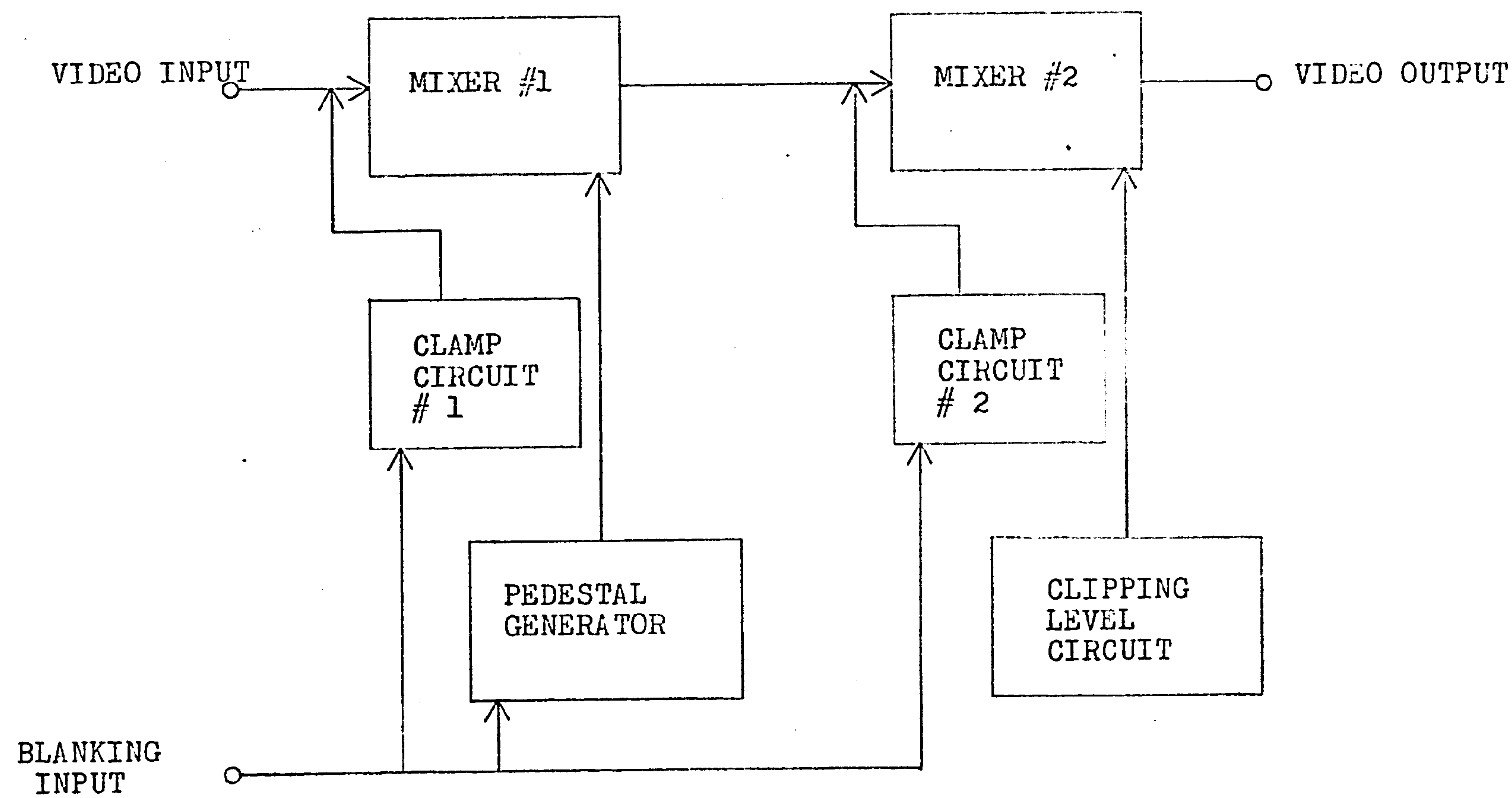


Fig. 24 PEDESTAL INSERTER AND CLIPPER BLOCK DIAGRAM

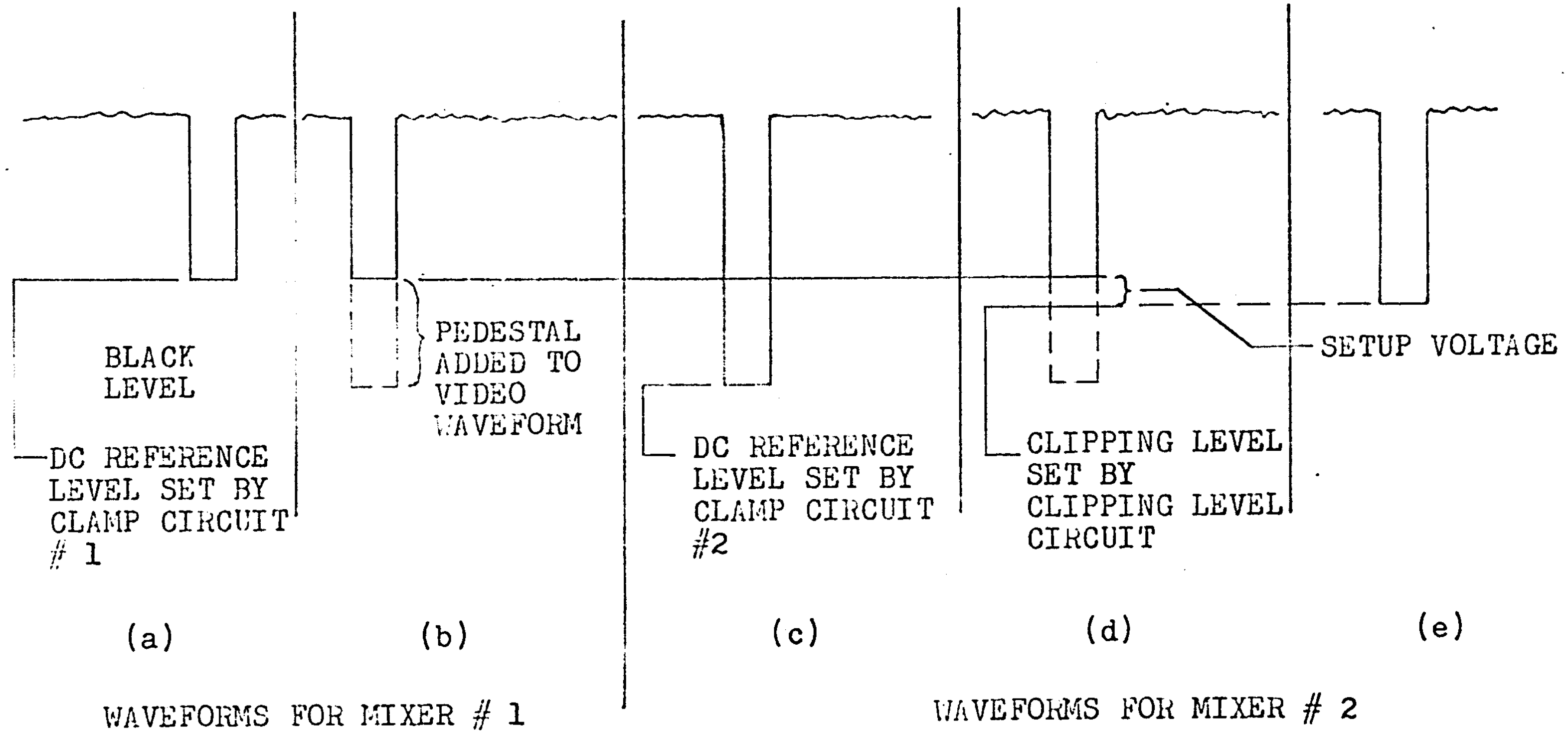


Fig.25 PEDESTAL INSERTER AND CLIPPER WAVEFORMS

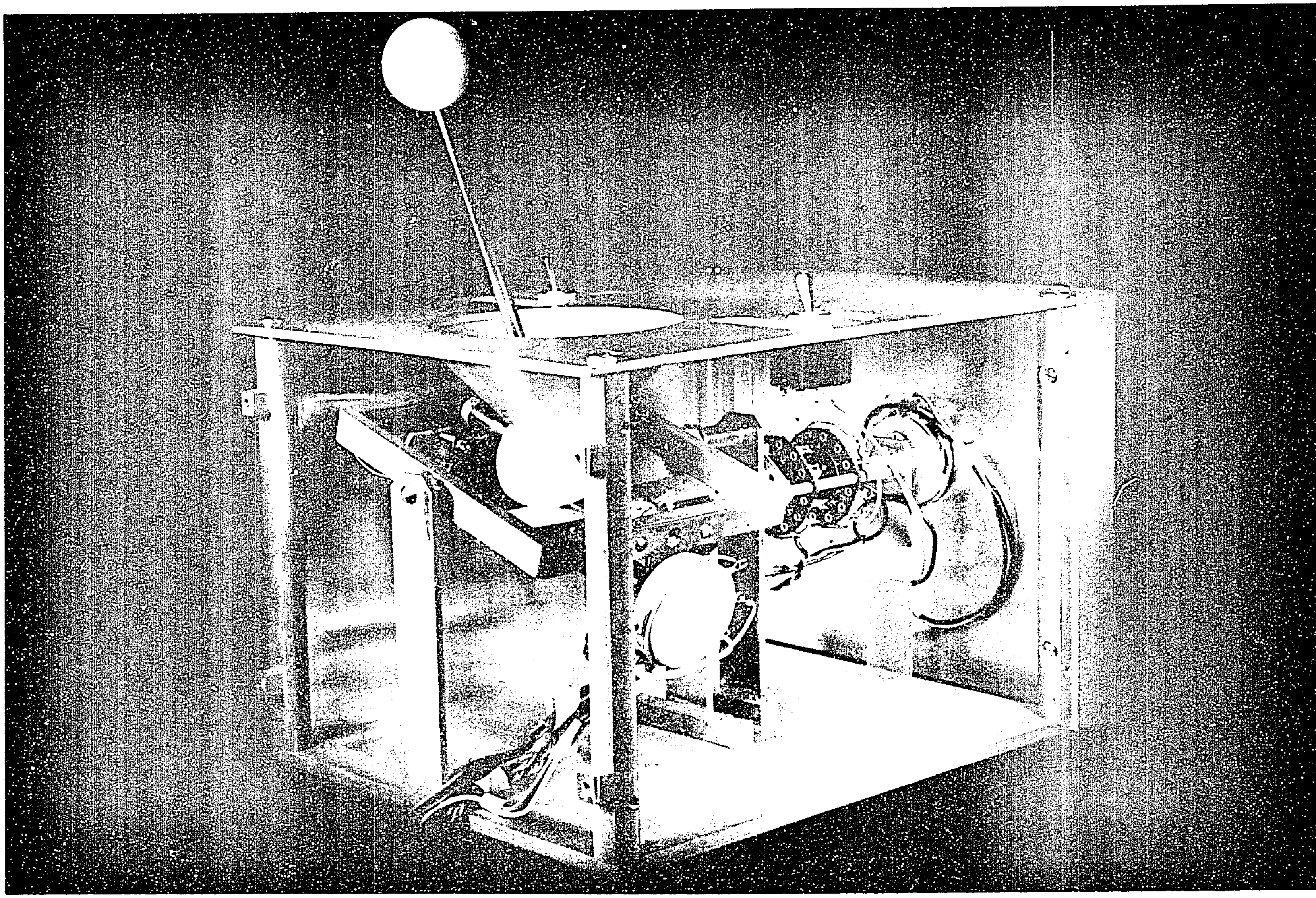


Fig. 26 Photograph of Stage Control Box

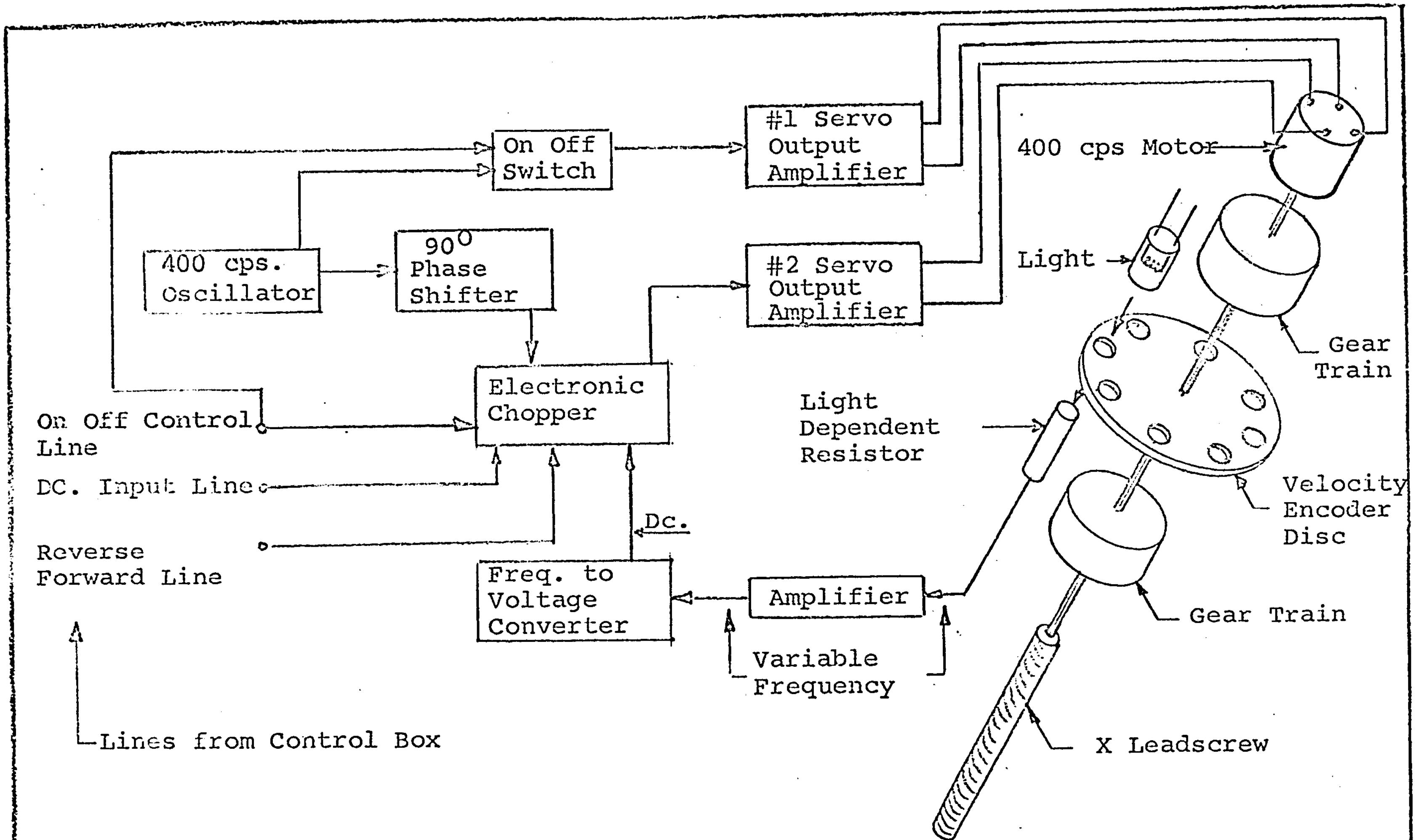


Fig. 27 X Velocity Servo System.

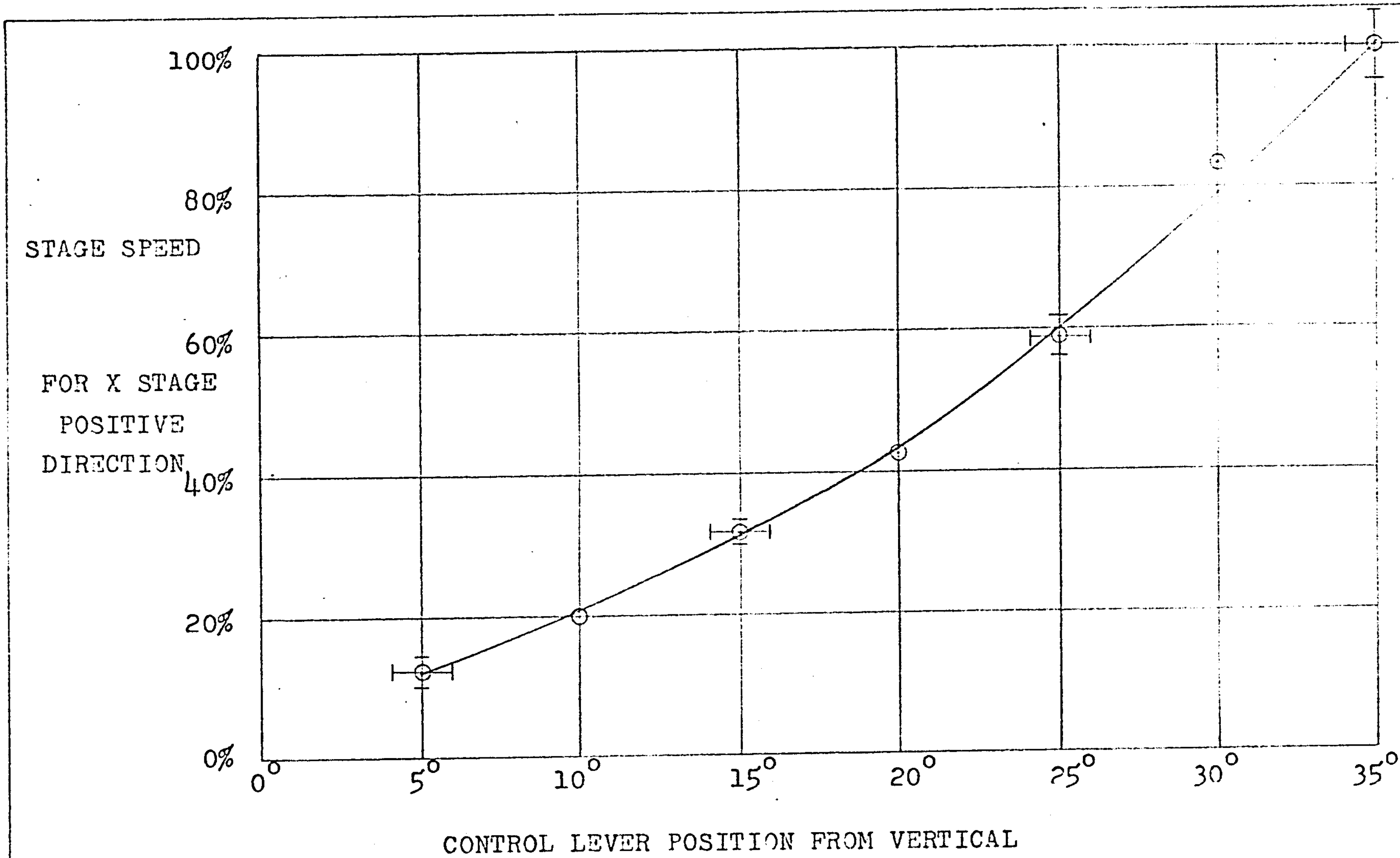


Fig. 28 GRAPH OF STAGE SPEED VERSUS CONTROL LEVER POSITION

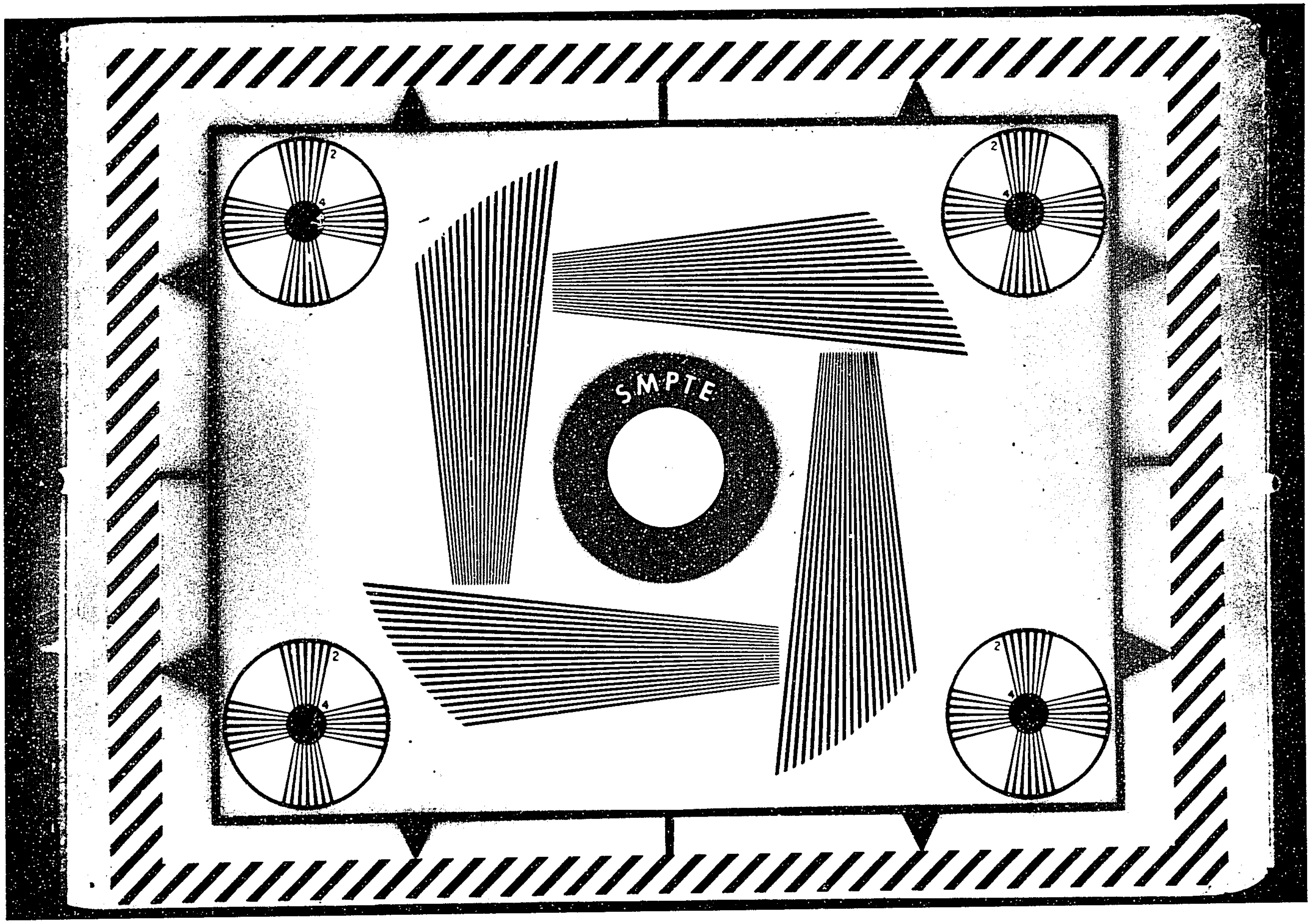


Figure 29. Photograph of SMPTE Resolution Slide.

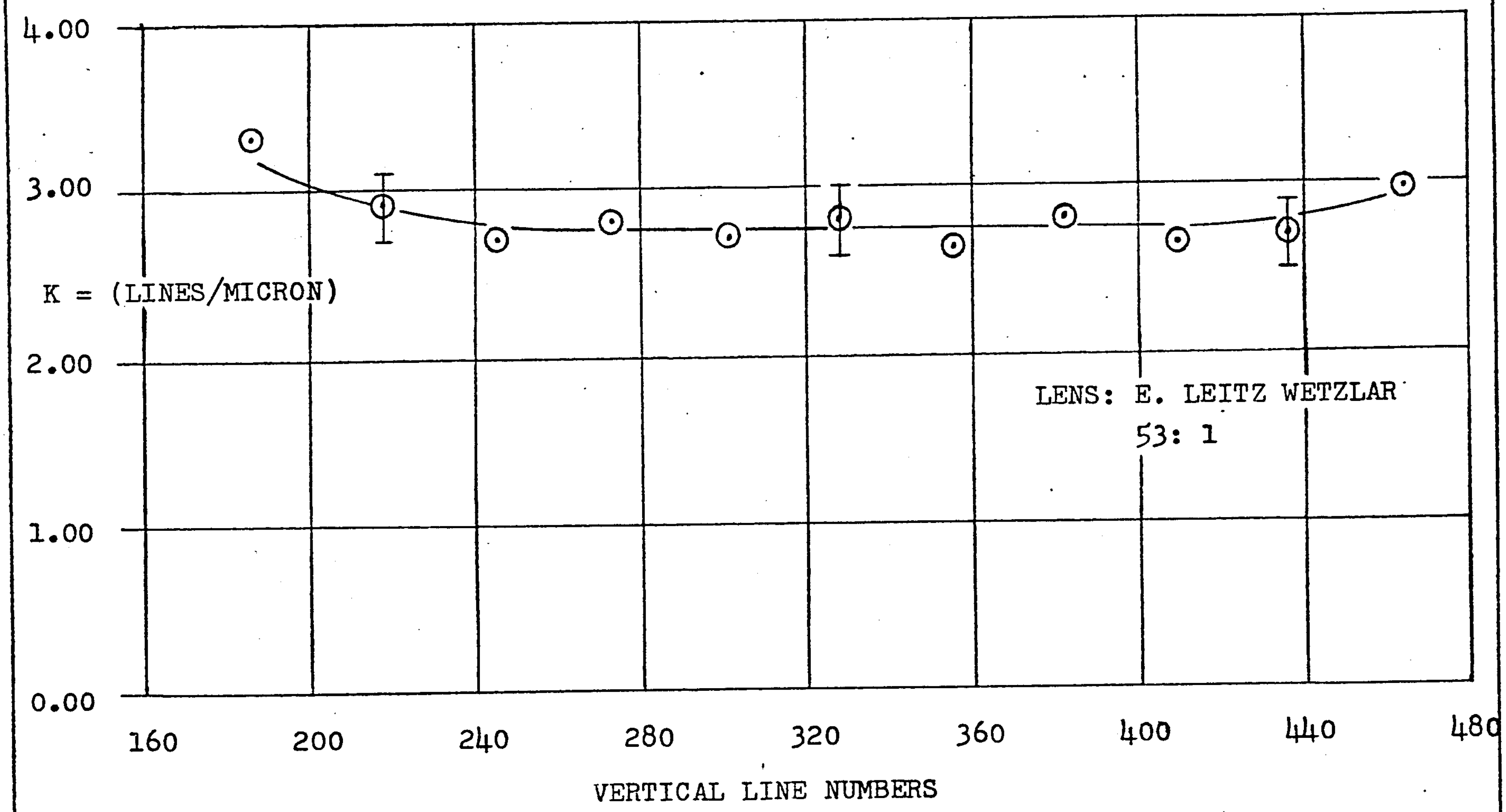


FIG. 30 VERTICAL CALIBRATION FOR F. S. MICROSCOPE

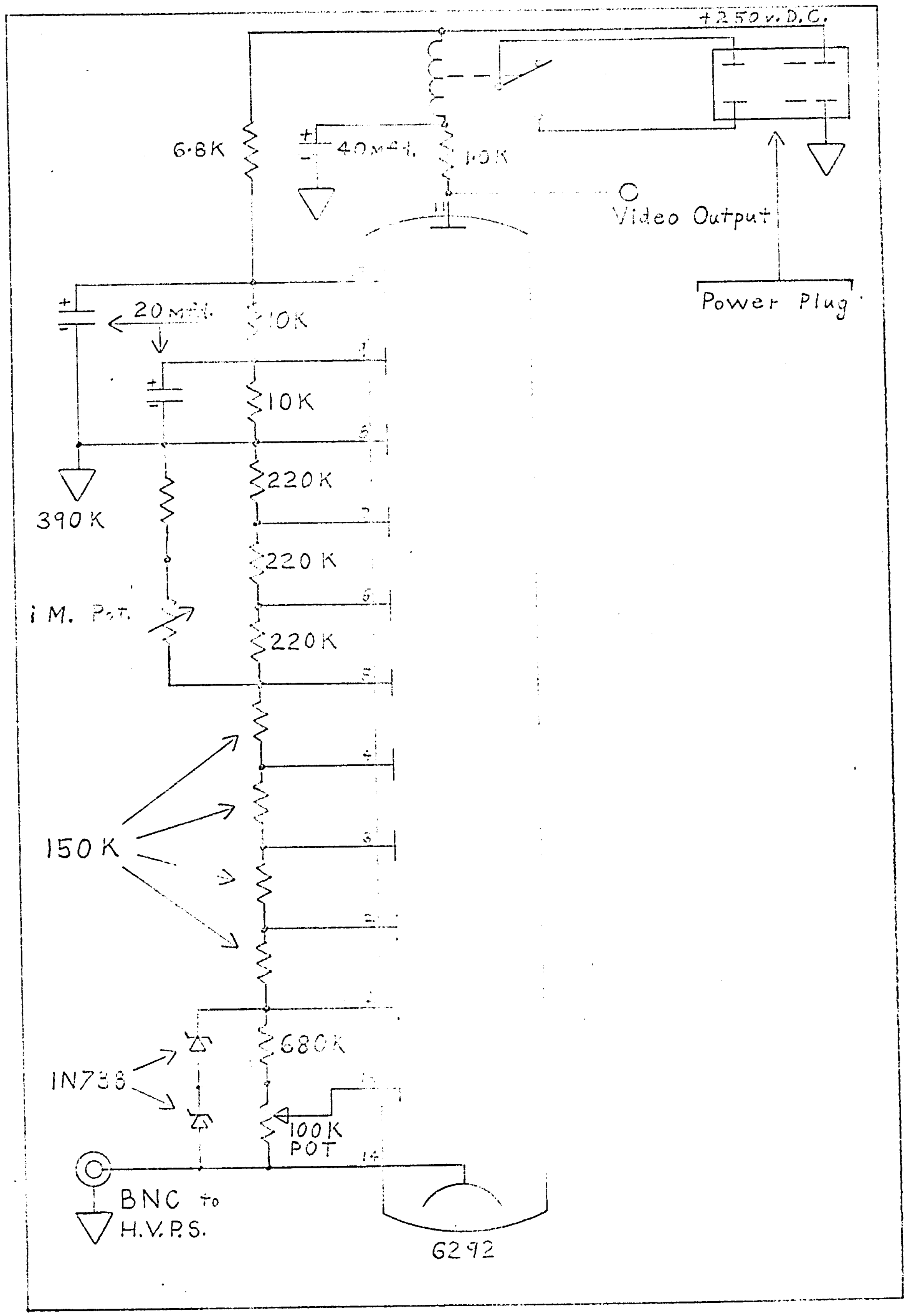


Fig. 31 PHOTOMULTIPLIER CIRCUIT

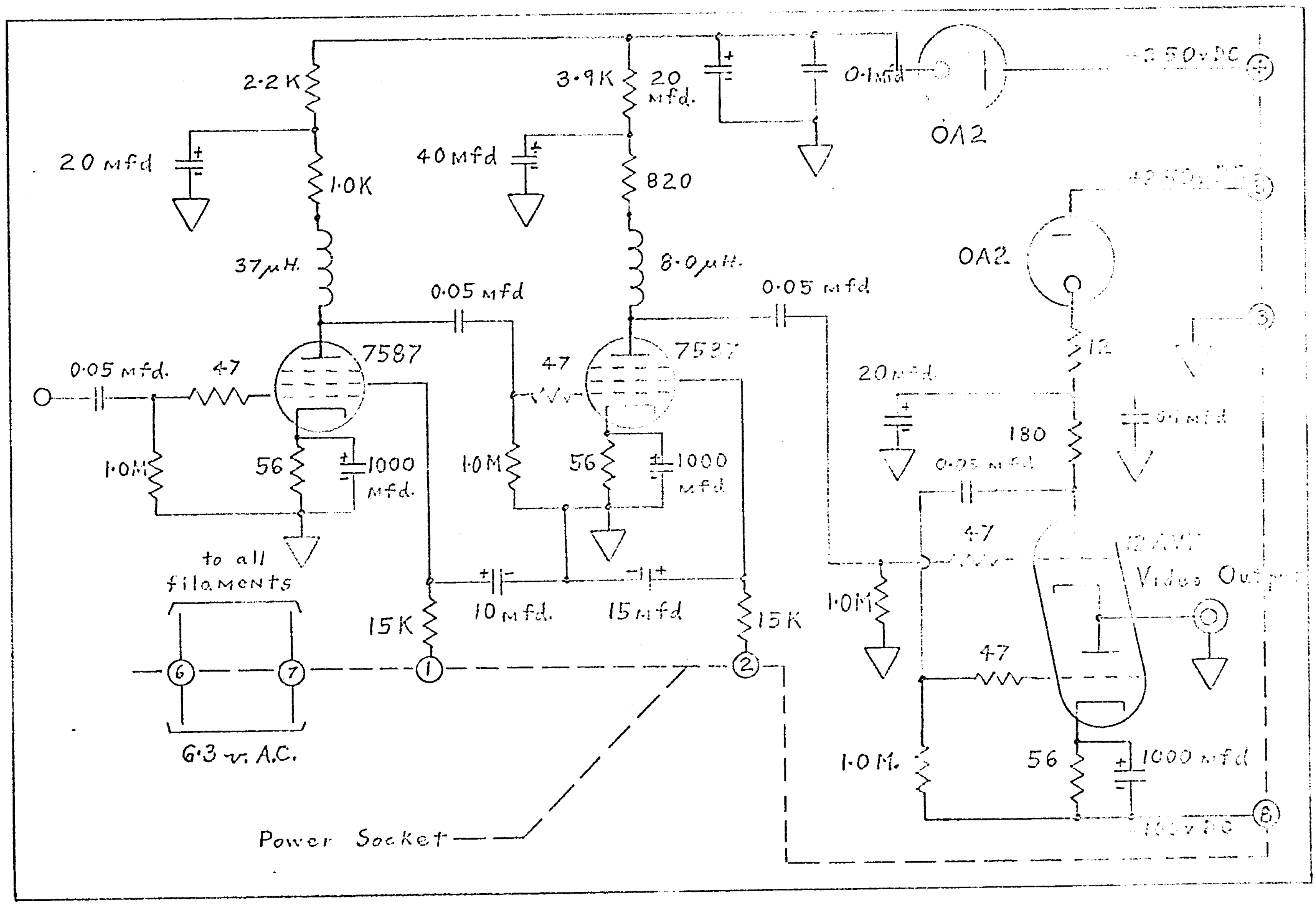


Fig. 32 PREAMPLIFIER CIRCUIT

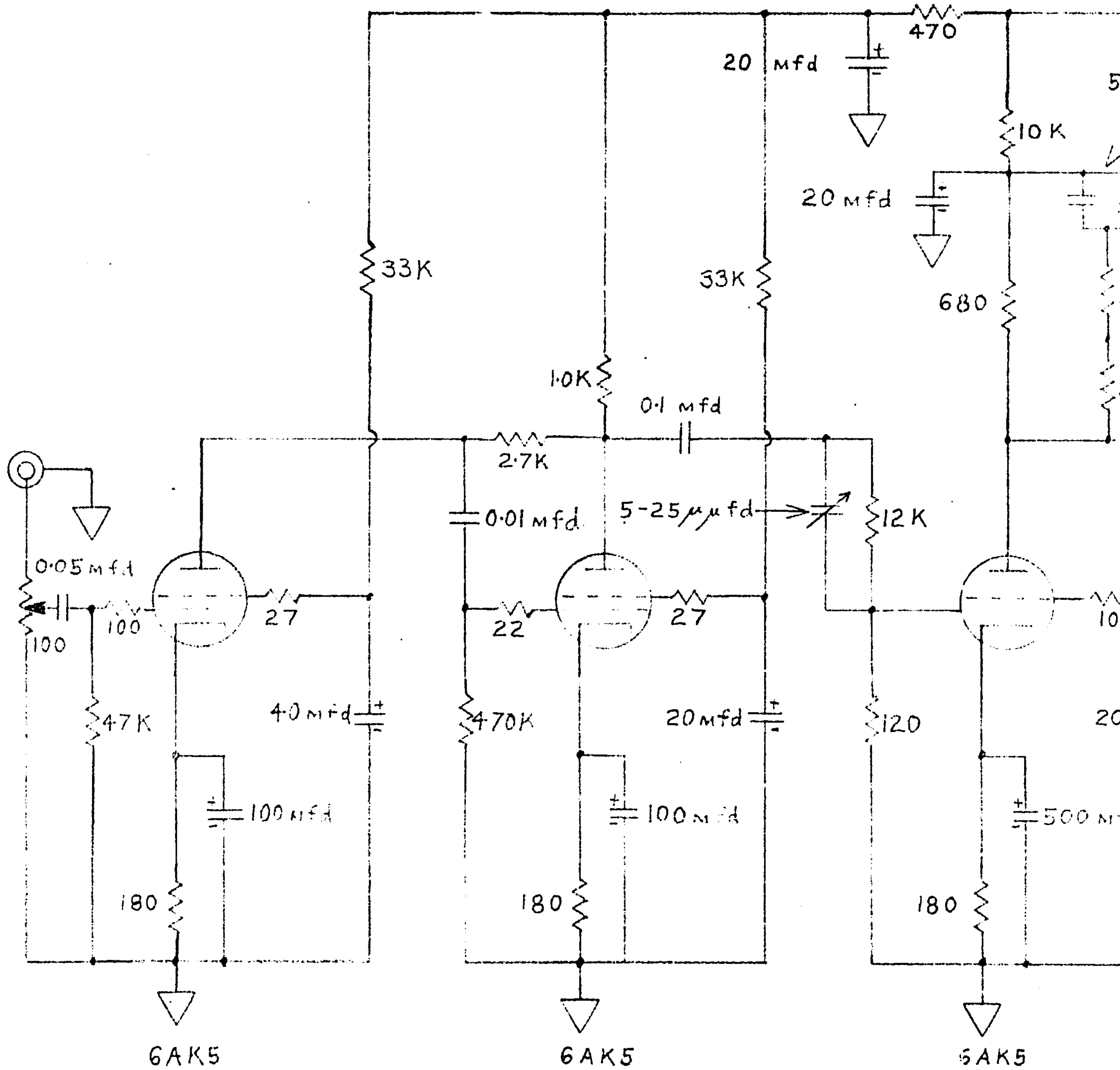
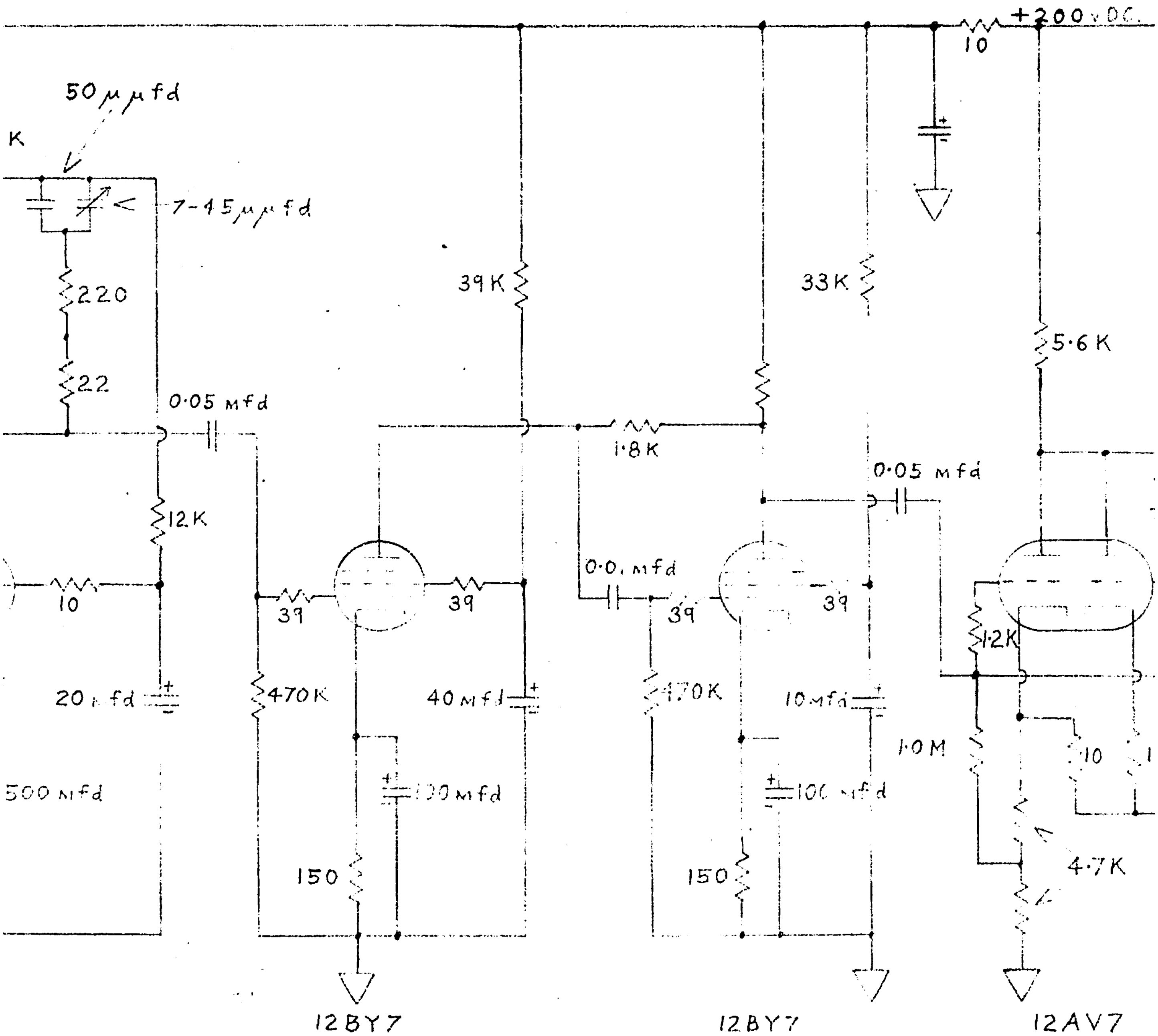
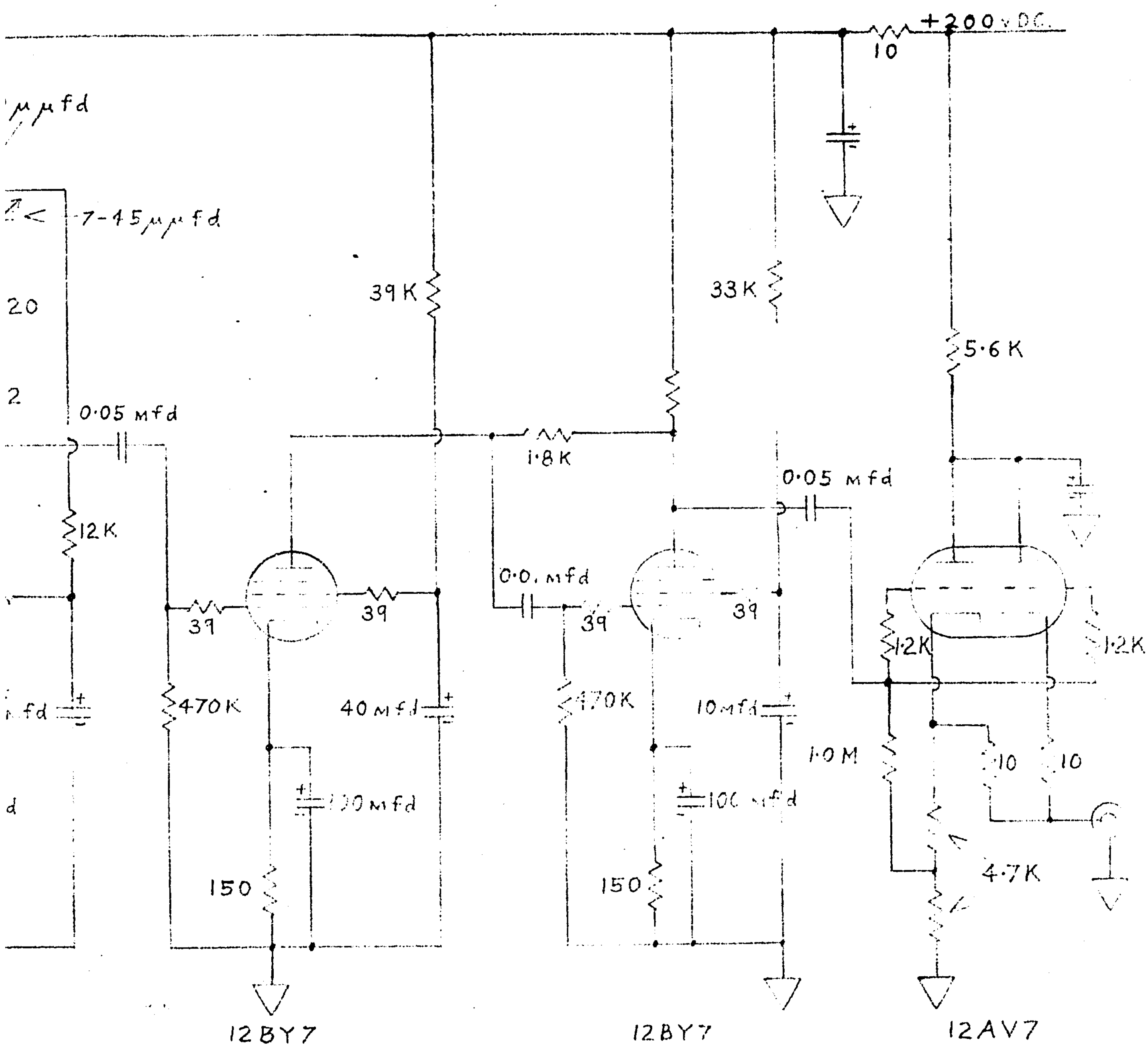


Fig. 33 PHOSPHOR COR



PHOR CORRECTOR CIRCUIT



RRECTOR CIRCUIT

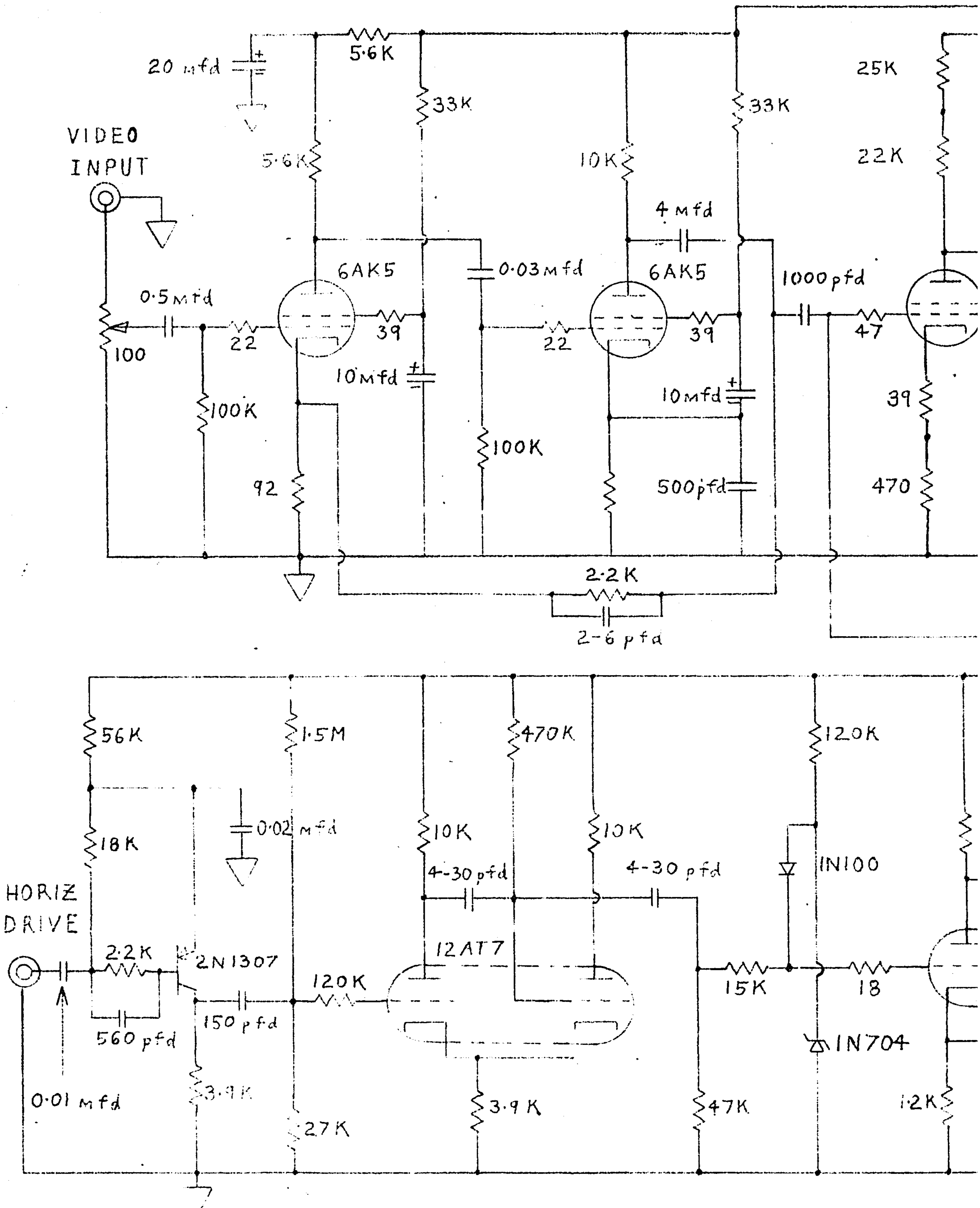
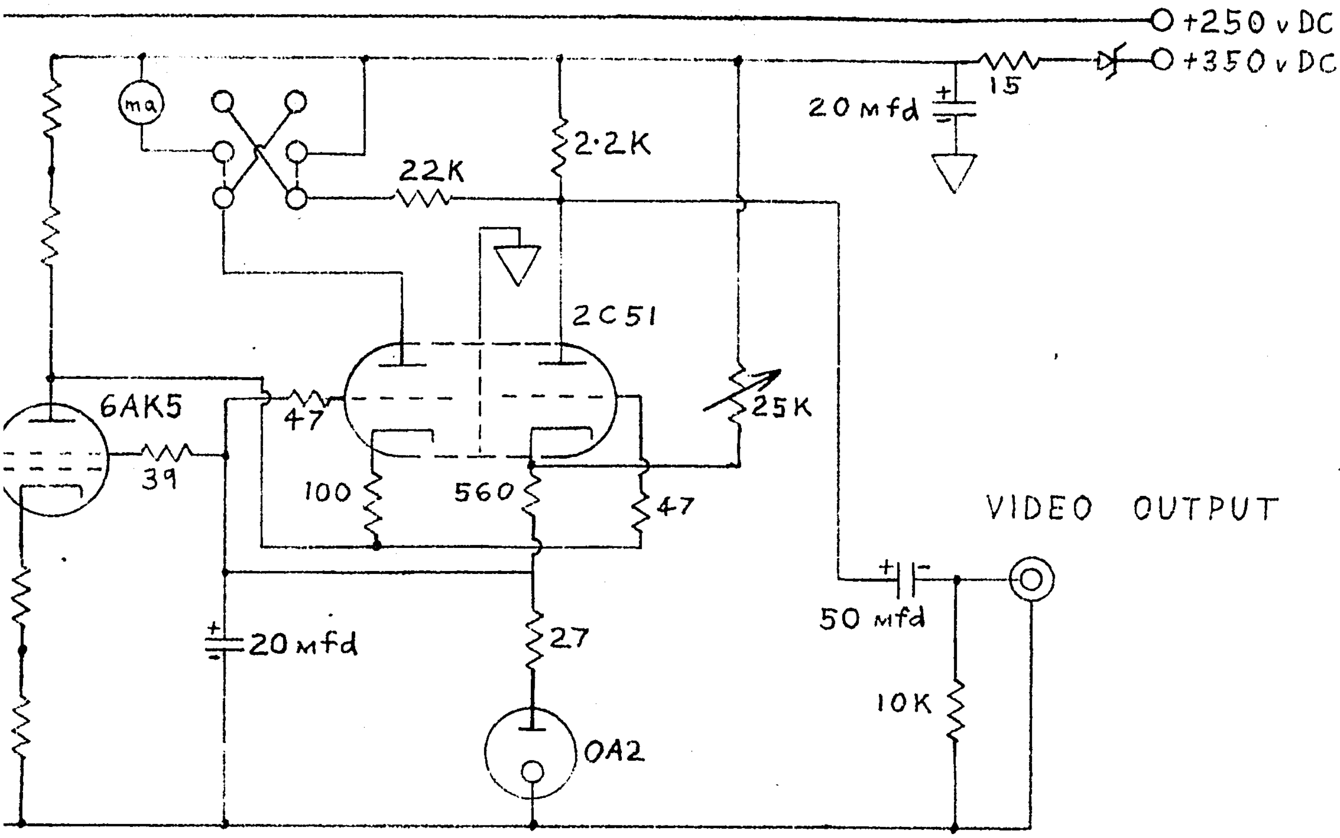
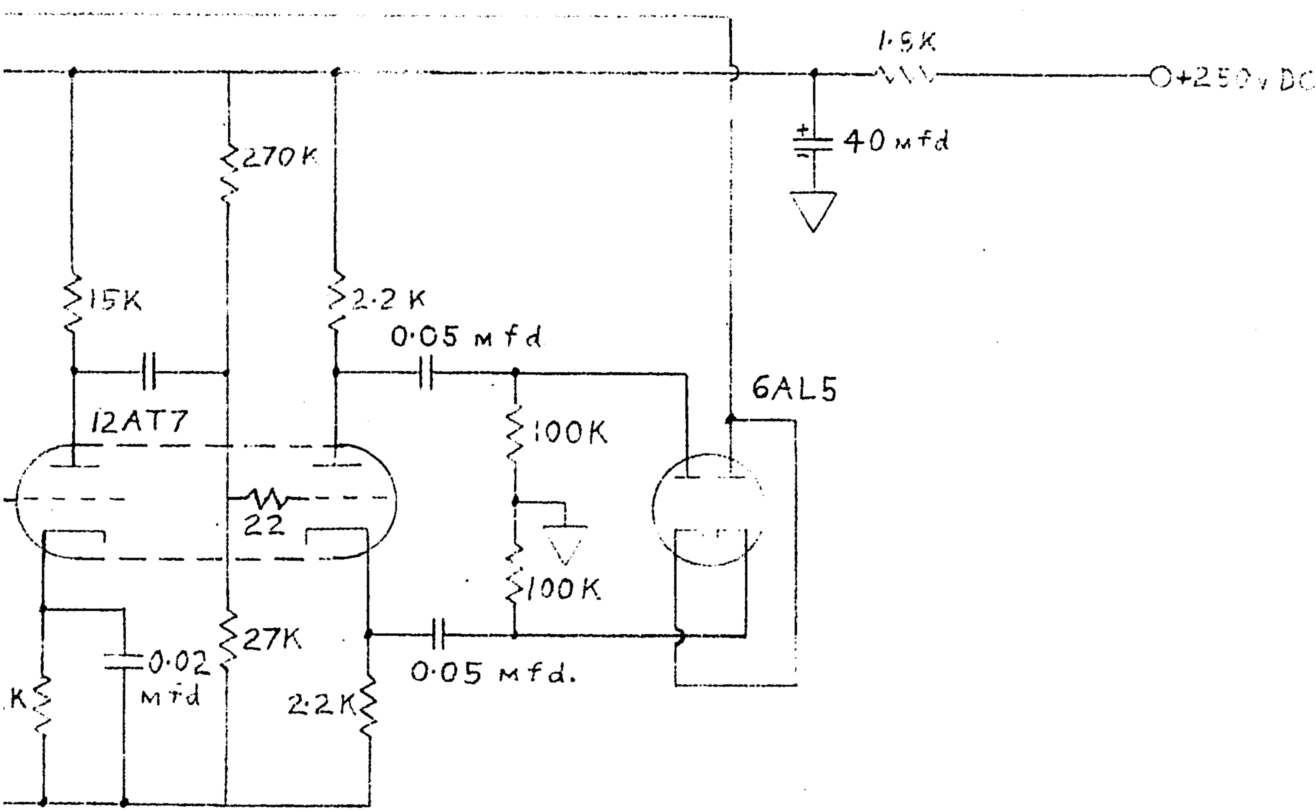


Fig. 34 GAMMA CORRECT





ORRECTOR CIRCUIT

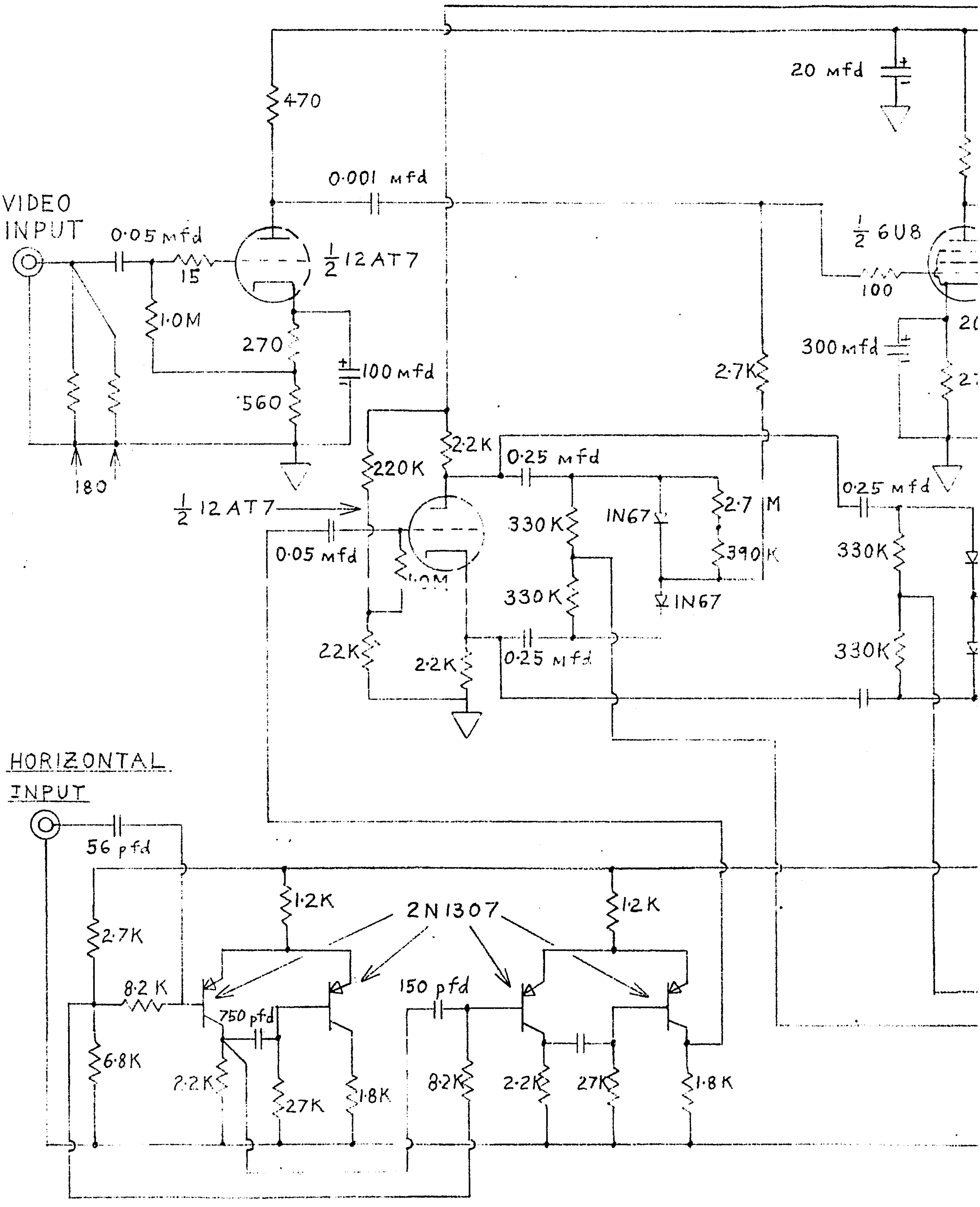
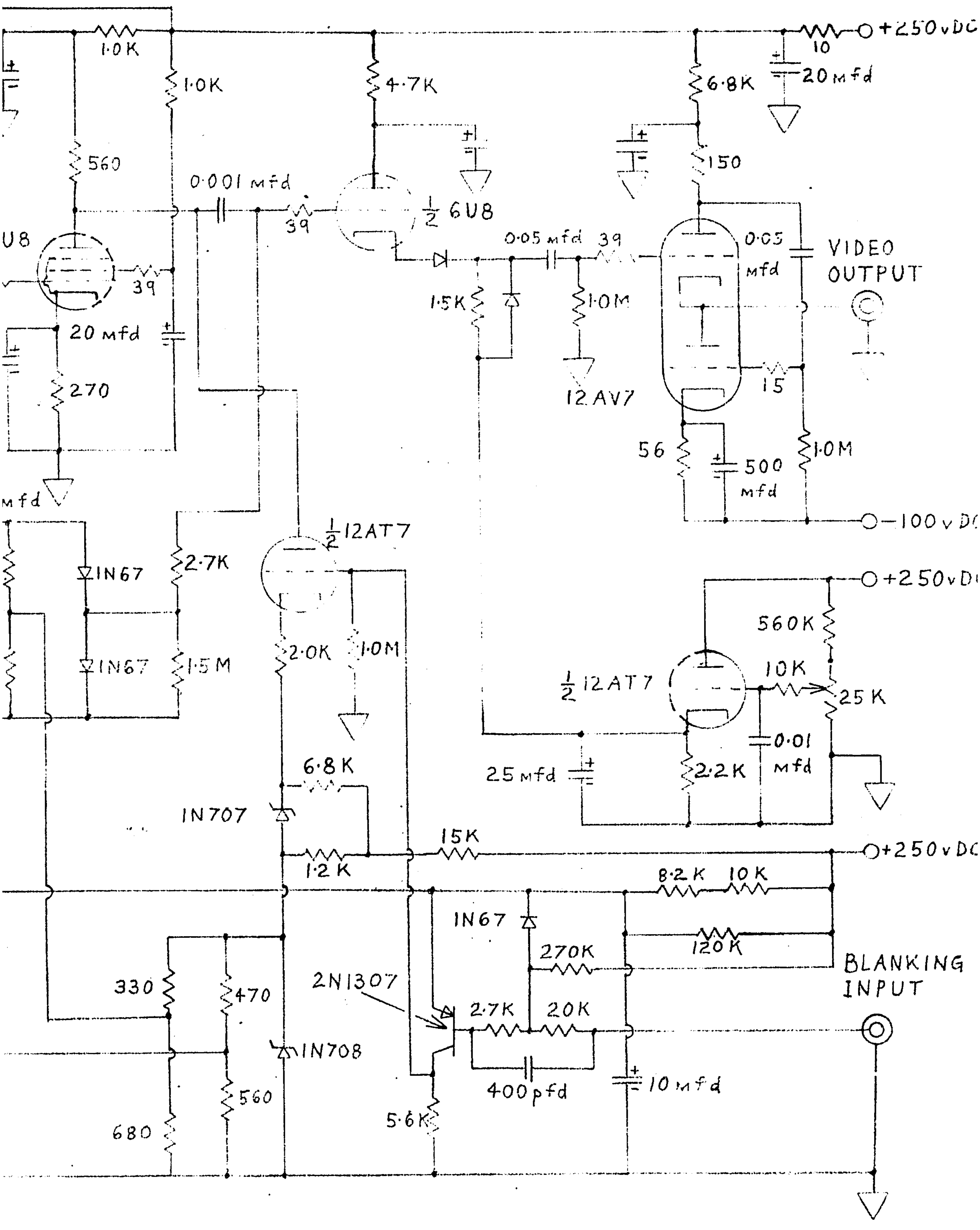


Fig. 35 PEDESTAL INSERTER AND



RTER AND CLIPPER CIRCUIT

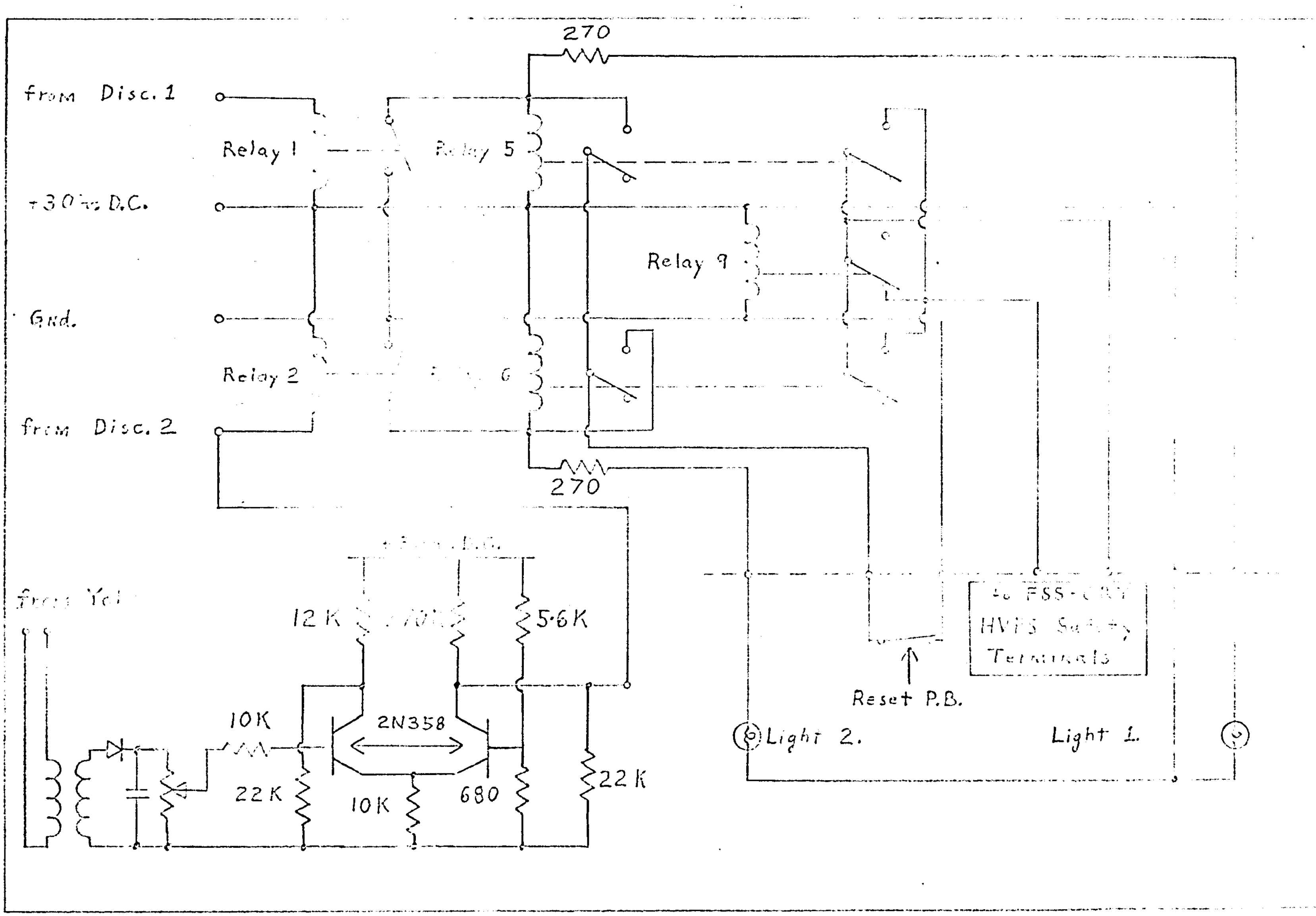


Fig. 36 FSS CRT SAFETY CIRCUIT

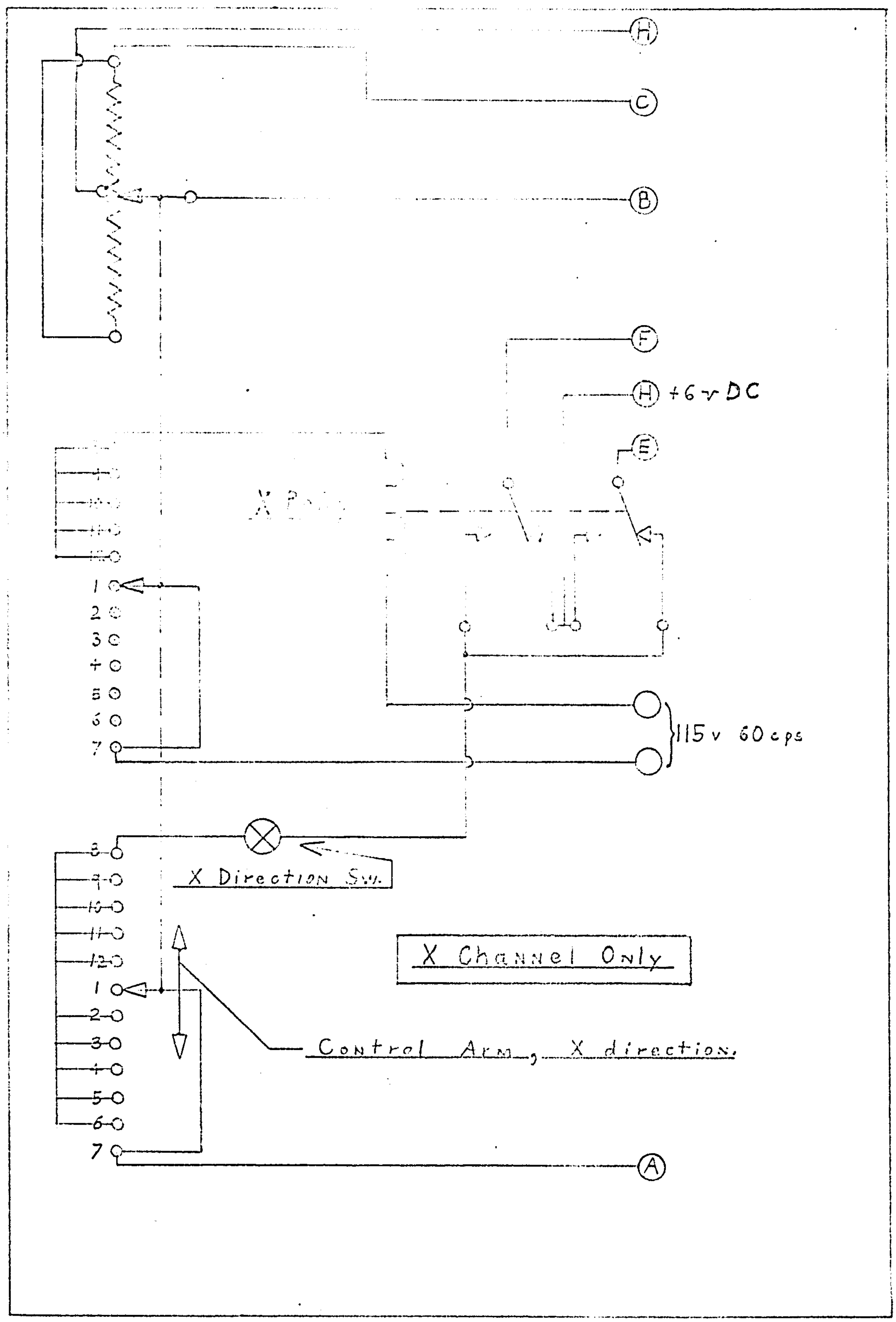


Fig. 37 X Y STAGE, CONTROL BOX WIRING

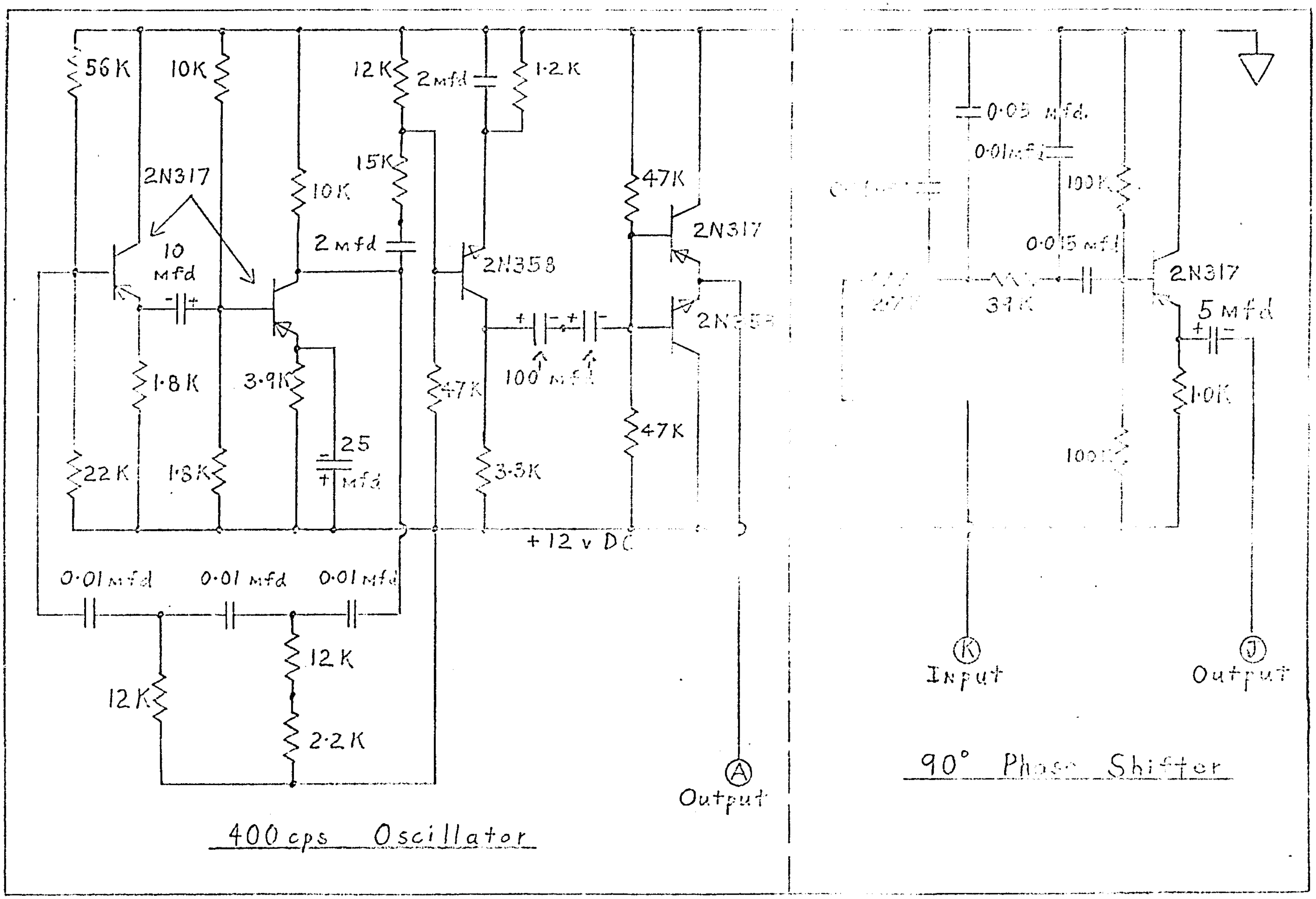


Fig. 38 400 cps OSCILLATOR, AND 90 DEGREE PHASE SHIFTER

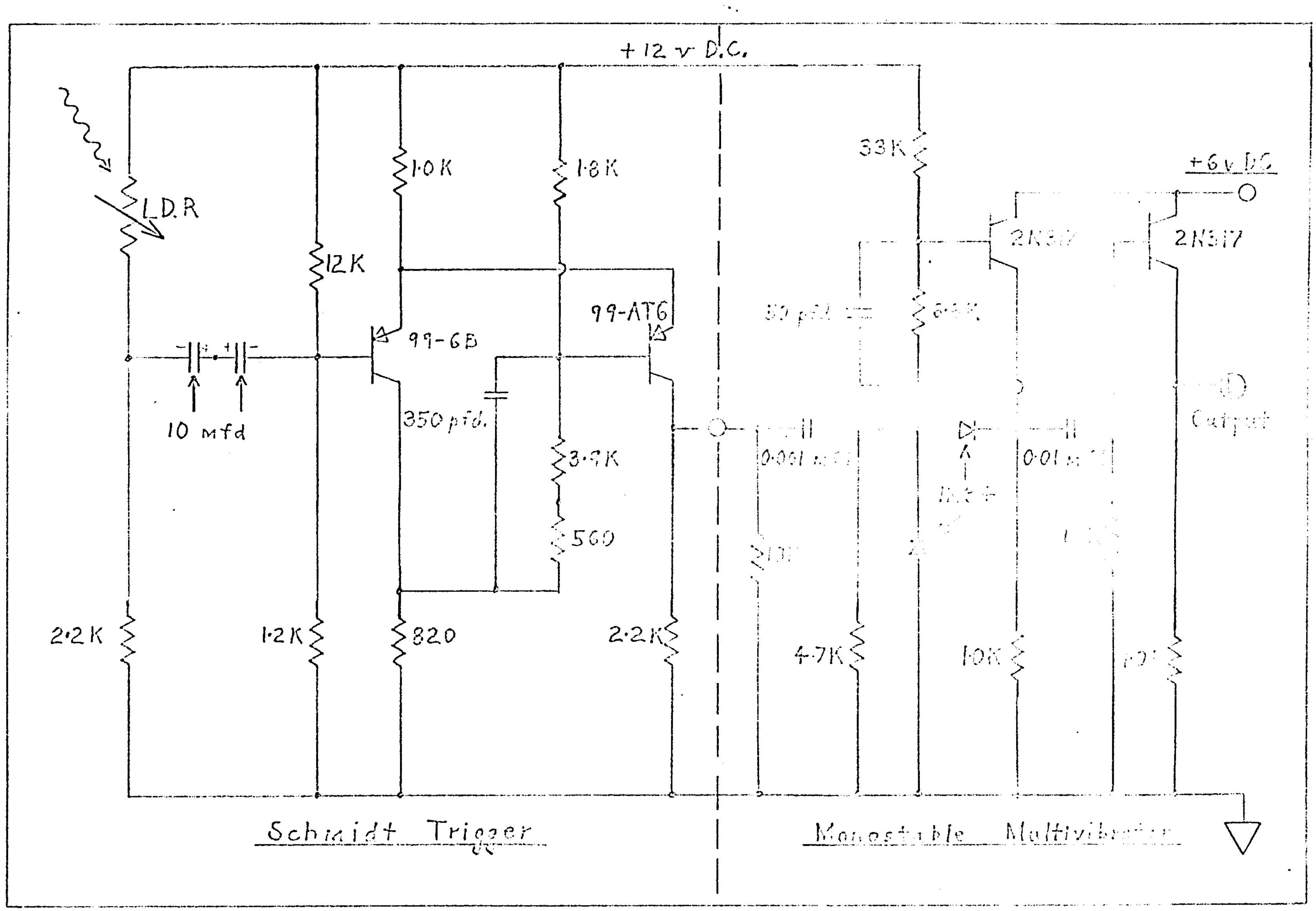


Fig. 39 VELOCITY DISC INPUT CIRCUIT, SCHMIDT TRIGGER, AND MONOSTABLE MULTIVIBRATOR

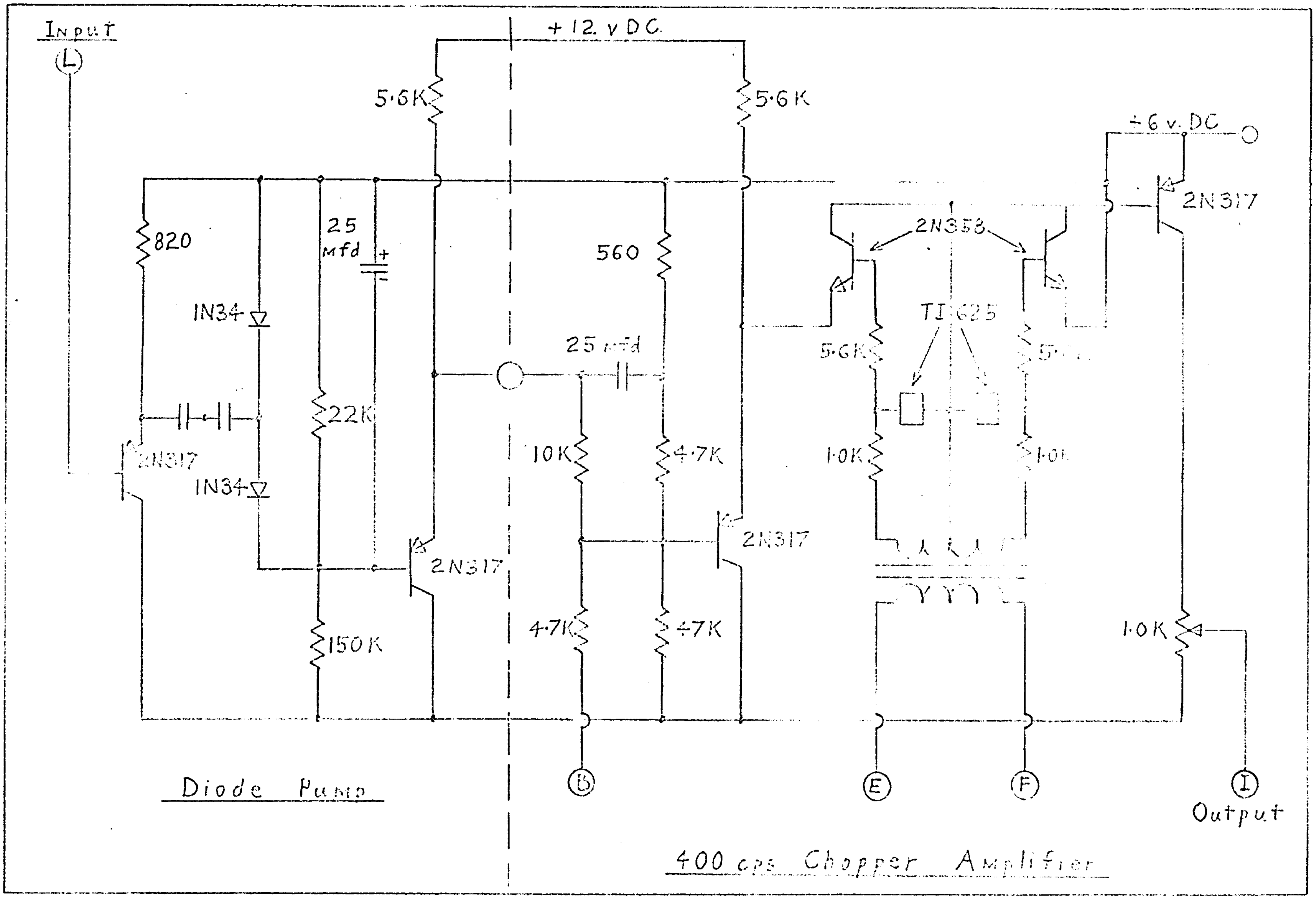
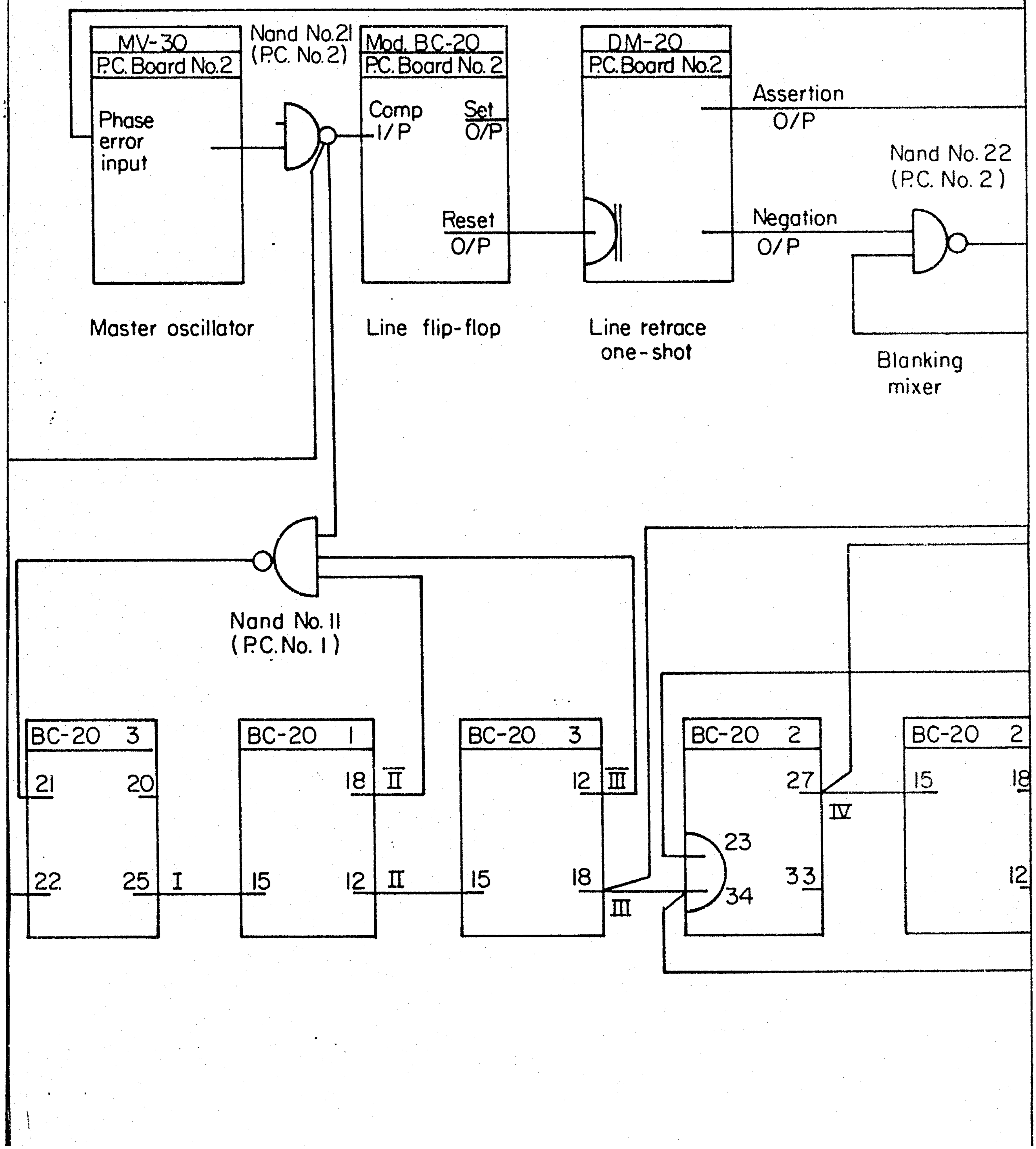
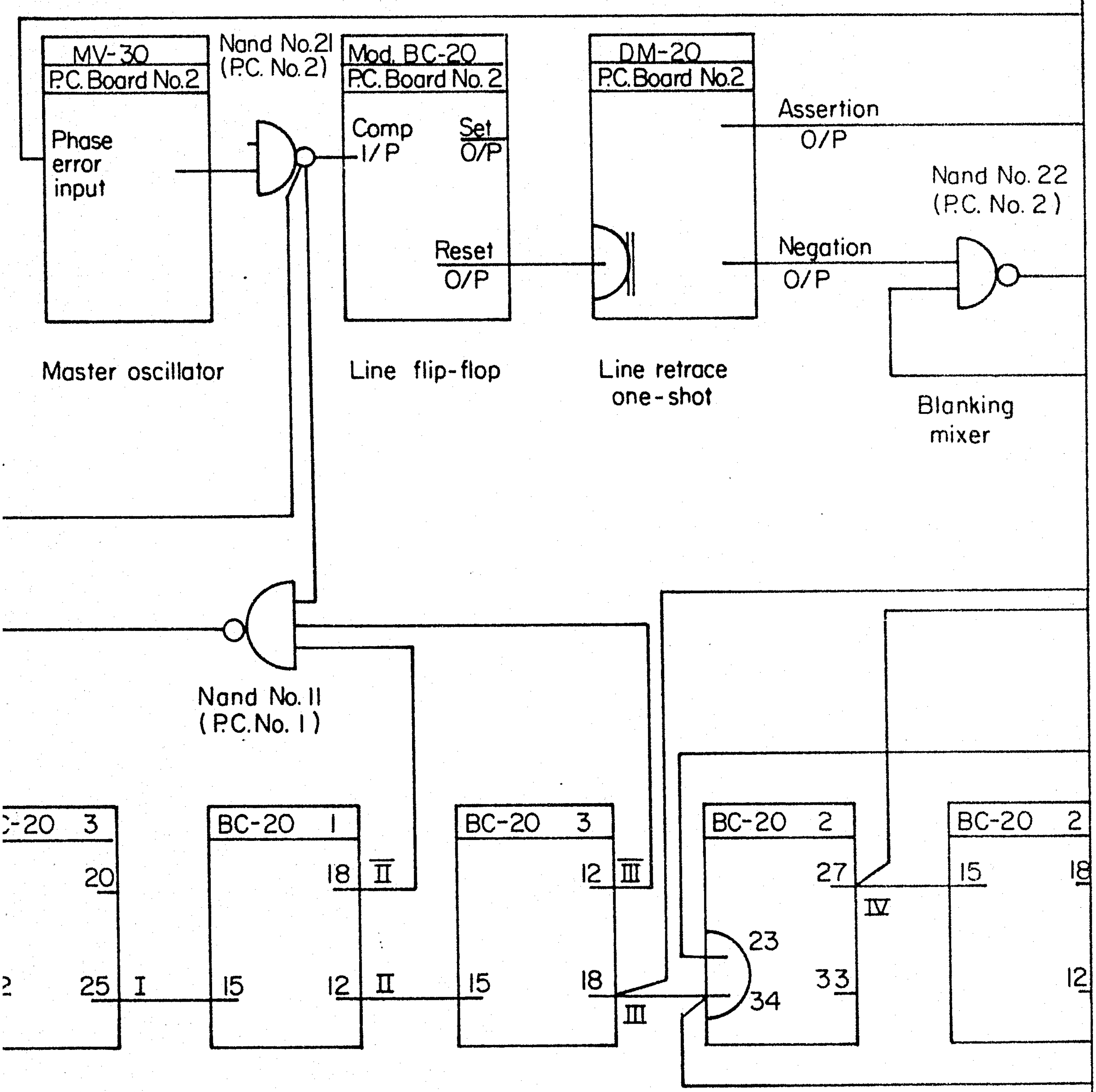
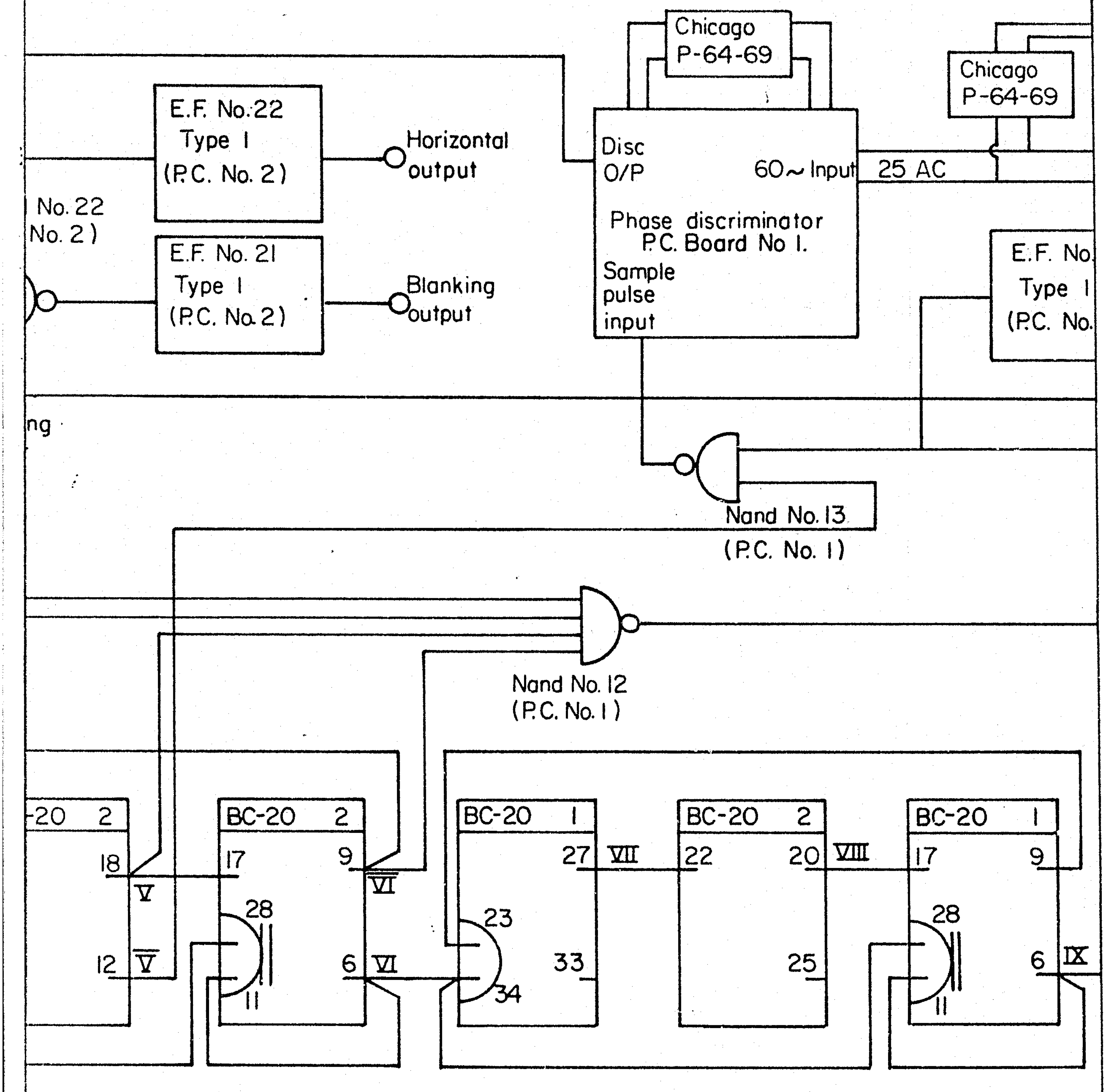


Fig. 40 DIODE PUMP CIRCUIT, AND 400 cps CHOPPER AMPLIFIER


MV-30
P.C. Board No.2
Phase error input
Master oscillator
Nand No.21 (P.C. No.2)
Mod. BC-20
P.C. Board No. 2
Comp I/P
Set O/P
Reset O/P
Line flip-flop
DM-20
P.C. Board No.2
Assertion O/P
Negation O/P
Line retrace one-shot
Nand No. 22 (P.C. No. 2)
Blanking mixer
Nand No. 11 (P.C. No. 1)
BC-20 3
21
20
22
25
I
BC-20 1
18
II
15
12
II
BC-20 3
12
III
15
18
III
BC-20 2
27
IV
23
33
34
BC-20 2
15
18
12



MV-30
P.C. Board No.2
Phase error input
Master oscillator
Nand No.21 (P.C. No.2)
Mod. BC-20
P.C. Board No.2
Comp I/P
Set O/P
Reset O/P
Line flip-flop
DM-20
P.C.Board No.2
Assertion O/P
Negation O/P
Line retrace one-shot
Nand No. 22 (P.C. No. 2)
Blanking mixer
Nand No. 11 (P.C.No. 1)
BC-20 1
BC-20 3
BC-20 2
BC-20 2
20
25
15
18
12
23
34
27
33
I
II
III
IV



Chicago
P-64-69
Chicago
P-64-69
E.F. No.22
Type I
(P.C. No. 2)
Horizontal
output
Disc
O/P
60~ Input
25 AC
No. 22
No. 2)
Phase discriminator
P.C. Board No I.
E.F. No.
Type I
(P.C. No.
E.F. No. 21
Type I
(P.C. No. 2)
Blanking
output
Sample
pulse
input
ng
Nand No. 13
(P.C. No. 1)
Nand No. 12
(P.C. No. 1)
-20 2
BC-20 2
BC-20 1
BC-20 2
BC-20 1
18
17
9
27
VII
22
20
VIII
17
9
V
VI
28
23
28
12
V
6
VI
33
25
6
IX
34
11
11

Fig. 42

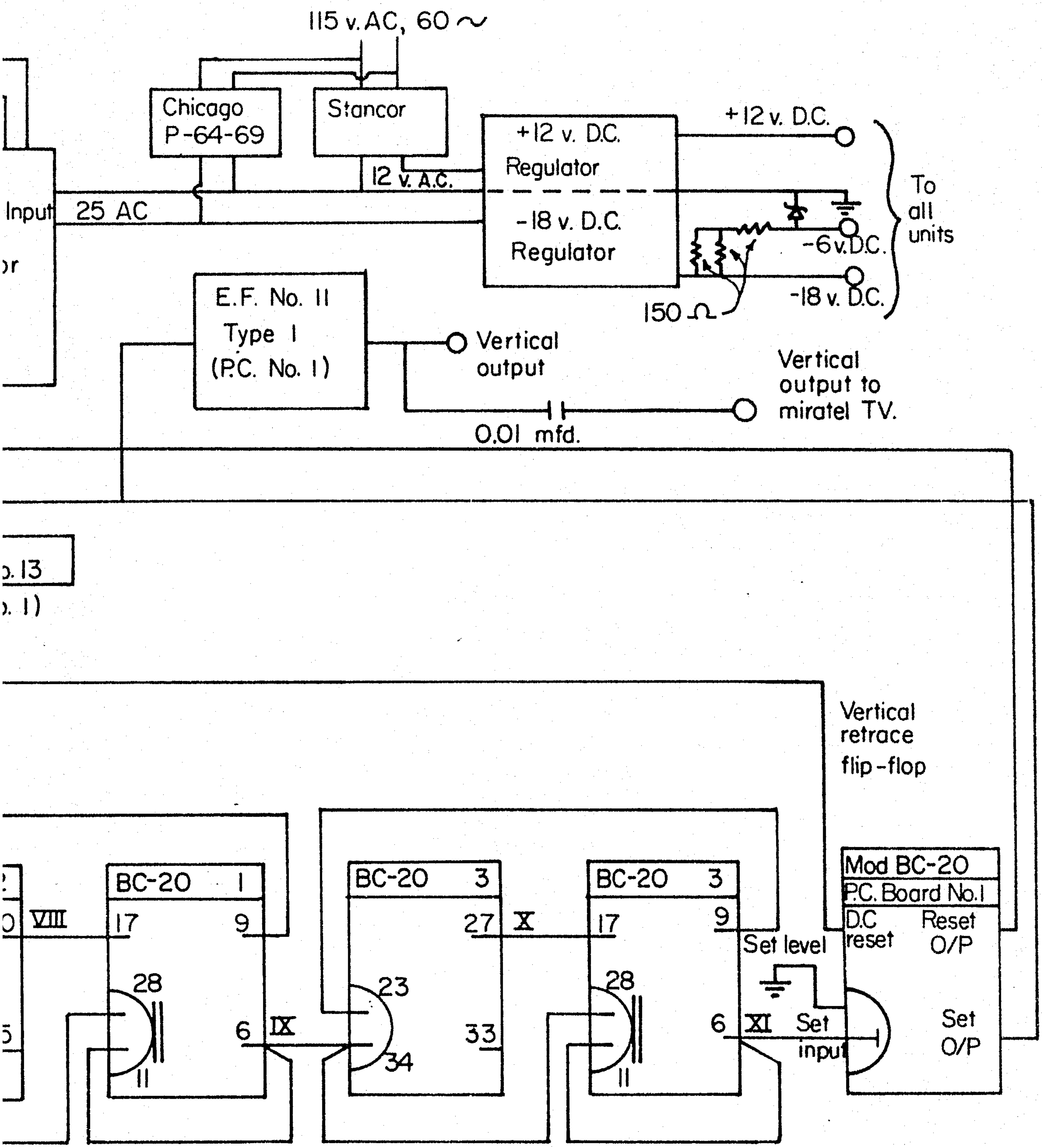
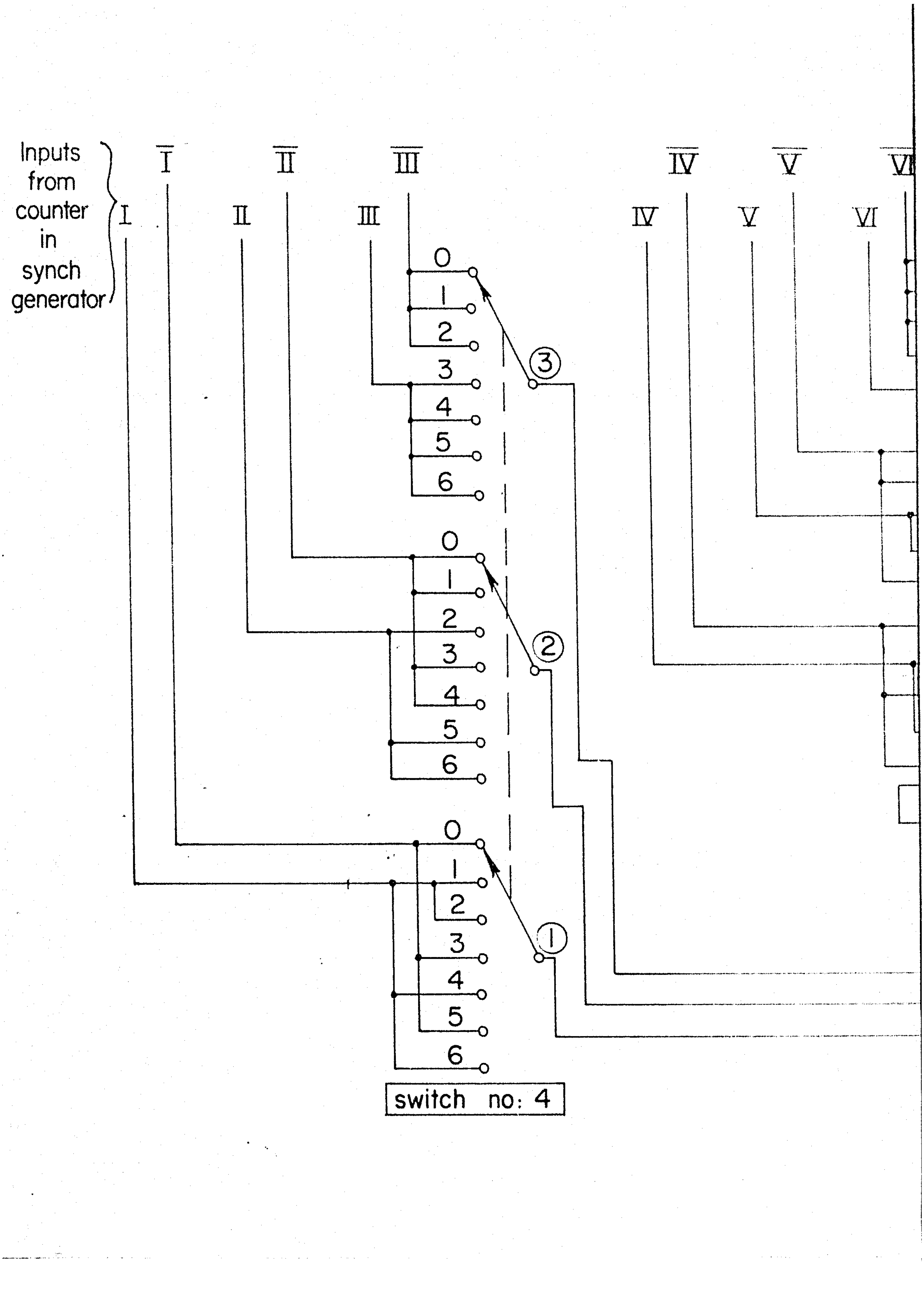
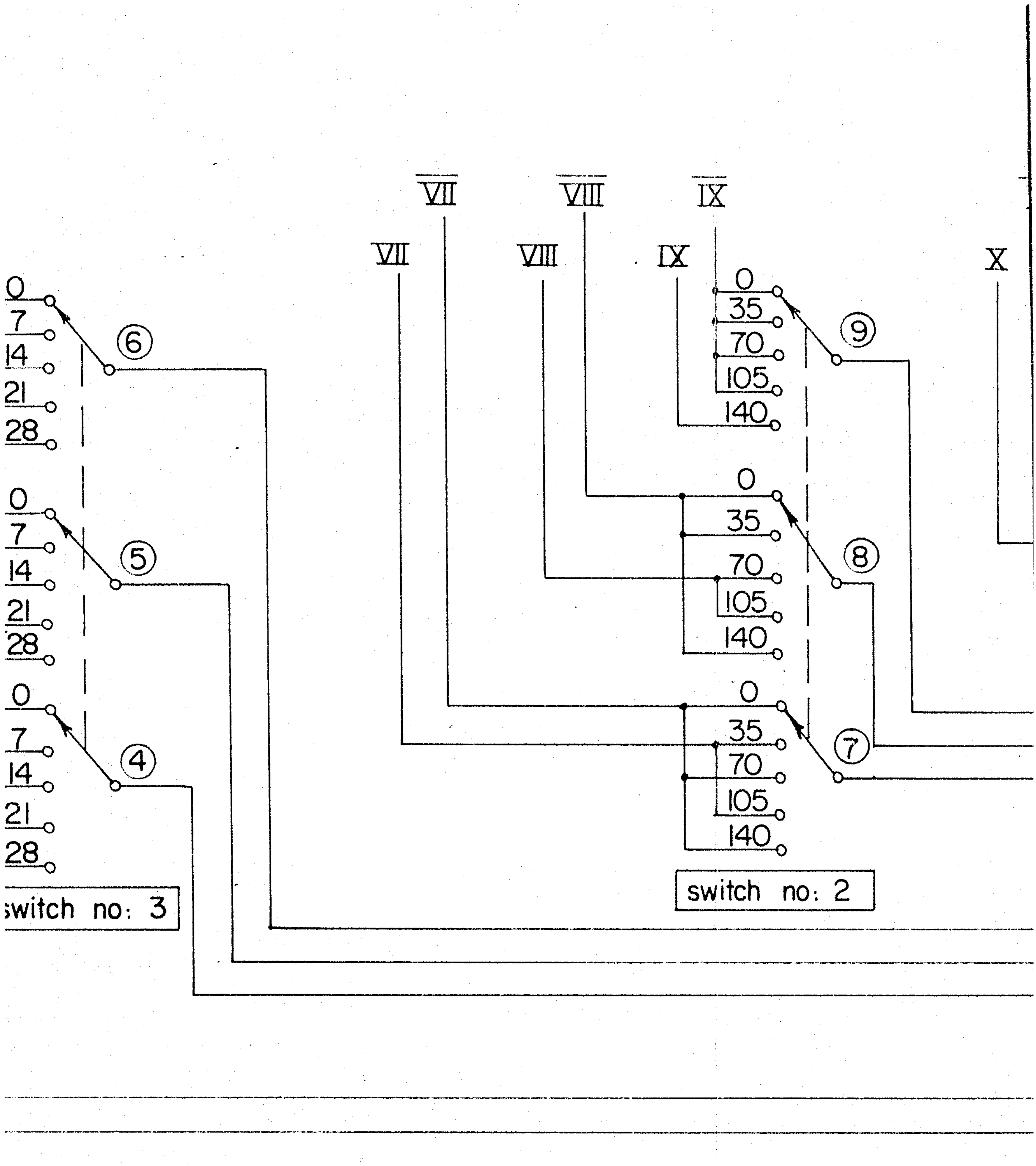


Fig. 42 Synchronizing Generator for Flying Spot Microscope

B. Wiggins


Inputs from counter in synch generator
$\overline{I}$ $\overline{II}$ $\overline{III}$ $\overline{IV}$ $\overline{V}$ $\overline{VI}$
I II III IV V VI
0 1 2 3 4 5 6
3
0 1 2 3 4 5 6
2
0 1 2 3 4 5 6
1
switch no: 4



VII
VIII
IX
VII
VIII
IX
X
0
7
14
21
28
6
0
7
14
21
28
5
0
7
14
21
28
4
switch no: 3
0
35
70
105
140
9
0
35
70
105
140
8
0
35
70
105
140
7
switch no: 2

Fig. 43

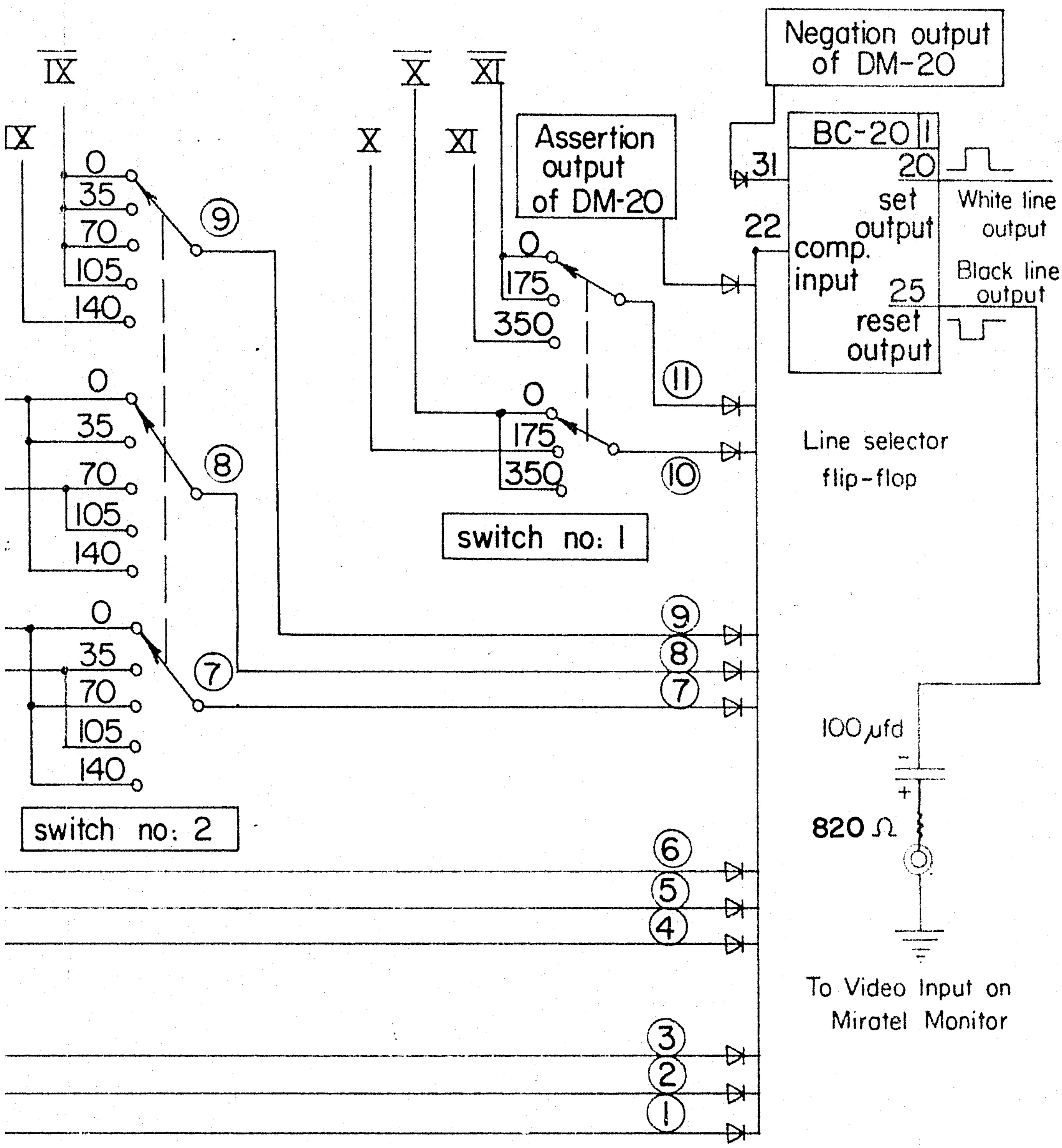


Fig. 43 Line selector
B. Wiggins