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"SUPERSCOPE" — A 48-CHANNEL WIDEBAND OSCILLOSCOPE SYSTEM

1. Introduction

A 48-channel nanosecond oscilloscope, known as "Superscope", was built to obtain scintillation counter information for SLAC experiment E56, "A Search for Neutrino-Like Particles". The experiment utilized a detector consisting of four spark chamber modules and three planes of scintillation counters (Fig. 1). Each of the 21 scintillation counters had an active area 11 inches wide and 8 to 9 feet in length. They had a 56 AVP photomultiplier tube located at each end, making 42 tubes in all. Detailed information about the time and size of pulses in the PM tubes was needed to match tracks of particles in the spark chambers with the signals they produced as they traversed the counters, and also to determine the direction of flight of the particles as they went through the apparatus. This information allowed us to discriminate between a neutrino event in the detector giving a single outgoing muon and the case of a cosmic ray muon entering from the opposite direction and stopping in the chamber.

Since the minimum spacing between the counter planes was two feet, the time difference for the counters had to be known to $\approx$ 2 ns in order to determine the direction of flight. Therefore, the superscope was designed with a horizontal sweep rate of 10 ns/cm. Two phototube signals, one with its polarity inverted and delayed by 35 ns, were displayed on each oscilloscope. The 42 signals were assigned to the tubes so that first, the two sides of a single counter were displayed on different CRT screens and second, that the chance of a screen having both signals present in an event was small. The vertical sensitivity was 1 volt (input phototube signal)/cm. The array of 24 oscilloscopes and Nixie identification was photographed on 70 mm film. This film was then matched with the spark chamber film and measured on a scanning table.

2. System

A block diagram of the system is given in Fig. 2 and its characteristics are summarized in Table 1. Signal input to the system was either in the form of phototube signals from the apparatus or an 8 ns square wave from a calibration signal generator which was a modified Tektronix 109 pulser driven at 5 Hz or in "single shot" mode. Its output was fanned out to inputs on each of the resistive divider boxes by a 50 Ω transformer splitter network. The phototube signals were directly connected to these boxes. Two outputs of the resistive dividers were used as inputs for the high speed logic and the vertical amplifiers of the individual oscilloscopes respectively; the third output served as a test point.

The high speed logic required about 70 ns to deduce the validity of an event and to generate a trigger. This trigger was used to generate a 120 ns signal which was fanned out to each of the CRT unblanking circuits (see Section 5). These circuits generated a $\approx$ 100 V pulse for the duration of the gate to turn on the electron beam in the oscilloscope. A 120 ns pulse was sent to each of the horizontal amplifiers after the start of the unblanking gate. This circuit gave the two ramp signals that drove, in push-pull, the horizontal plates of the oscilloscope.

At the end of the horizontal sweep, triggers were sent to each of the flood gun amplifiers. The flood gun amplifier was an adjustable monostable (set at approximately 20 μs) that controlled an electron gun which uniformly illuminated the screen. This was used to post-sensitize the film, thus increasing its speed. All of these trigger functions were performed by conventional high speed logic. The time delay between the presence of a signal at the resistive divider and the start of the useable horizontal sweep was $\approx$ 150 ns. The early inputs to the vertical amplifier were delayed by this amount and the late inputs were delayed an additional 35 ns. These delay lines and the lines from the phototubes to the divider boxes were made of RG213 in order to minimize signal degradation in the 160 feet or more of cable.

The high speed logic trigger was also sent to the camera control box. This slower device generated the identification number which was flashed by Nixie tubes onto both the spark chamber and superscope pictures. It also controlled the film advance for both cameras.

The CRT used was a Hewlett Packard HP5083-2042 with a P11 phosphor, the same as used in the HP183A oscilloscopes. It was chosen for its speed, availability, and photogenic characteristics (Table 2).

The 24 oscilloscopes and a 6-digit Nixie readout were mounted in a light tight enclosure and were viewed by a camera with a 100 mm, f/2 lens, see Fig. 4. The fast logic, the dc power and all the controls for the oscilloscopes were mounted on separate racks for ease of accessibility. The superscope mainframe contained 24 CRT's, a Nixie display and the optical system.

3. Mechanical Construction

The CRT's were mounted individually into open rectangular frames made of 1" × 1" aluminum angle just large enough to accept the magnetic shield around the CRT as shown in Fig. 3. The electronic circuits for the CRT's were then installed on each frame to achieve good high frequency characteristics.

The face of the CRT was light-sealed to the end of the frame using duc-seal and adhesive tape. A strip of foam rubber was attached around the end of the frame to complete the light seal when the frame was inserted into a pigeon-hole type of rack and pushed forward against a vertical face plate. The traces were photographed through holes in the face plate. The light tight enclosure thus extended from the face of the CRT's to the camera; the bodies of the CRT's and the associated electronics being outside of the enclosure. With this structure it was possible to remove one CRT frame from the pigeon-hole rack and service it without disturbing the operation of the remaining units.

The base of the instrument was a welded 6" aluminum channel structure to which the pigeon-hole rack and the camera and lens mount were bolted, see Fig. 4. The light enclosure was made of thin aluminum sheets rivetted together, and painted black inside. The top section was removable and a large camera-type bellows permitted adjustment.

The 24 CRT's were arranged in a 5×5 array, the extra slot being used for a Nixie-tube frame counter. The amount of light available was minimal for photography and fast lenses usually have a fairly rapid decrease in light transmission with angle, for rays entering the lens at more than about 15°. Therefore, the dimensions of the pigeon-hole rack were made as small as possible. The size of the area photographed was 25" (V) × 28" (H). We chose to mount the lens 60" from the face plate, and at this distance light rays from the extreme corner traces entered the lens at somewhat less than 17°.

In order to reduce the overall length of the instrument, the camera and lens were mounted above, and viewed the face plate through, a 45° mirror. The camera mount was arranged to accept a Graphlex back with a ground glass screen and a 4" × 5" Polaroid film pack, as well as a 70 mm roll film camera.

Due to the extremely high film sensitivity, the instrument was installed in a room with subdued lighting and great care was taken to seal all light leaks with duc-seal or adhesive tape.

4. Optics

The most suitable film we could find was 70 mm unperforated Kodak 2485, a very high speed panchromatic recording film. However, to obtain the optimum speed, Kodak recommends a special developer which we were unwilling to use since it was not compatible with other film processing being done on the SLAC automatic machines. We used instead, the SLAC standard, Dupont X-ray developer and obtained maximum sensitivity by slightly overdeveloping so that the background fog from the flood gun was a fairly dense grey. This required running at the spray machine's lowest reliable speed, 50 fpm, with a temperature of 95° F. The low speed had the additional advantage of a longer drying period for the film, which has an unusually thick emulsion.

One of the disadvantages of this film was its very coarse grain. By just fitting the frame to the 70 mm film width, the face of each CRT appeared as a rectangle approximately 4.5 mm × 7 mm on the film (Mag. $\approx$ 14.5). Even at this size, the coarse grain of the film added to the difficulty of resolving the fainter portions of the trace.

The lens had to meet criteria of ready availability, low cost, high speed, and a focal length of about 100 mm. The focal length was determined by the need to have the image on the film as large as possible, as mentioned above, and the choice of a 60" object-to-lens distance, as described in Section 3.

We first tried an f/1.2 lens from a Tektronics oscilloscope camera that was available in the laboratory. This was a special purpose lens designed for an object to image ratio close to 1:1. Although it was the fastest lens we tested, it was unusable at the magnification we needed.

Three 100 mm large format lenses were then obtained for testing. Their speeds were f/2.0, f/2.3, f/2.8. Bench tests eliminated the f/2.3 because of its poor resolution. The f/2.8 lens was a Schneider Xenotar and although it was an excellent lens it was not fast enough for our application. We therefore chose the third and fastest lens an Angenieux 53 Anastigmat f/2.0. Even using this lens light collection was marginal at the 17^{o} angle subtended by the CRT's in the corner locations.

The lens was mounted on a precision ball slide assembly and spring loaded against a micrometer head. This, along with the vacuum platen in the camera, enabled us to obtain the necessary precise and repeatable focus.

5. Electronic Circuitry

In this section we describe the electronics circuits for the superscope, as distinct from the system's general circuits that include the fast logic, Nixie displays, generation of calibrating pulses, etc., which were discussed in Section 2.

The driver circuitry mounted on the individual superscope modules was designed solely for the intended operating conditions of the superscope, and is thus in most cases much simpler than conventional oscilloscope circuits.

The CRT circuitry includes 1) a vertical amplifier, 2) a horizontal amplifier, 3) an unblanking circuit, 4) a flood gun amplifier, 5) external controls for the CRT static operation, and 6) power supplies and interlocks.

The vertical amplifier, shown in Fig. 5, uses a differential cascode configuration to achieve fast rise times and a push-pull output that drives the 330 ohm (nominal) impedance of the CRT vertical deflection plates. It delivers a maximum deflection of 1.5 cm in the linear region, corresponding to a push-pull voltage at the deflection plates of ≈ 4.5 volts. The rise and fall times are 1.5 ns (10% to 90%). The average potential at the vertical deflection plates is +44 volts for correct electron optics. Two signals, one of which is delayed, are applied to the two inputs and appear on the time base with opposite polarities.

The horizontal amplifier, shown in Fig. 6, consists of two complementary sawtooth generators to produce the requisite push-pull waveforms at the horizontal deflection plates of the CRT. The NPN differential pair, Q41 and Q42, and its constant current source Q43 generate a positive going sawtooth at the horizontal plate SC2 of the CRT. The corresponding negative going sawtooth at SC1 is generated by the PNP differential pair, Q44 and Q45, and its constant current source Q46. Discharge of the plates through 100K resistors provides the retrace, which is very slow and occurs after the unblanking signal is removed. Although under normal operation cycle time of the superscope is limited by the camera and a complete retrace will occur, the horizontal sweep circuit will show a position shift if a repetition rate much above 100 pps is used during calibration and testing. The linearity of the horizontal sweep is limited mainly by the static deflection characteristics of the tube.

The quiescent potential at SC1 and SC2 is controlled by Q47, Q48, and the associated network. Specifically, the potential at the geometric center between the horizontal deflection plates SC1 and SC2 is kept constant at +47 volts independent of the horizontal positioning control. In this way, the electron optical characteristics of the tube are not affected by horizontal positioning.

Coarse adjustment of the sawtooth slopes is done with capacitors C11 and C17. Fine control of the slopes can be effected remotely through adjustment of 50 Ω potentiometers, one for each current source. A standard NIM signal of -0.7 volts and >100 ns duration is required to develop the horizontal sweep having a speed of 10 ns/cm.

The unblanking amplifier and the remote intensity control, shown in Fig. 7 determine the potential of the CRT grid with respect to its cathode. A standard NIM -0.7 V pulse is applied to Q_1 of Fig. 7 and is amplified to yield a positive pulse up to 100 volts in amplitude and a rise time of 50 ns (10% to 90%) at the collector of Q5. In the quiescent (blanked) state the potential of the CRT grid is 100 volts negative with respect to the cathode. Capacitor values were chosen to limit the unblanking duration to 150 ns, maximum. The amplitude of the unblanking pulse, up to 100 volts, is set by the intensity control. The maximum useable intensity is limited by beam defocusing and varies from tube to tube.

Since the unblanking pulse is superposed on a -3.1 kV potential, the last stage of the amplifier, Q5, is ac coupled to its preceding stage and is referenced to -3 kV. The coupling capacitor, C9, has a 6 kV dc rating and protection diodes have been added to prevent damage to transistors during turn-on and turn-off transients of the -3 kV supply. The output pulse is applied to the CRT grid via a 300 ohm (nonterminated twin TV) cable to reduce radiated noise during signal transitions. The rate of rise of the pulse was limited and special care was exercised in signal ground returns to minimize noise originating from pulses of 250 mA amplitude. The input to the unblanking amplifier is applied well before triggering of the horizontal sweep to ensure full light intensity at signal display time.

Flood gun. The CRT (HP5083-2042) incorporates a flood gun cathode and grid. When energized immediately after the sweep it can enhance writing speed by illuminating the screen which reactivates the phosphor. In addition, illumination of the phosphor "fogs" the photographic film and thus enhances its sensitivity. The flood gun circuit of Fig. 8 generates a 14-volt negative pulse that is superposed on the + 19 V dc potential of the flood gun cathode. The flood gun grid is at + 18.4 V in its quiescent state. The pulse applied to the (heated) cathode releases the electrons required for illumination of the screen. The intensity of the illumination can be controlled by changing the duration of the flood gun signal over a range of 5 μs to 50 μs.

Power supplies and interlocks. Numerous separate power supplies were required for the superscope. For personnel and equipment protection, an interlock was built which controls the order of turn-on/turn-off of the various voltages, and which shuts the system down if a critical supply fails. To ensure proper intensity control of the tubes, the first supply energized is the 120 volt bias supply which derives the 3.12 kV control grid voltage from the main 3 kV cathode supply. Without this supply, all tubes would run at full intensity continuously. Therefore, the turn-on sequence does not continue until this supply has reached its set voltage and failure of this supply sutomatically shuts down the system. The other low voltage supplies are turned on at this time. Next, the 17 kV post-acceleration supply is energized. If the tube is operated with the 3 kV initial acceleration voltage only, much of the focused electron beam may be stopped by the fine "pattern" mesh just after the horizontal deflection plates, melting a hole in it and ruining the tube. Therefore failure of the 17 kV supply also shuts down the system. At this point we also require that the +100 and +47 volt supplies be up to voltage. Finally the 3 kV supply is energized, and once it reaches set voltage, the system latches on and the on-pushbutton may be released. Pushing the green OFF button shuts down the supplies in the inverse order. The emergency-off button immediately de-energizes all supplies.

Controls. The superscope controls are located on two panels, each of which is organized in a 5$\times$5 array corresponding to the module positions in the superscope, with one complete set of controls as a spare. One panel contains the Intensity, Focus, Astigmatism and Flood Duration 10-turn controls with dials. The other panel contains the following one-turn controls: Left Horizontal and

Right Horizontal (time base), Horizontal Positioning, Pattern, Trace Rotate and Vertical Deflection Rotate. The latter two controls set the current in two axial coils inside the tube's magnetic shield. One, placed between the vertical and horizontal plates, rotates vertical deflections only. The other, placed forward of the horizontal plates, rotates the entire display. These were intended to compensate for misalignment of the gun assemblies relative to the graticule. Since the graticule was not visible in the photos these adjustments proved unnecessary.

6. Performance

The superscope was used for the first time in a two week data run. During this period there were only six breakdowns all of which could be easily repaired and none interrupted data taking for a significant period. Performance was monitored after each roll of film by taking Polaroid pictures of the calibration signals and the signals from LED's that were imbedded in each of the counters.

A total of 10,000 feet of film, 50,000 pictures, were taken. The exposure of the film was such that all but the three CRT's in the corners of the 5×5 array were easily readable. Film was analyzed on a scanning table with a film to table magnification of ≈ 10. The image on the scanning table was approximately 0.7 times real size and each oscilloscope tube face covered an area 68×41 mm. The horizontal scale was 1.4 ns/mm. The trace width was 1 - 2 mm. and measurements of the signal's leading edge were done to this precision. At the beginning of each roll there were frames generated with the calibration signals on each of the scope inputs. The leading edge of these pulses was used as the time zero for each of the channels. The location of this point relative to the edge of the scope face was stable within our measuring ability for the life of the tube and its circuits.

The time information in the two tubes associated with a single counter was sufficient to determine the position of the particle in the counter to 1 foot. After calibration we were able to discriminate between forward and backward tracks in 90% of a cosmic ray sample. The remaining 10% could be mostly attributed to lower pulse amplitudes in some phototubes. No loss in forward/backward discrimination could be attributed to the performance of the superscope.

7. Acknowledgements

The authors wish to acknowledge the invaluable assistance received from the following laboratory members: Bryan Brauer, Bud Burns, Don Clark, Karl Hense, Dale Ouimette, and members of the Electronics Fabrication Shop. We are thankful to Mel Schwartz for suggesting the system and for his advice and support during the development stage. Thanks are due to the Hewlett-Packard Corporation for making available the CRT's and for supplying us with their performance characteristics.

8. References

Hewlett-Packard Journal, Vol. 21, No. 5, January 1970 (This issue is entirely devoted to the design consideration of the HP 183A oscilloscope which utilizes the fast CRT that was incorporated in our system).

TABLE 1

Characteristics of System

Number of Channels	48, on 24 oscilloscopes (removable modules)
Vertical Sensitivity	1V/cm (1.5 V max) as measured at input of resistive divider box
Horizontal Sweep	10 ns/cm
Repetition Rate	100 Hz (normally limited by film advance)
Lens	f/2.0 100 mm Angenieux Anastigmat 53
Film	70 mm Kodak 2485 High Speed Recording Film
Effective Resolution	1-2 ns (as measured on scanning table)
Frame Identification	6 Nixie tubes mounted in one module
Space Requirements	Front panel space: 12' in 19" rack. Main Frame of superscope: 7' long × 3' wide × $5\frac{1}{2}$' high. Additional space for $\approx$1 mile of RG 213/U 50 Ω delay cable (total for 42 channels).

TABLE 2

Characteristics of the Cathode Ray Tube

Cathode Ray Tube	HP 5083-2042
Vertical Sensitivity	3.1 V/cm, average
Horizontal Sensitivity	6.1 V/cm, average
Focus Voltage	-1940 V
Cathode Potential	-3 kV
Flood Gun Grid	≈ +20 V dc
Flood Gun Cathode	+5 V to +20 V, dc or pulsed
Post Acceleration Potential	+17 kV
Phosphor	P11
Graticule Dimensions	6 cm (vertical) × 10 cm (horizontal)
Writing Speed*	4 cm/ns
Bandwidth (at vertical deflection plates)	>250 MHz

*Conditions of measurement: HP camera model 195A, with fast f/1.3 lens, 10,000 ASA film and P31 phosphor.

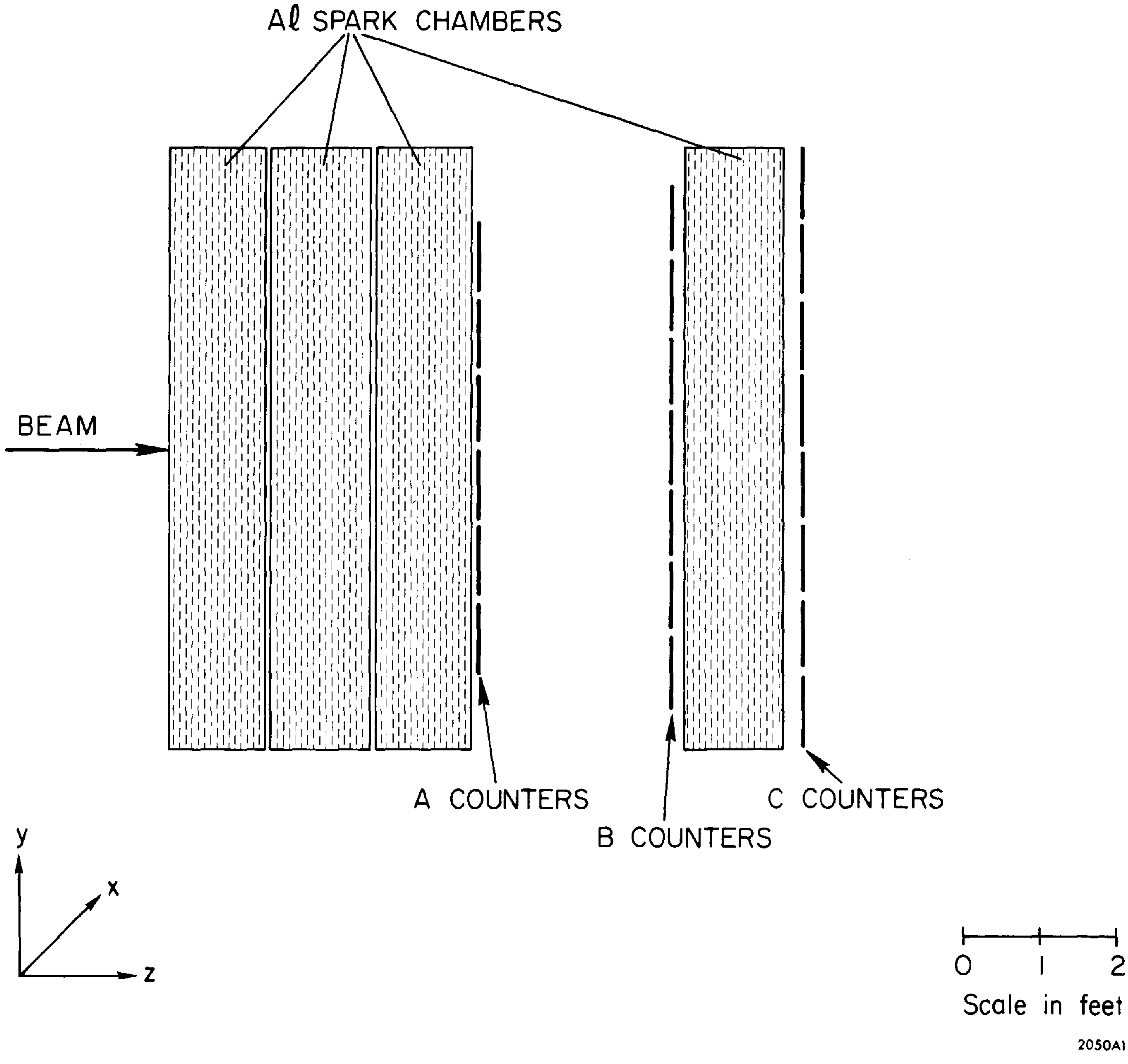


FIG. 1--Detection apparatus.

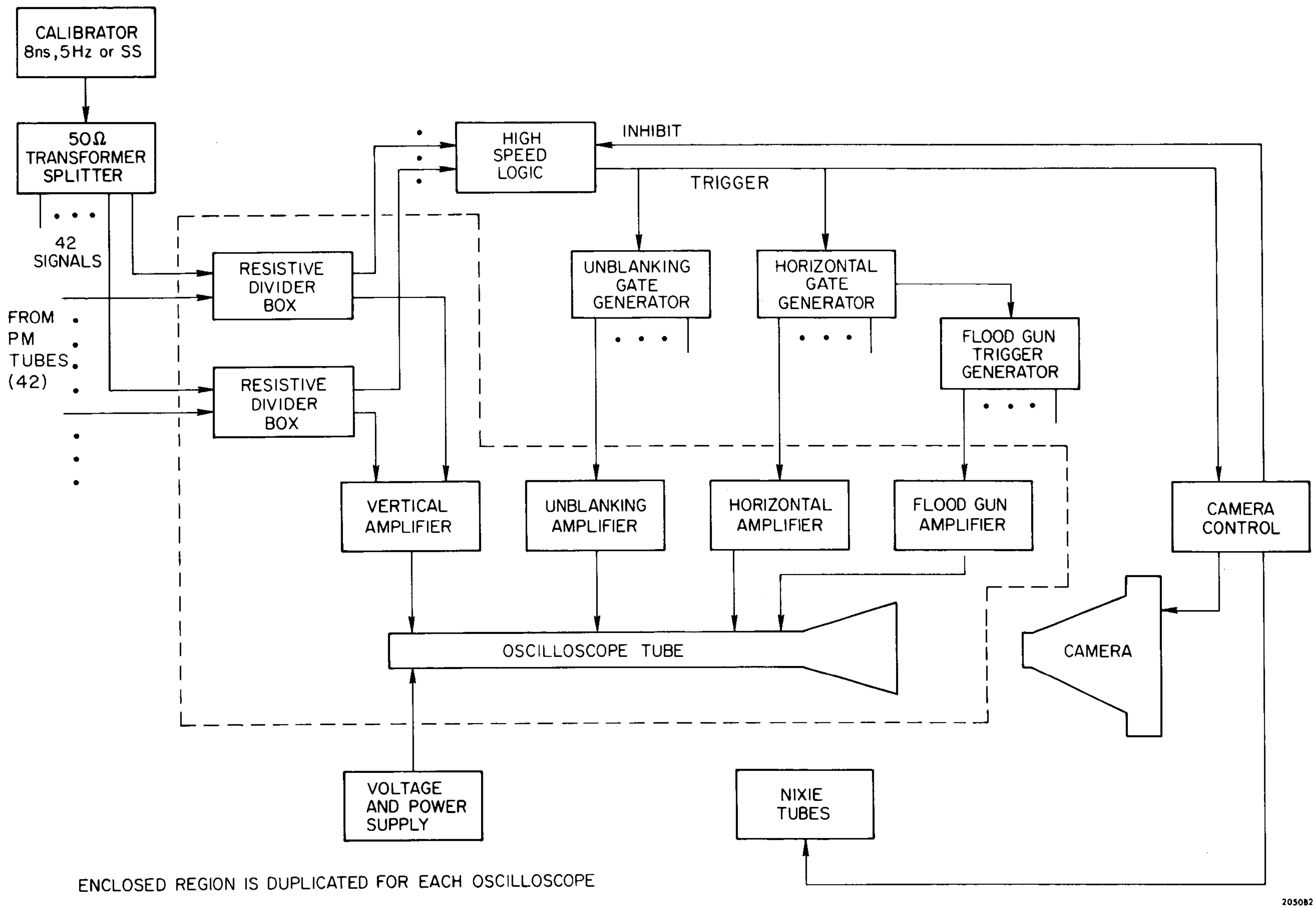
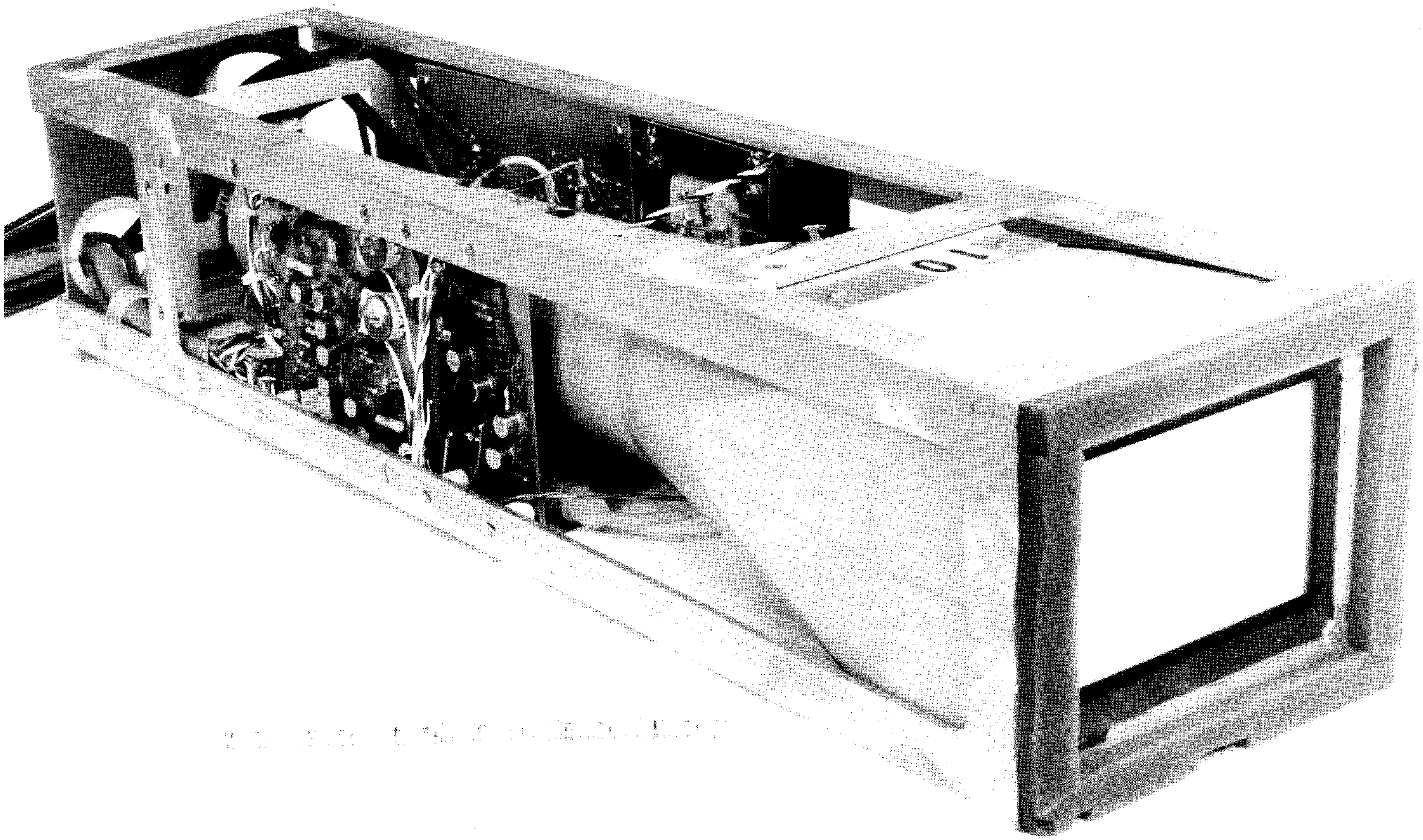
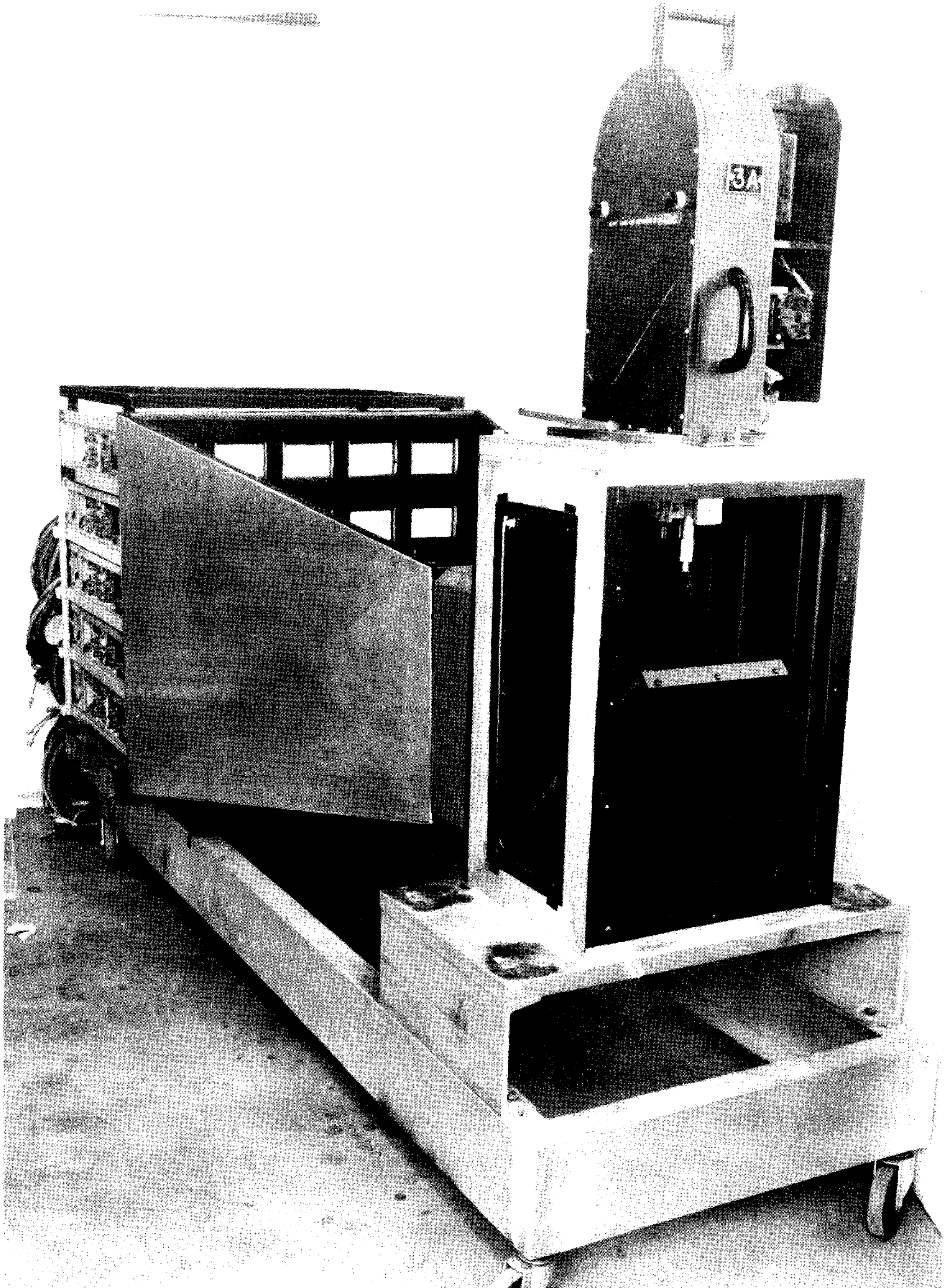


FIG. 2--System block diagram.



2050A7

FIG. 3--Superscope, single oscilloscope module.



2050A8

FIG. 4--Superscope.

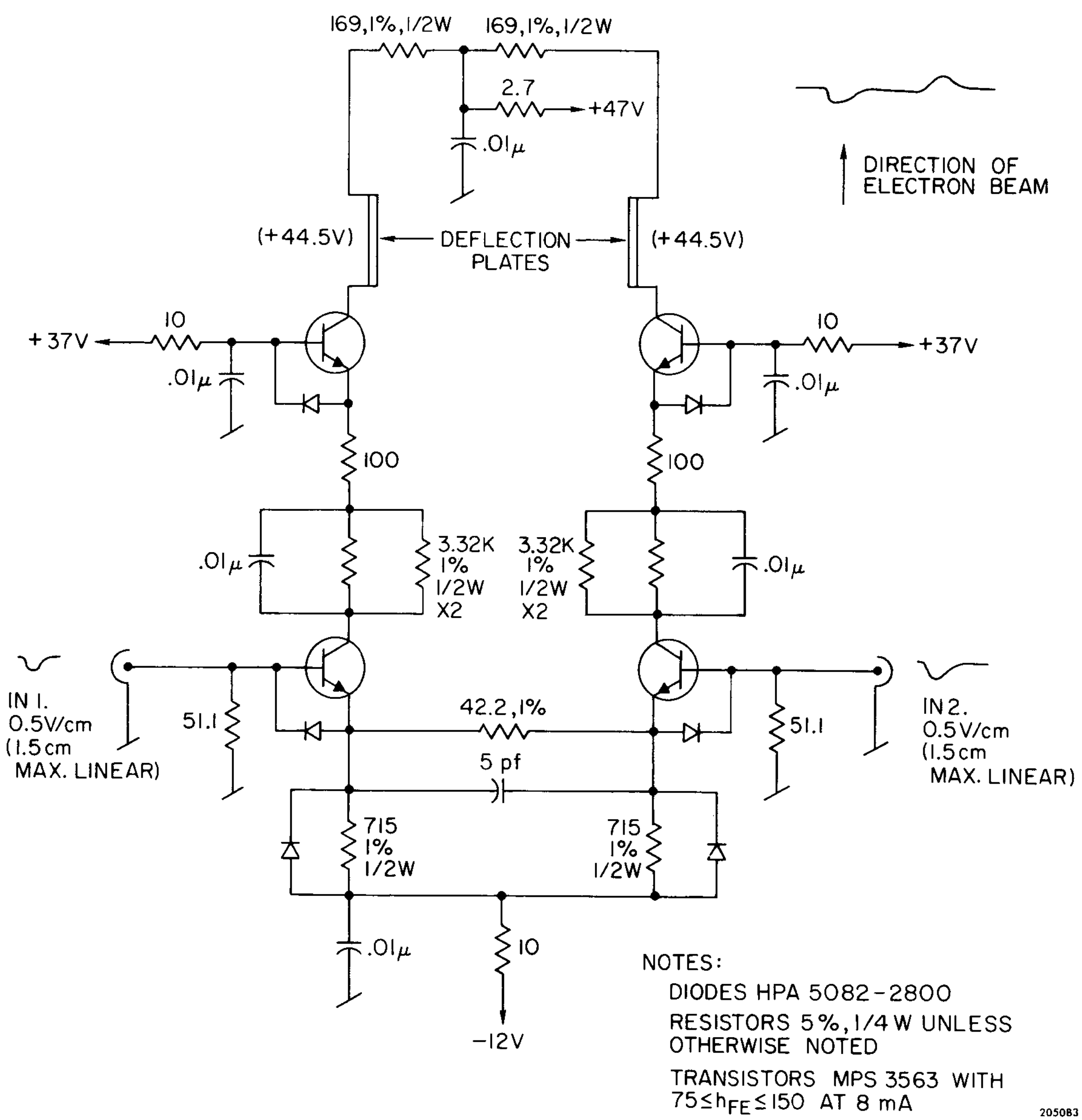


FIG. 5--Vertical amplifier.

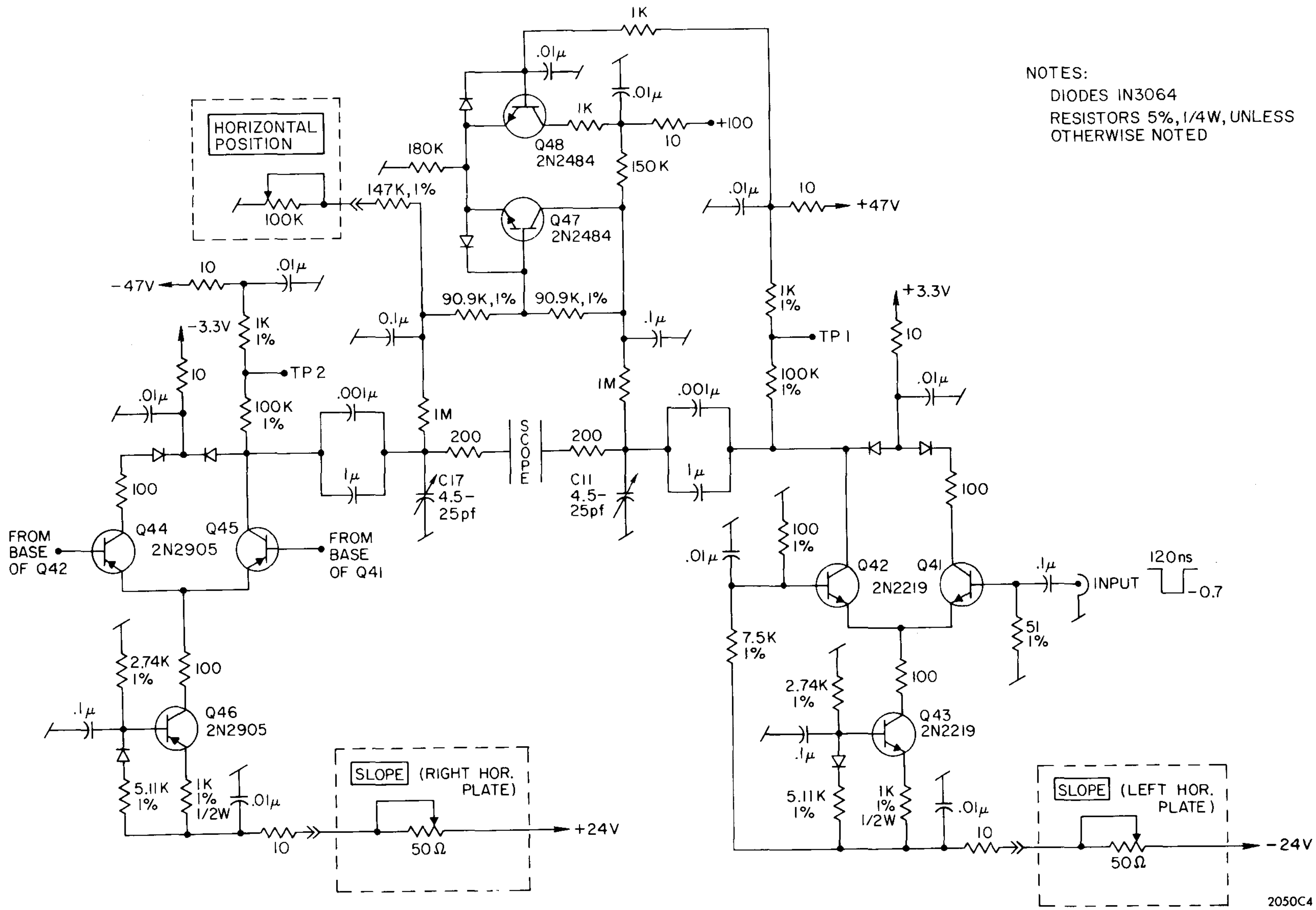


FIG. 6--Horizontal amplifier.

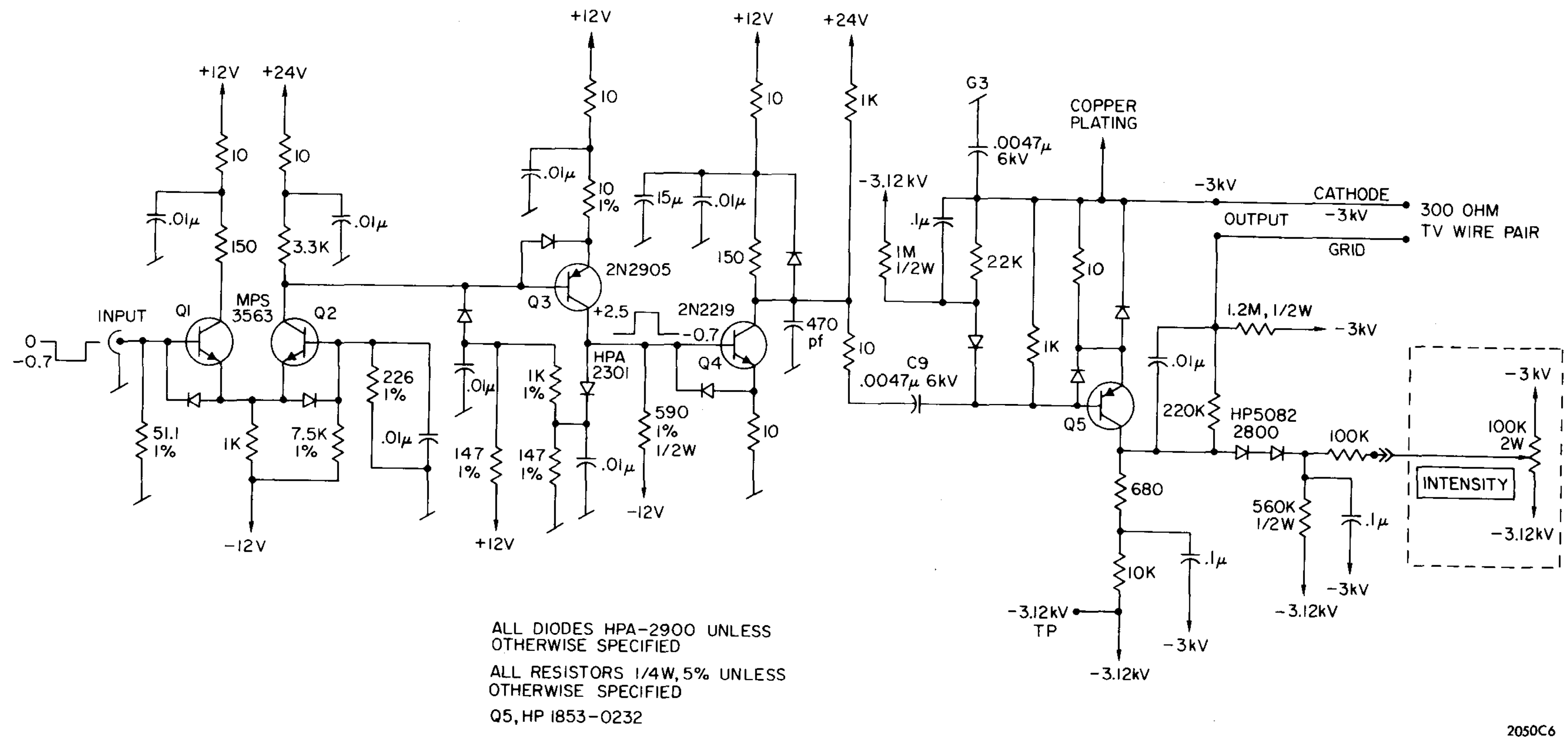


FIG. 7--Unblanking amplifier.

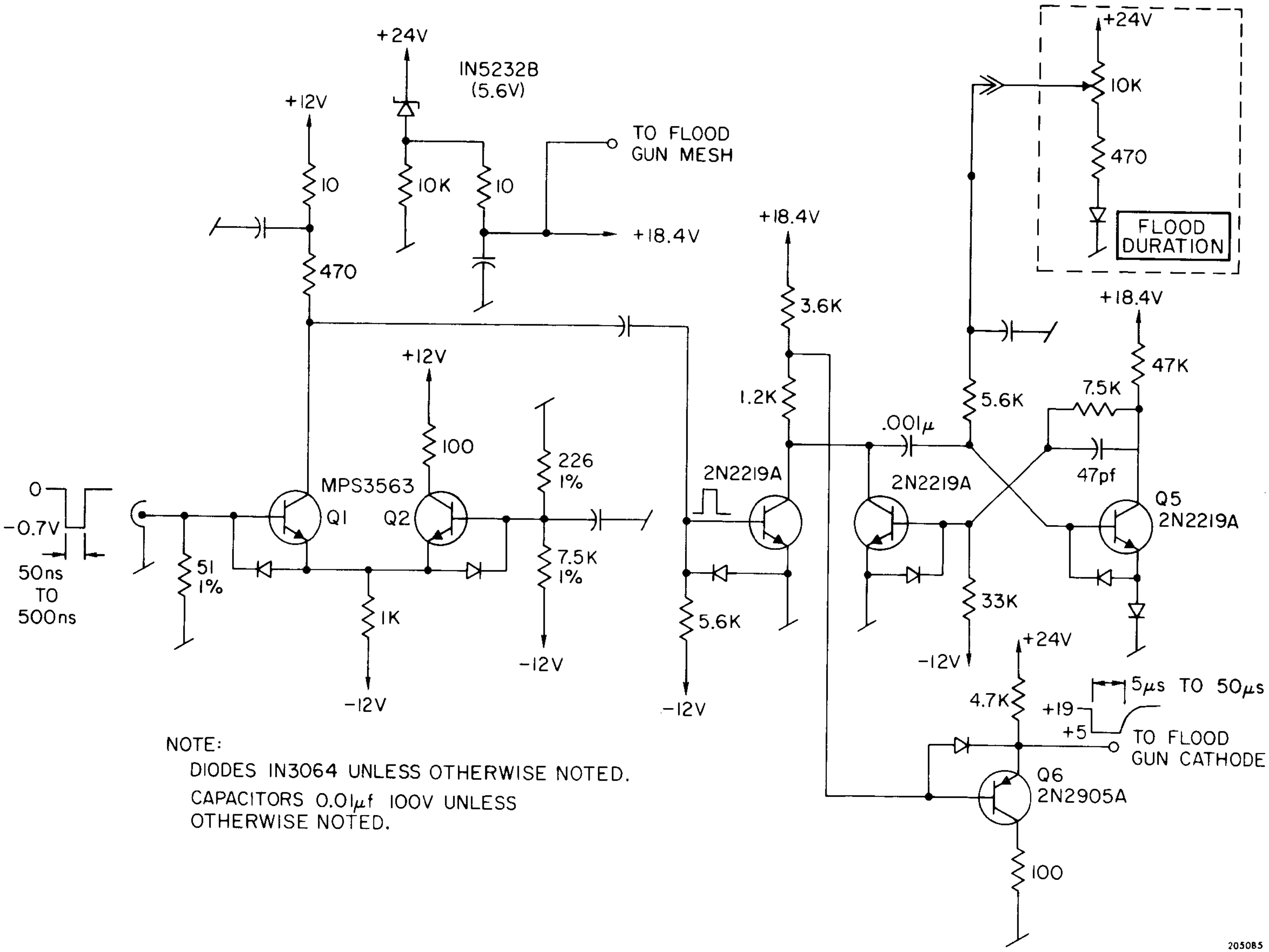


FIG. 8--Flood gun amplifier.