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LAMS - 573 C.3

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A TEN CHANNEL PULSE-HEIGHT ANALYZER

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[redacted]

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ADDENDA TO LAMS-573

6 January 1949

Figures 4 and 9, not included previously in this report but referred to on page 19 herein as being a future LAMS-573A, have been put in their proper place at the end of this report.

[redacted]

A TEN CHANNEL PULSE-HEIGHT ANALYZER

Abstract

This report describes an electronic device for recording voltage pulses according to their various amplitudes. The pulses are sorted into ten amplitude intervals so that ten points of a differential bias curve are obtained simultaneously. Pulses can be handled at rates up to 12,000 per minute. Provision is made for examining a complete distribution curve in large intervals or for examining the fine structure of a distribution.

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A TEN CHANNEL PULSE-HEIGHT ANALYZER

Advancements in the technique of nuclear research have made it possible to obtain much significant data from the shape, size, and distribution of voltage pulses. The apparatus described here was designed to increase the speed and reliability with which information concerning the distribution in height of voltage pulses may be obtained.

The ten channel pulse-height analyzer separates pulses according to their voltage amplitudes into 9 channels of definite voltage width, the tenth channel giving an indication of the number of pulses with amplitudes too great to fall within the first 9 channels. In addition, it provides an independent count of the total number of pulses received, to enable a check of the operation of the analyzer to be made.

Previous methods of pulse-height discrimination have required weeks to obtain an amount of data sufficiently large to be statistically significant. This long period of time enabled factors influencing the results to vary appreciably. One of the procedures employed a simple voltage discriminator[1] whereby all pulses over a certain voltage were recorded. The triggering voltage could be shifted over a predetermined range. If consecutive sets of data are

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1 See LAMS 410

[redacted]

taken over equal time intervals and with equal increments of voltage, a curve of the amplitude distribution of the pulses is obtained. Such a method assumes that the average counting rate is uniform and that any amplifier employed retains a constant gain over a long period of time.

Another method makes use of the single channel pulse-height analyzer[2]. This device recorded all pulses between narrow voltage limits, rejecting pulses above and below this channel. By taking consecutive readings with the maximum limit of one reading replaced by the minimum limit of the following reading, an amplitude distribution curve was obtained.

An extension of this method produced a <u>ten channel pulse-height analyzer</u>, which was composed of 10 simple discriminators connected by circuits which permitted only the channel containing the peak of the pulse to count. The pulses coming from an electrical detector through a pulse amplifier, however, remain at their maximum amplitude for only a short time, perhaps a few microseconds. This device was so designed that the discrimination and counting all took place in this relatively short time, which was not sufficiently long to allow the various components to reach a stable condition. The result was greater speed in taking data but less reliable operation.

The ten channel pulse-height analyzer to be described makes use of "lock-in" discriminators and additional delayed pulses

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2 See Los Alamos Technical Series, Vol. I, Sec. 4.5-1.

which allow the separating and counting of pulses to be done with the circuit in a stable state. This modification produces more reliable operation with no loss in speed of taking data. The counting rate, amplifier gain and other possible variables must still remain practically constant during a given run, but the time involved is so much shorter than before that this condition is not so difficult to fulfill.

In Figure 1 is shown a block diagram of the complete analyzer. The analyzer is designed to operate in conjunction with a Model 100 amplifier[3]. The 6AC7 cathode follower output of the regular Model 100 amplifier has been replaced by a 6AG7, with the cathode resistor reduced from 10k to 5k. The additional driving power is necessitated by the large input capacitance of the analyzer.

The input signal of the analyzer connects directly to ten "lock-in" discriminators whose bias settings increase progressively from discriminator #1 to #10. A large variety of biases is available to provide a means for shifting the position of the voltage-spread covered by the complete set of channels over its range of 150 volts. The biases are taken from a series of resistors tapped at equal intervals. The voltage increment between consecutive taps determines the voltage width of the separate channels. The individual channel-width is selected from the three possible values of 2 volts, 5 volts, and 10 volts. Each of the channels from #1 through #9 is approximately the same number of volts wide, the <u>surplus channel</u> counting all pulses too large to fall in the other channels.

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3 See Los Alamos Technical Series, Vol. I, Sec. [redacted]

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All the discriminators that experience a voltage pulse sufficiently large to trigger them, flip to a quasi-stable state in which position they lock. The anti-coincidence circuits, Figure 1, receive signals from the channels they connect in such a way that a condition of unbalance is set up in each channel except the one that contained the peak of the input pulse. After a fixed delay, during which time the circuit reaches a stable state, the pulse-forming channel supplies to each of the anti-coincidence circuits a "registering pulse" which allows the channel with the balanced condition to register a count. One-half microsecond later the pulse-forming channel supplies a second pulse, called the "reset pulse", which releases the lock on the discriminators, returning them to the stable position. The principle advantages of having the discriminator lock after each pulse are that a definite dead time for the machine is defined, and that the circuit is in a stable state when the actual registering is accomplished.

Channels #1 through #9 have a scale of 8 preceding the register driver stage to reduce the counting rate imposed upon the mechanical register. The <u>total</u> channel uses a scale of 32, and the surplus, or #10 channel, a scale of 16. The "RESET" button is provided to return all the scalers to their original positions, extinguishing all interpolator lights. The "COUNT-STOP" switch enables one to start and stop the counting simultaneously in all channels without removing the source of pulses. In the "COUNT" position the registering pulse is applied to the regular circuit. In the "STOP" position the registering pulse is not applied to the

[redacted]

circuit, but is fed into a dummy load which permits the formation and use of the reset pulse only. Discriminators continue to be triggered and reset, but no counts are recorded.

The principle of operation of the anticoincidence device consists in having a plate load resistor of a tube shunted by two triodes (tube T-12, Figure 3). If these triodes are conducting they effectively short circuit the plate load resistor of the 6SH7 tube. A pulse impressed upon the grid of the 6SH7 tube will then not result in a very large output pulse. If the triodes are cut off, a high plate load impedance is presented and a large output pulse occurs for an input pulse impressed upon the grid.

The anticoincidence is obtained by connecting the grids of the triodes to two separate channels such that if one channel is operated by the incoming pulses but the other is not, both triodes are cut off. This gives a high plate impedance and results in an output pulse. If both channels are actuated then one triode becomes conducting and no output pulse is obtained.

The pulses to the grids of these triodes are obtained from the output of the discriminators described.

We may consider that two adjacent channels may have three possible states: a. that neither channel was operated by a pulse, b. that only one channel was operated by a pulse, and c. that both channels may have been operated by a pulse.

On this basis let us consider the operation of the circuit. This can best be done by reference to Figure 3. Let us consider the operation of the analyzer for an amplified pulse, the

[redacted]

peak of which falls into channel #2. As soon as the pulse triggers the discriminator (T-8 and T-9) of channel #2, the plate of T-8 rises in potential, raising the grid potential of the left half of T-11. This half of T-11 then begins to conduct, and draws a sufficiently large amount of current in the common cathode resistor to raise the cathode potential of T-8 and T-9 to cutoff. The left half of T-11 continues to conduct, locking T-8 and T-9 in the cutoff state. If the lock were not released by an external pulse, it would remain in this state for approximately 60 microseconds.

A positive step wave is thus produced on the plate of T-9. Inasmuch as channel #1 is operated by all the pulses, a positive step wave is produced in a like manner on the plate of T-9 of this channel. The pulse from this channel is differentiated and applied to the grid of a cathode follower T-5 in the total channel. The right half of T-5 is the cathode follower. The left half is used as a diode restorer to remove the negative pulse produced when T-9 in channel #1 returns to the conducting position. The positive pulse from the cathode of T-5 in the total channel is impressed on the grid of T-1 in the pulse-forming channel. This triggers the first blocking oscillator, T-2, in the pulse-forming channel, whose cathode impedance is a 10 microsecond delay line tapped at 2.5, 5, and 10 microseconds. The positive pulse from the tap on the delay line triggers a second blocking oscillator, the left half of T-4 in the pulse-forming channel, which has a 0.5 microsecond delay line in its cathode. The registering pulse is obtained from the cathode of this

[redacted]

second blocking oscillator; that is, before the pulse enters the 0.5 microsecond delay line. Since a registering pulse is obtained for each pulse triggering channel #1, this pulse is applied to the grid of T-6 in the total channel where it is amplified and used to drive the scalers[4] of the total channel. The registering pulse proceeds along the 0.5 microsecond delay line in the pulse forming channel to the grid of the right half of T-4. From the cathode it emerges as the reset pulse. The bias for the two blocking oscillators is taken from a cathode follower, the left half of T-3, which provides a constant bias from a low impedance source, allowing the blocking oscillators to recover quickly.

We have assumed that none of the discriminators above channel #2 have triggered because of the biases, so only the anti-coincidence circuit connecting channels #2 and #3 is in the second possible state. The left grid of T-12 in channel #2 is at a large negative potential with respect to its cathode potential of about +300 volts, since the left plate of T-11 decreased in potential when the left half of T-11 began to conduct. In channel #3, which has not been triggered, the plate of T-9 is in its stable (least positive) state. The right grid of T-12 in channel #2 is directly coupled to the plate of T-9, and this grid is at a large negative potential with respect to its cathode.

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4 See Los Alamos Technical Series, Vol. I, Sec. 4[redacted]

Since both grids of T-12 of channel #2 are now biased to cutoff, this tube is a high impedance and any current drawn by T-13 will flow through the resistor from +300 V to the cathode of T-12. While the circuit is in this state the positive registering pulse is formed and applied to the grid of T-13 of all channels. This produces a negative pulse on the cathode of T-12 which serves to trigger the first scaler stage (SL_1) of channel #2 (see Figure 5a, 5b for circuit diagrams of scalers). The reset pulse is applied to the right grid of T-11 in each channel one-half microsecond later. This positive pulse causes the potentials of the right plates of T-11, and also the plates of T-9 of the channels that are conducting, to decrease. The left grids of T-11 are driven beyond cutoff, releasing the locks and resetting the discriminators.

After eight pulses have entered the scaler stages, a negative pulse is impressed on the left grid of T-14 of channel #2. The left plate then rises to +200 volts, producing a positive pulse on the right grid of T-14 which actuates the register.

Let us consider next what would have happened if channel #3 had triggered. The plate voltage of T-9 in channel #2 would have risen as we have seen and, therefore, the potential of the right grid of T-12 of channel #2 would be very nearly equal to its cathode potential since it is coupled directly to T-9 of channel #3. The left grid of T-12 in channel #2 would be at a large negative potential with respect to its cathode as described previously. Since the right grid of T-12 in channel #2 would not be biased beyond cutoff when the registering

[redacted]

pulse is applied to the grid of T-13 in channel #2, as well as all the other channels, T-12 offers a very low impedance to the current drawn by T-13, so very little current would flow through the resistor from +300 to the cathode of T-12. The pulse thus formed has about one-tenth the amplitude of the pulse produced when T-12 offers a high impedance, and the first scaler would not be triggered. Channels #1 through #3 would then be reset as before and the analyzer is ready for another pulse.

The operation of each channel from #2 through #9 is the same. Since the operation of any one channel, however, is made possible by a signal from the channel with the next largest bias, channel #10 is modified to terminate the anti-coincidence circuits. Both grids of T-12 in channel #10 are tied together as shown in Figure 3. If discriminator #10 is not triggered, the potential of both grids of T-12 is very close to the cathode potential and a very small pulse is impressed on the scaler. If discriminator #10 is triggered, both grids of T-12 are at a large negative potential with respect to the cathode and a pulse sufficiently large to trigger the scaler (SN_1) is produced. The channel is reset in the same manner as the others.

The need for the time delay between the input pulse and the registering pulse is now evident. The input pulse must have time to reach its maximum value and return to a value less than that required to trigger the first discriminator before the reset pulse occurs. If any discriminator still experiences a signal large enough to trigger it when the reset pulse occurs, this channel will be reset only momentarily, returning to the triggered position as soon as the reset pulse passes. This will produce another registering pulse and another reset pulse, causing some pulses to be recorded at least twice.

The ideal pulse would be one which rose to its maximum value and then dropped suddenly to zero. The delay line pulse shaper[5] most nearly provides this shape. The amplifier, therefore, includes such a device.

The length of the pulse produced by the delay-line pulse shaper will determine the necessary delay between the beginning of the pulse and the application of the registering pulse. Delays of 2.5, 5, and 10 microseconds are available in positions 1, 2, and 3, respectively, of S-3, Figure 3. The shortest time that will allow the pulse to return to a value less than that required to trigger discriminator #1 is the proper delay, for then the overall resolving time is a minimum. If the counting rate is kept below 200 counts per second, with no more than 100 counts falling in any one channel, the error due to counting losses is less than 0.1%. Counts will be lost only when two pulses falling into different channels are less than 6 microseconds apart, or when two pulses in the same channel are separated by less than 30 microseconds. The first limitation is imposed by the first 6SN7 scaler unit in the total channel, and the second limitation by the first 6SL7 scaler unit in each of the regular channels.

The number of scaling units required depends upon the maximum permissible counting rate and the type of register selected. The Model 300 analyzer employs the "Mercury Register" manufactured by the Production Instrument Company. A reliable counting rate for this

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5 See Los Alamos Technical Series, Vol. I, Sec. 3.2-2

[redacted]

register is 15 counts per second. The scaling factors of 32, 16, and 8 for the total, surplus, and regular channels respectively, reduce the maximum permissible counting rate to values below 15 counts per second.

When some previously unexamined group of pulses is under consideration, it is necessary to determine the approximate amplitudes and distribution before some particular group can be examined. This cursory examination is made with the 10 volt channel-width. Closer examination may then be made with the 5 or 2 volt channel-widths. Referring to Figure 6, with S-1 in position 1, S-4 in open position and S-5 in position "ON", a current of 10 milliamperes flows through the resistor network. Hence, with S-2 in position 1, the values of the bias voltages relative to ground are -10, -20, ..., -100 volts. The entire sequence is made more negative in 10 volt steps by advancing the position of S-2. The maximum possible bias available for discriminator #10 is -150 volts. The effect of changing the position of S-2 is that of taking resistance from one side of the bias resistors and adding an equal amount to the other side.

The proper gain setting for the Model 100 amplifier must be determined before more accurate data is attempted. If many pulses with amplified amplitudes greater than +150 volts are permitted, grid current is drawn in the discriminator and the biases will be shifted. To avoid this, the number of pulses with an amplified height of 150 volts or more must be kept below 1%. Set S-1 and S-2 of Figure 8 to position 5 with S-4 in open position. The bias applied to discriminator #10 is then -150 volts, and the gain of the amplifier is adjusted so that no more than 1% of the pulses

[redacted]

are falling into the surplus, or #10 channel. This gain setting must not be exceeded for analyzing the particular pulses under consideration.

Advancing S-1 to position 2 doubles the resistance of the network and thus halves the current through the resistors. This reduces the difference between the biases of successive discriminators to 5 volts. S-1 and S-2 act together to change the position of the entire sequence. The 2 volt channels are obtained by shunting the bias resistors with the proper resistor to create a 2-volt drop across each one. Closing S-4 connects the shunt, with S-1 and S-2 still serving to shift the potential of the entire set of channels. All possible bias combinations are given in Figure 7a and Figure 7b. With S-4 closed and S-1 in position 1, the channels are approximately 8 volts wide. Since there is little advantage in such a channel width over the 10-volt width, the portion of the charts representing this combination of switch settings is marked, "Do not use in this region".

When S-5 is in position "OFF", the regular bias is removed and all discriminators have the same bias of approximately -10 volts. This condition is used to aid in adjusting the "ZERO SET" control provided with each discriminator, since all or none of the discriminators should trigger when the circuit is supplied with test pulses of adjustable amplitude.

The adjustment and testing of the analyzer is accomplished by the use of the Model 100 sliding pulse generator[6].

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6 See the Los Alamos Technical Series, Vol. I, Sec. 6.2-1

[redacted]

The amplitude of the pulse is set manually so that the proper operation of the individual channels is ascertained. Then the generator is used to produce periodically recurring pulses whose amplitudes slowly increase in a linear fashion with respect to time to some predetermined value, then decrease to zero. This operation repeats itself automatically as many times as desired. With the exception of the surplus channel, each channel should receive the same number of pulses for each excursion of the sliding pulse generator. It is impossible to set the channels exactly the same, so discrepancies must be expected. For most applications, variations of 10% in the channel widths are not excessive. The equality of channel-widths and the overall operation may be checked at the same time, for the number of pulses recorded in the total chassis equals the sum of the counts in all the other channels exactly when all components are functioning properly.

When the analyzer is in constant use, it is advisable to check its operation daily in the manner previously described. If a mal-function occurs, it is usually observed as a difference between the total count and the sum of the parts. Very often the sources of such an error are the scaler units. It is possible for an unbalanced scaler to miss one or more pulses completely. And it is possible for a slightly unbalanced scaler to feed pulses through without scaling, so that one pulse is recorded as two. Since this action may occur in any of the channels including the total channel, it is sometimes difficult to determine where the trouble lies. The probability of occurrence of such improper operation may be reduced considerably by careful construction of

[redacted]

the scaler units, using components with 5% tolerance ranges.

Occasionally, it is evident over a period of several days that the channel-widths of two adjacent channels are drifting in opposite directions. The drift of one channel in any one direction precludes that an adjacent channel must change in the opposite direction, since there can be no overlapping of channel-widths. The cause of the drift in channel width is usually a weak or aging discriminator tube.

Duplication of data may be obtained consistently when the limits of probable error are recognized. It has been determined experimentally that a discriminator of the type used here does not always trigger on exactly the same size pulse, the necessary height varying about 0.2 volts. When using 10-volt channel widths, this introduces an uncertainty of 2%, for 2-volt channel widths an uncertainty of 10%. Greater significance may be attached to any set of data taken with the analyzer if a check on the channel widths is made with the sliding pulse generator, for then the channels may be weighted and the error due to unequal channel widths is reduced. This procedure also enables apparent discrepancies between sets of similar data to be reconciled.

The usefulness of the analyzer has been extended by making it possible to admit for discrimination only those pulses containing certain desirable information or those conforming to certain predetermined standards. A device must first be built which will cause only those pulses with the desirable characteristics

[redacted]

to produce a positive triggering pulse. Then the circuit of Figure 8 is used to gate the registering pulse of the analyzer. The positive triggering pulse is applied to the grid of T-1 in the gating chassis. The univibrator, T-2, is flipped to its quasi-stable state, producing a long negative gate on the left grid of T-3. The left half of T-3, previously conducting is cut off, allowing the plate to rise in potential about 10 volts. When the positive registering pulse is formed, it is inverted, amplified by T-4 and impressed on the right grid of T-3. Both sides of T-3 are cut off for the duration of the original registering pulse and a positive pulse of approximately 40 volts amplitude is produced on the plates of T-3. This gated registering pulse is applied to the circuit from a cathode follower, right half of T-4, in place of the normal registering pulse. The time constant of the univibrator is chosen to allow the resumption of the stable state shortly after the occurrence of the registering pulse. If, however, no triggering pulse is produced by the pulse-selecting apparatus, no negative gate is applied to the left grid of T-3 and the registering pulse produces about a 10-volt "pip". This is much too small to actuate the anticoincidence circuits in the analyzer. Figure 9 shows typical wave shapes for the gating circuit. The original registering pulse has not been altered, so it carries on as usual, producing a reset pulse at the proper time. Although the channels may be triggered and reset many times, only when a particular type of pulse occurs does the analyzer record.

The main power supply is a +300, -150-volt regulated supply, for which the circuit is given in Figure 10. The +300 supply

[redacted]

is designed to deliver +250 milliamperes, the -150 supply, 200 milliamperes. A +250 volt supply is obtained by using T-9 as a cathode follower with its grid potential set by a voltage divider across the +300 volt supply. An added feature is a device for effectively removing the +300 volts in the event that the -150-volt supply should fail. Removal of the bias from the various tubes would allow the passage of currents sufficiently large to damage tubes and other components. The left half of T-6 is cut off during normal operation by a voltage taken from a bleeder between the +300 and -150-volt supplies. A failure in the bias supply will allow the potential of the grid of T-6 to begin to rise towards ground potential. As soon as this half of T-6 begins to conduct, its plate decreases to a very low positive potential, causing the grids of the regulator tubes, T-2 through T-5, to do likewise. The regulator tubes then offer a very high impedance and the +300 volts is reduced very nearly to zero.

The filament power is supplied by seven 6.3-volt, 10-ampere filament transformers, mounted on a separate chassis in such a way as to keep the leads as short as possible. A second advantage of using separate filament transformers is that part of the filaments are operated at +300 volts and part at ground.

Extremely poor regulation of the line voltage at the place of operation necessitated the addition of one more supply. The anticoincidence tubes in each chassis had their plates tied to the +450 volt unregulated side of the +300-volt supply. Large reductions in line voltage, about 20 volts, produced unreliable

[redacted]

operation of the anticoincidence circuits. To prevent this, a +150-volt, moderately well regulated supply was floated above the +300-volt supply. For ordinary operation this supply is unnecessary.

The analyzer is sufficiently complex that it is important to design the physical layout to provide ready access to all points of the various circuits, while the circuit is in operation. Furthermore, the entire circuit dissipates more than one kilowatt of power, so that a construction of an open type is desirable. Both of these requirements are met if closely associated parts of the circuit are built on long, relatively narrow strips of metal, which can be mounted vertically across a wide relay rack. The Model 300 analyzer has all the components mounted in this vertical position. It has been found that the power supplies require practically no servicing at all, so the next model will have the power supplies mounted in the customary horizontal manner.

There is little doubt but that a simpler design could be produced, which would suffice for lower counting rates and straight-forward amplitude discrimination. However, the present model was designed to be as fast, as flexible, and as reliable as possible. The provision for clamping the discriminators makes for greater reliability, and the availability of the registering and reset pulses makes for greater flexibility.

[redacted]

Figures 4 and 9 were not completed at the time this report was issued. These figures are illustrative.

When the figures are completed by the author, they will be issued as LAMS 573A.

Ed.

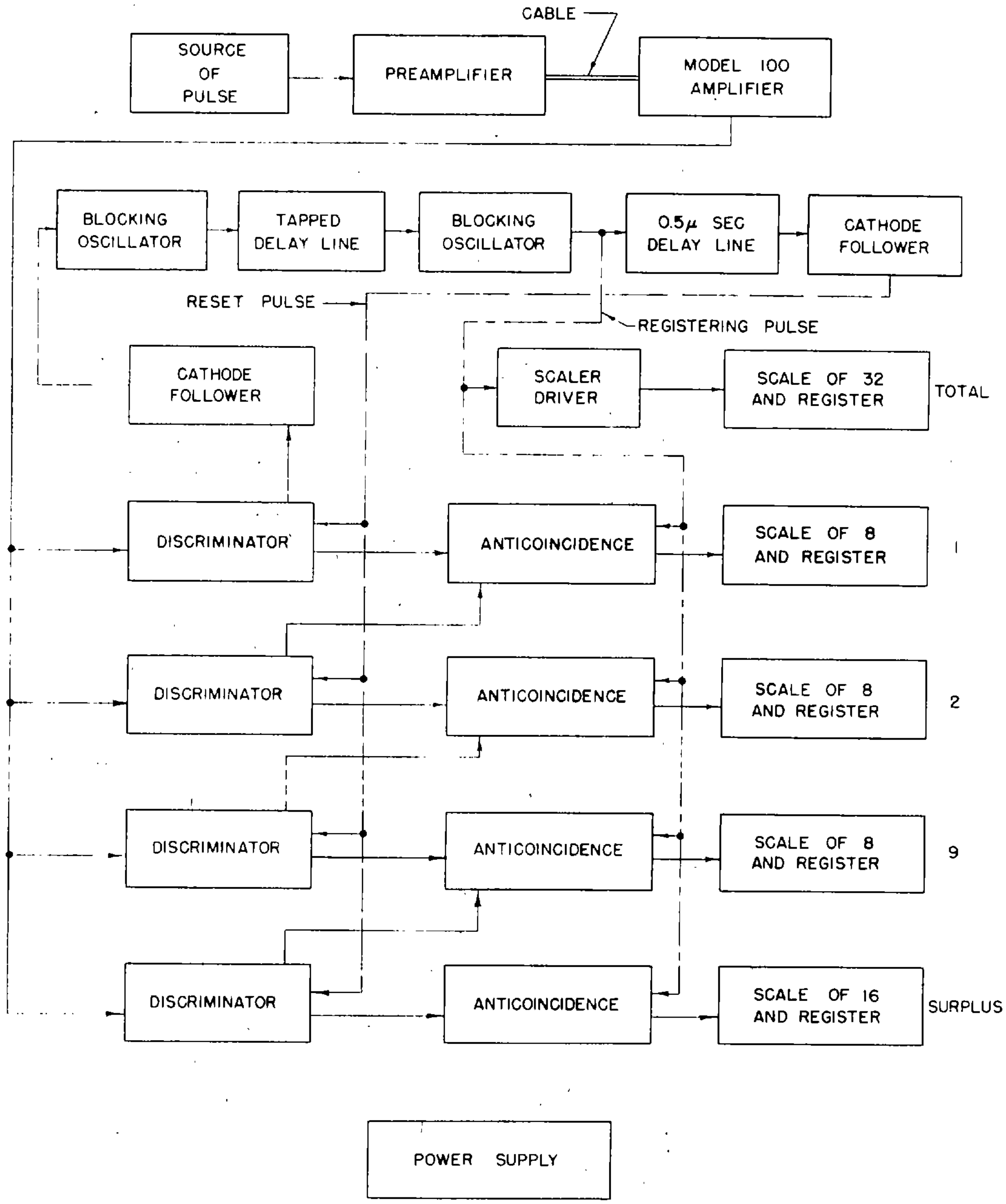
CABLE
SOURCE OF PULSE
PREAMPLIFIER
MODEL 100 AMPLIFIER
BLOCKING OSCILLATOR
TAPPED DELAY LINE
BLOCKING OSCILLATOR
0.5μ SEC DELAY LINE
CATHODE FOLLOWER
RESET PULSE
REGISTERING PULSE
CATHODE FOLLOWER
SCALER DRIVER
SCALE OF 32 AND REGISTER
TOTAL
DISCRIMINATOR
ANTICOINCIDENCE
SCALE OF 8 AND REGISTER
1
DISCRIMINATOR
ANTICOINCIDENCE
SCALE OF 8 AND REGISTER
2
DISCRIMINATOR
ANTICOINCIDENCE
SCALE OF 8 AND REGISTER
9
DISCRIMINATOR
ANTICOINCIDENCE
SCALE OF 16 AND REGISTER
SURPLUS
POWER SUPPLY

FIG. 1

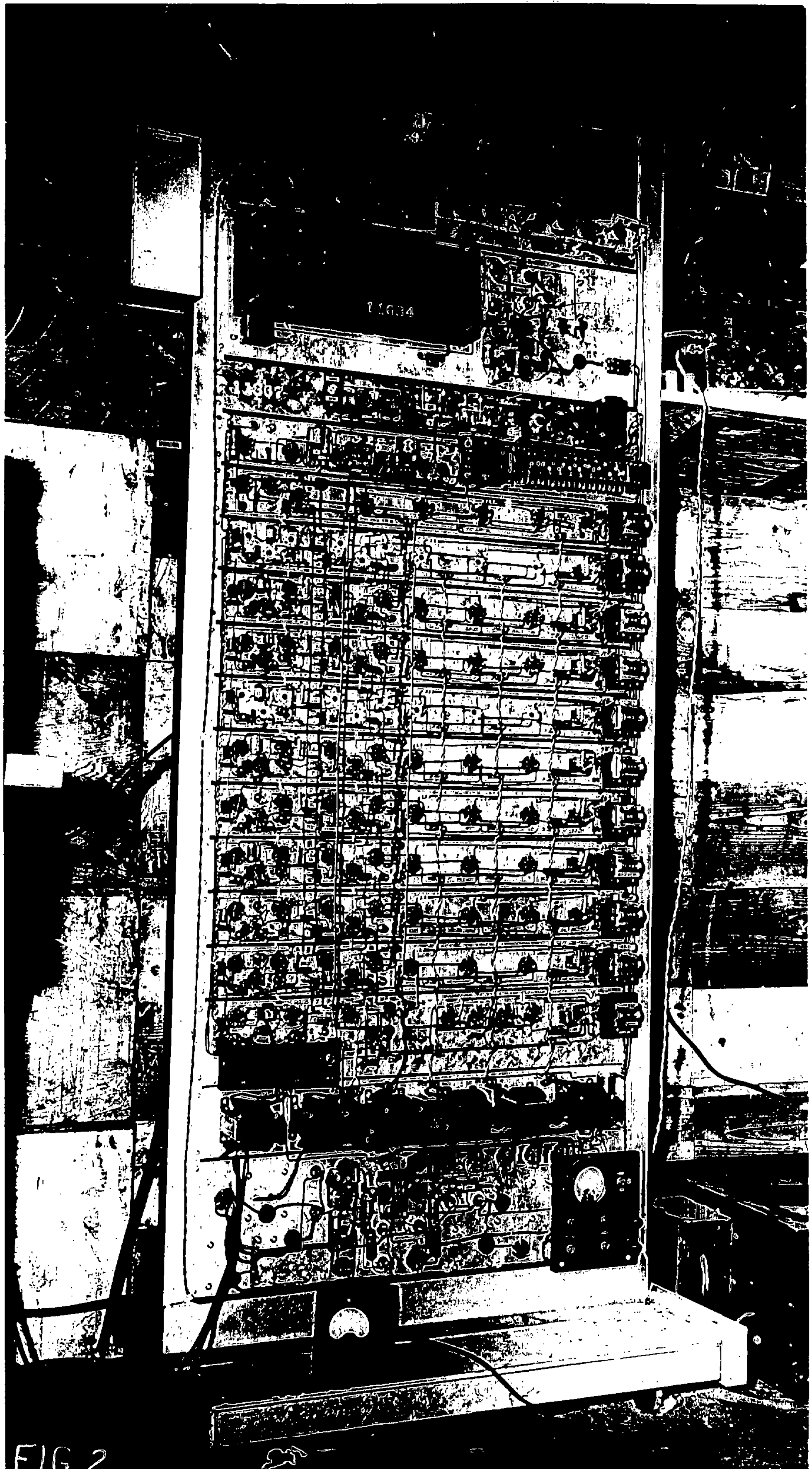

FIG. 2

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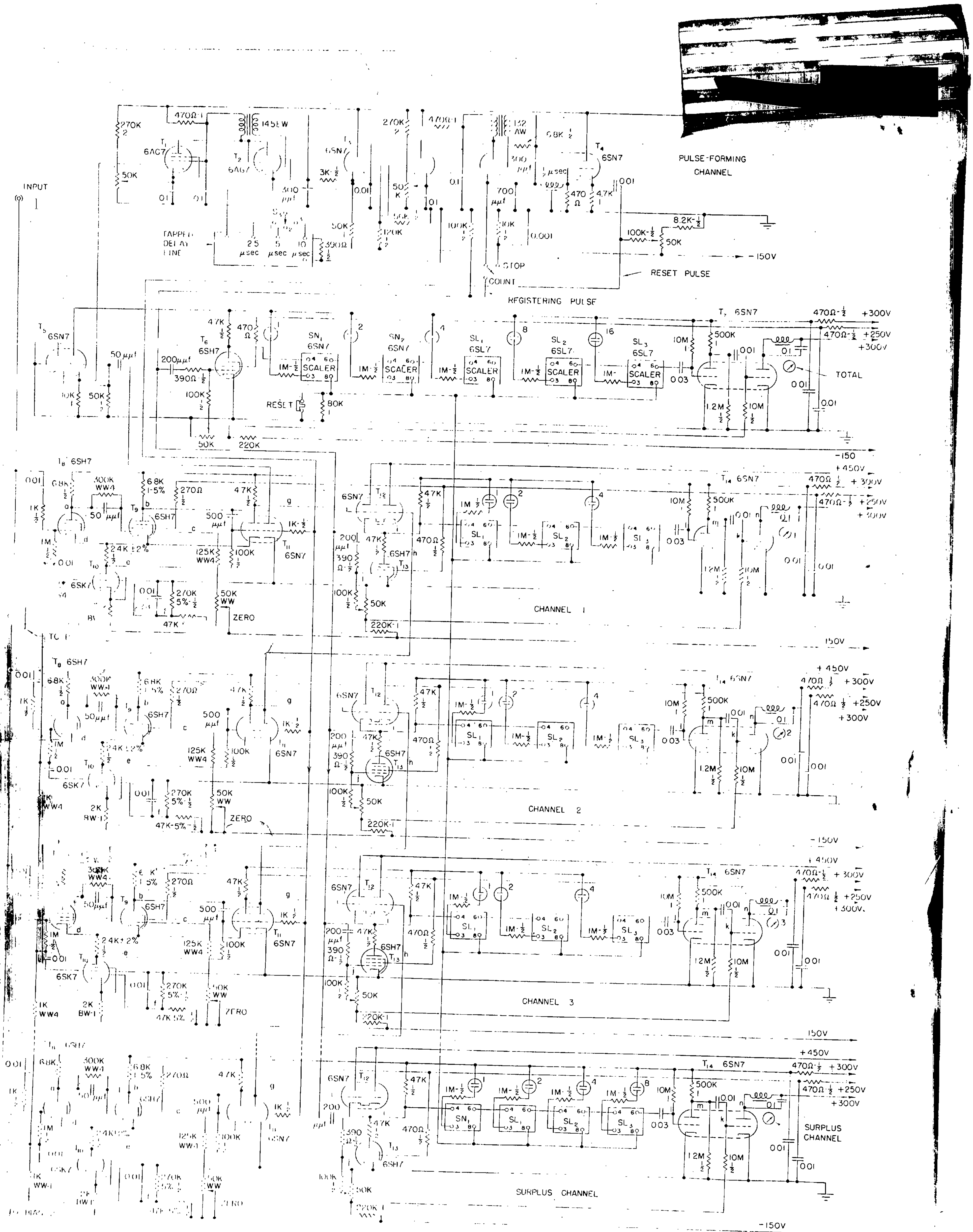
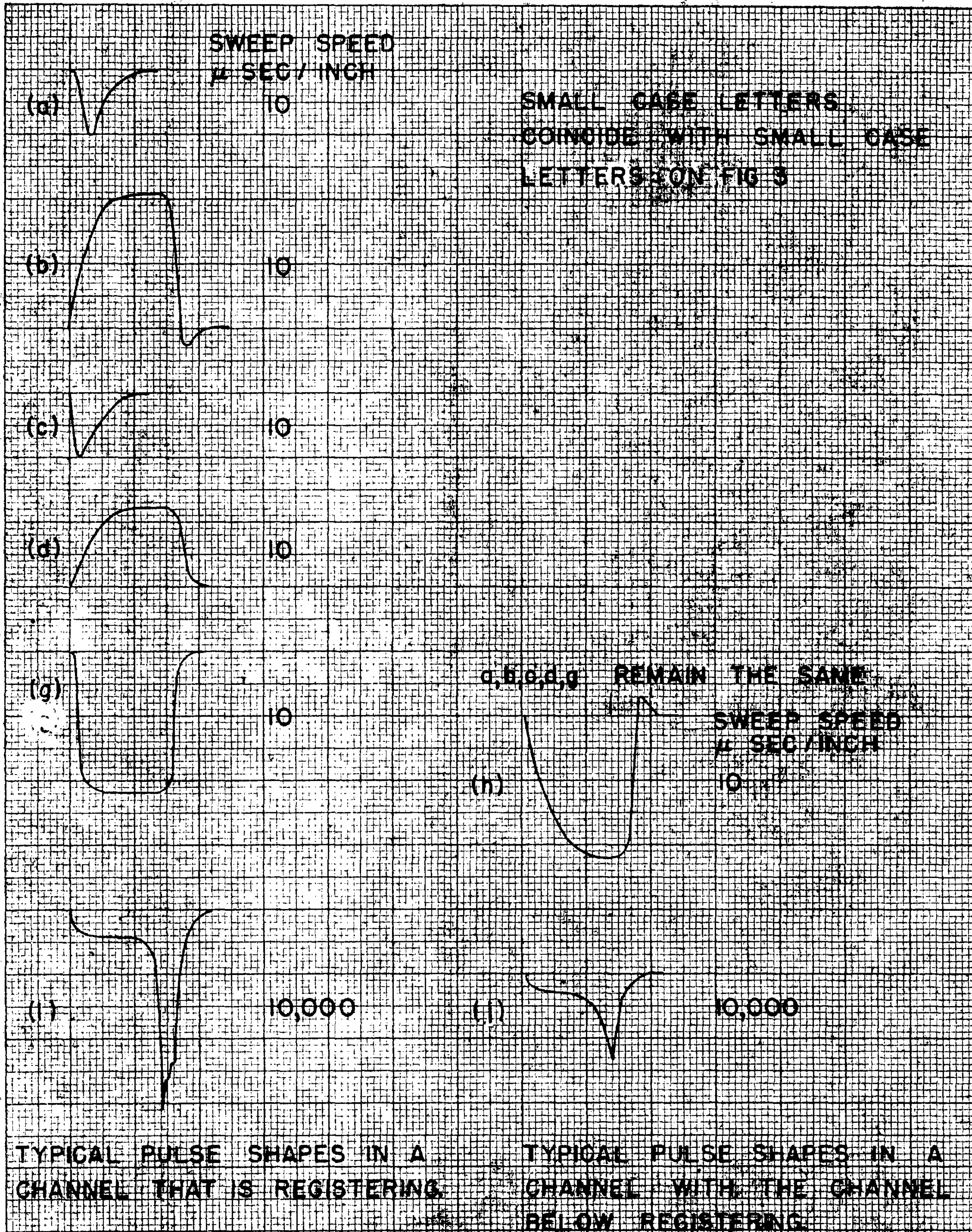

INPUT
TAPPED DELAY LINE
PULSE-FORMING CHANNEL
STOP
COUNT
RESET PULSE
REGISTERING PULSE
TOTAL
CHANNEL 1
CHANNEL 2
CHANNEL 3
SURPLUS CHANNEL
SURPLUS CHANNEL
ZERO
-150V
+300V
+250V
+450V

FIG 3



TYPICAL WAVE SHAPES
FIG 4

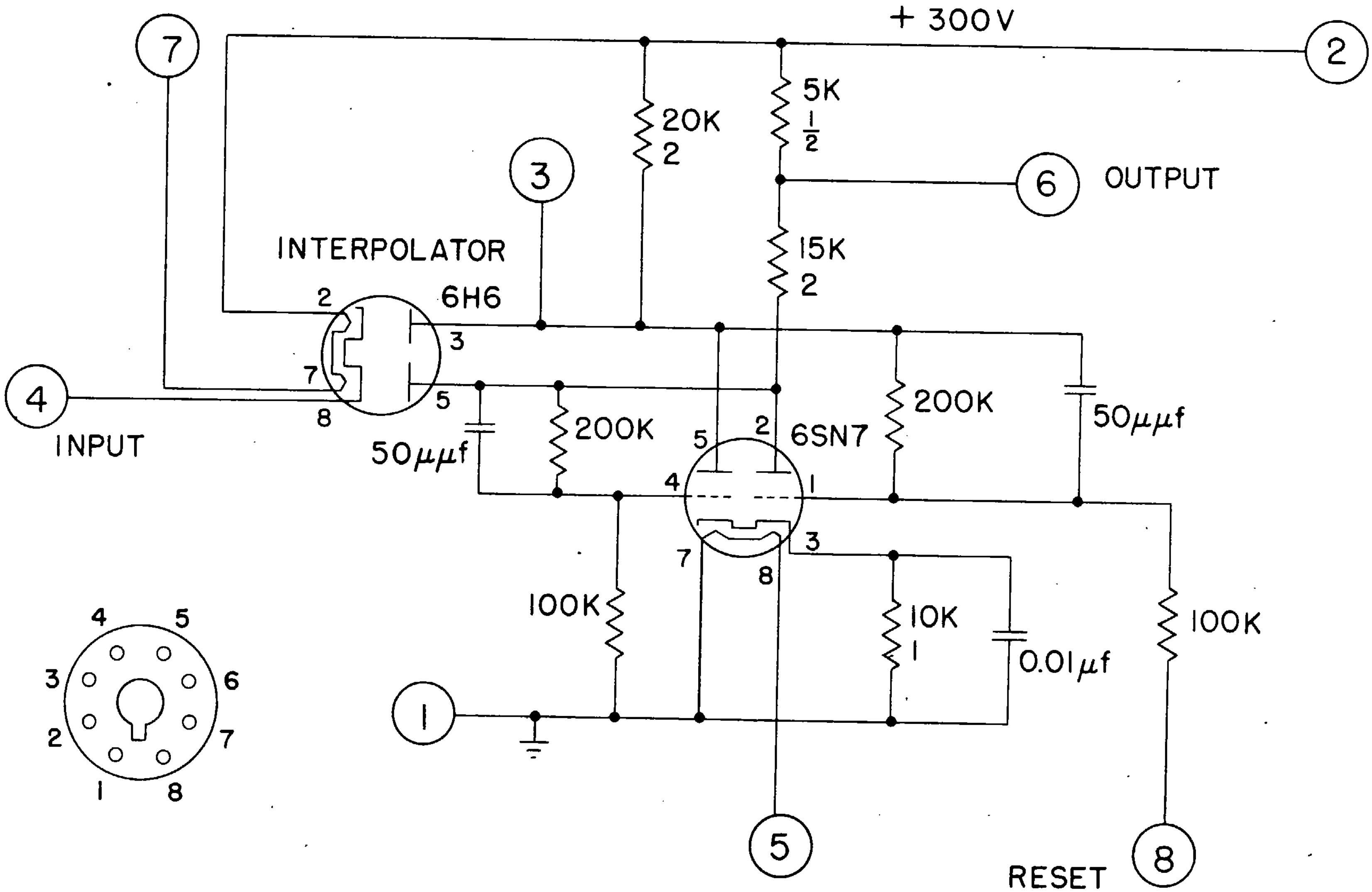


FIG. 5A

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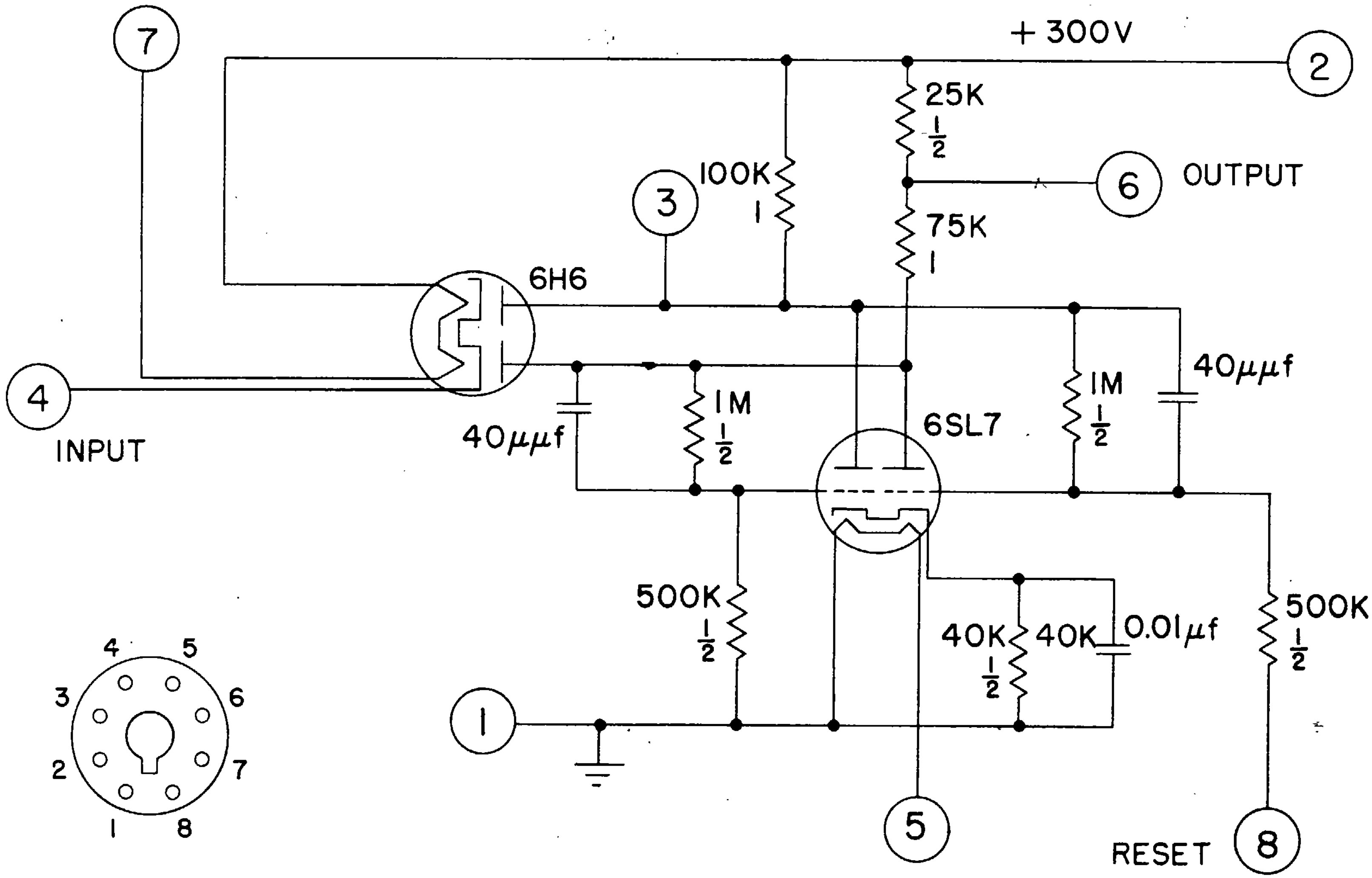
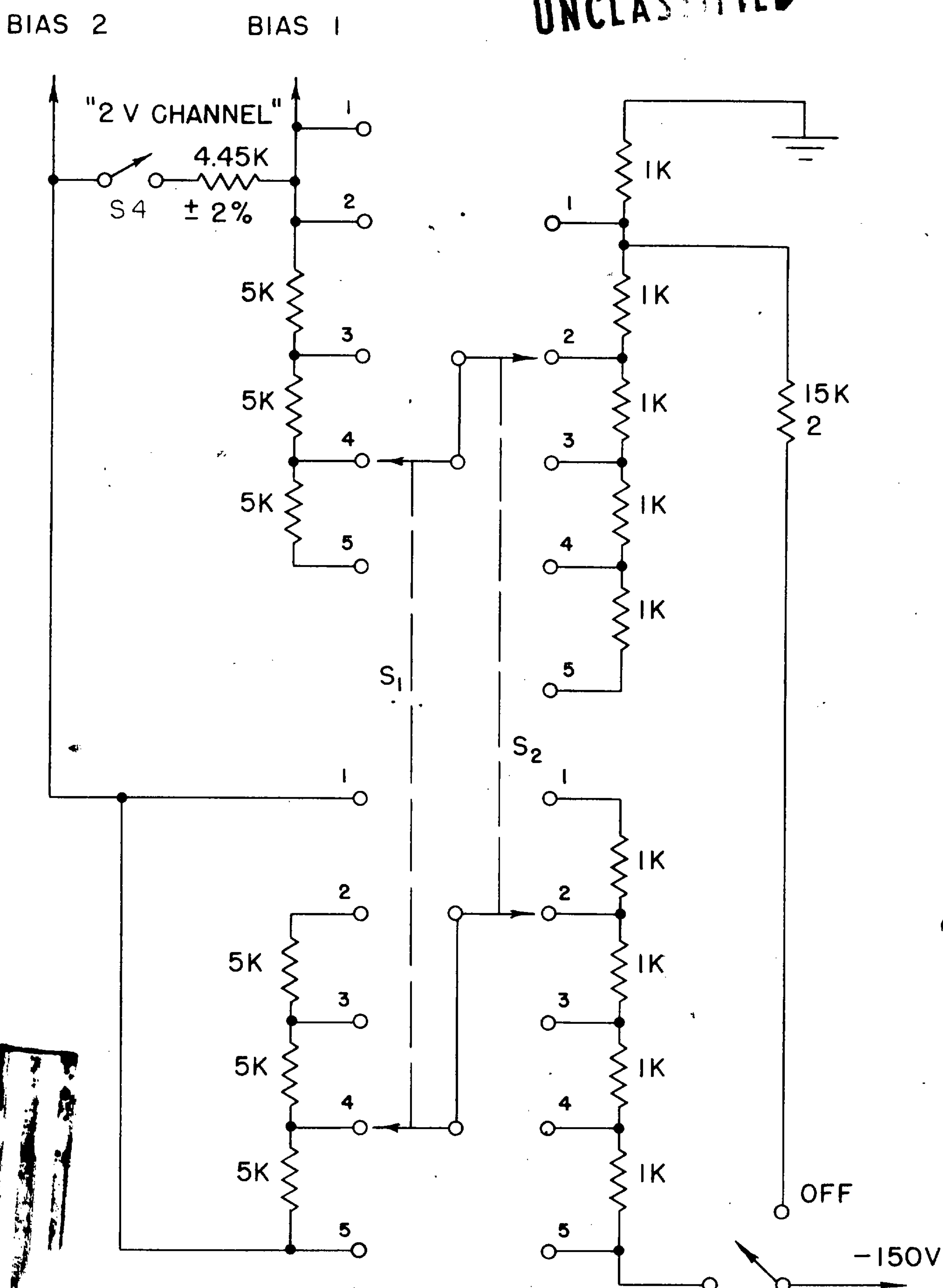

7
+300V
2
25K
1/2
100K
1
3
6
OUTPUT
75K
1
6H6
4
INPUT
40μμf
1M
1/2
6SL7
1M
1/2
40μμf
500K
1/2
40K
1/2
40K
0.01μf
500K
1/2
4
5
3
6
2
7
1
8
1
5
RESET
8

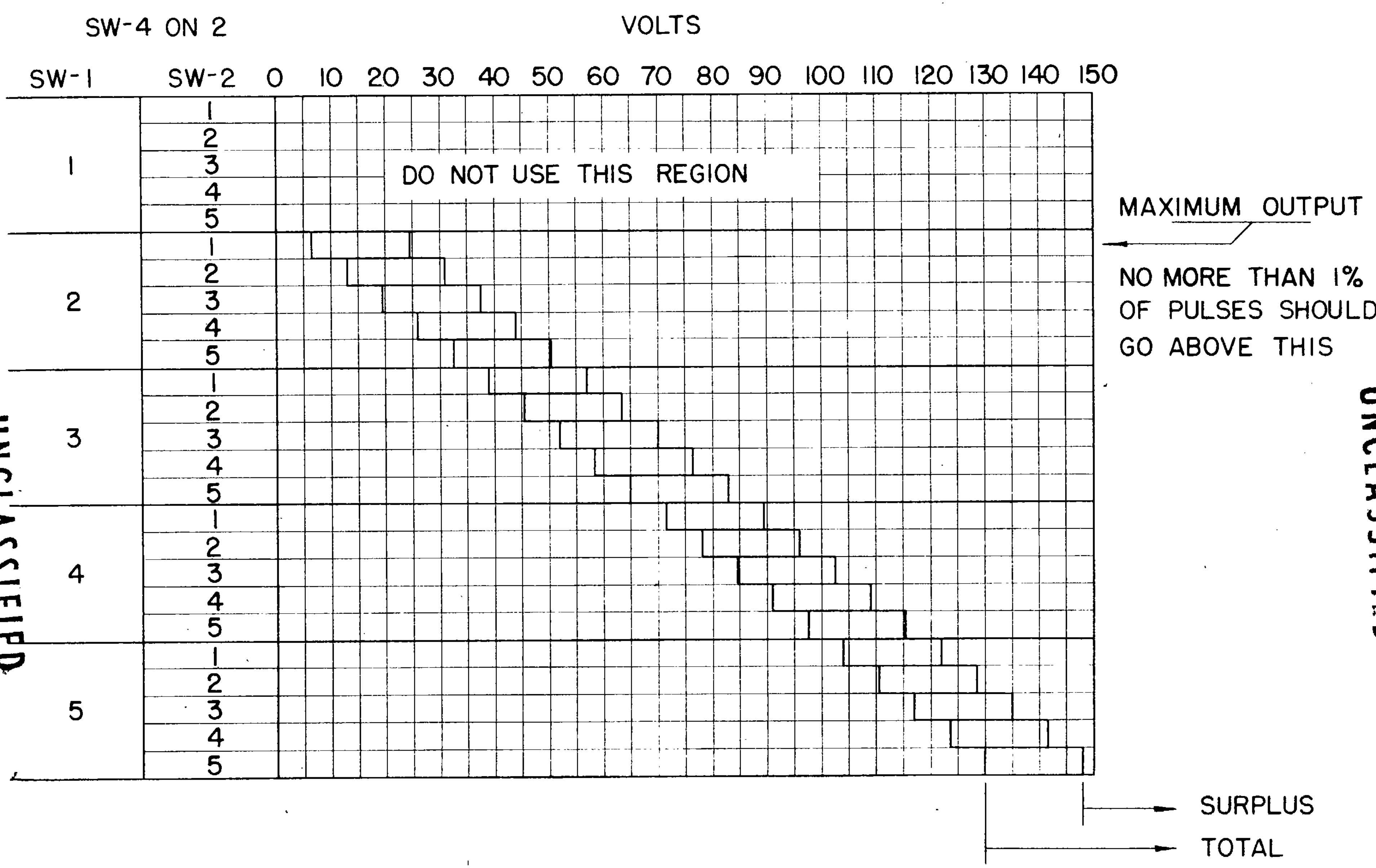
FIG. 5B



NOTE - ALL RESISTORS ARE WW-4

FIG. 6

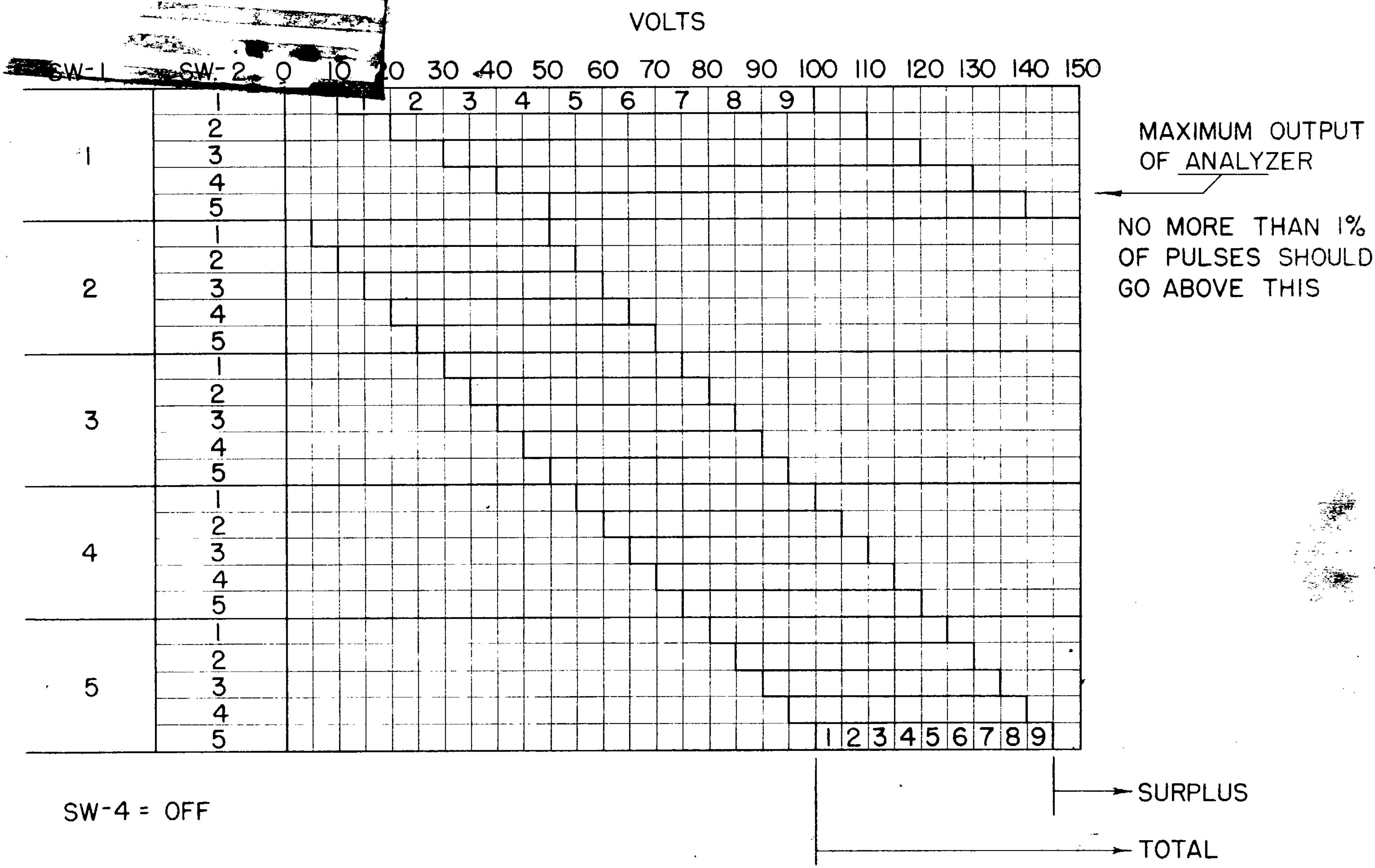
[redacted]



SWITCH SETTINGS FOR 2 VOLT CHANNELS

FIG. 7A

[redacted]



SWITCH SETTINGS FOR 5 AND 10 VOLT CHANNELS

FIG. 7B

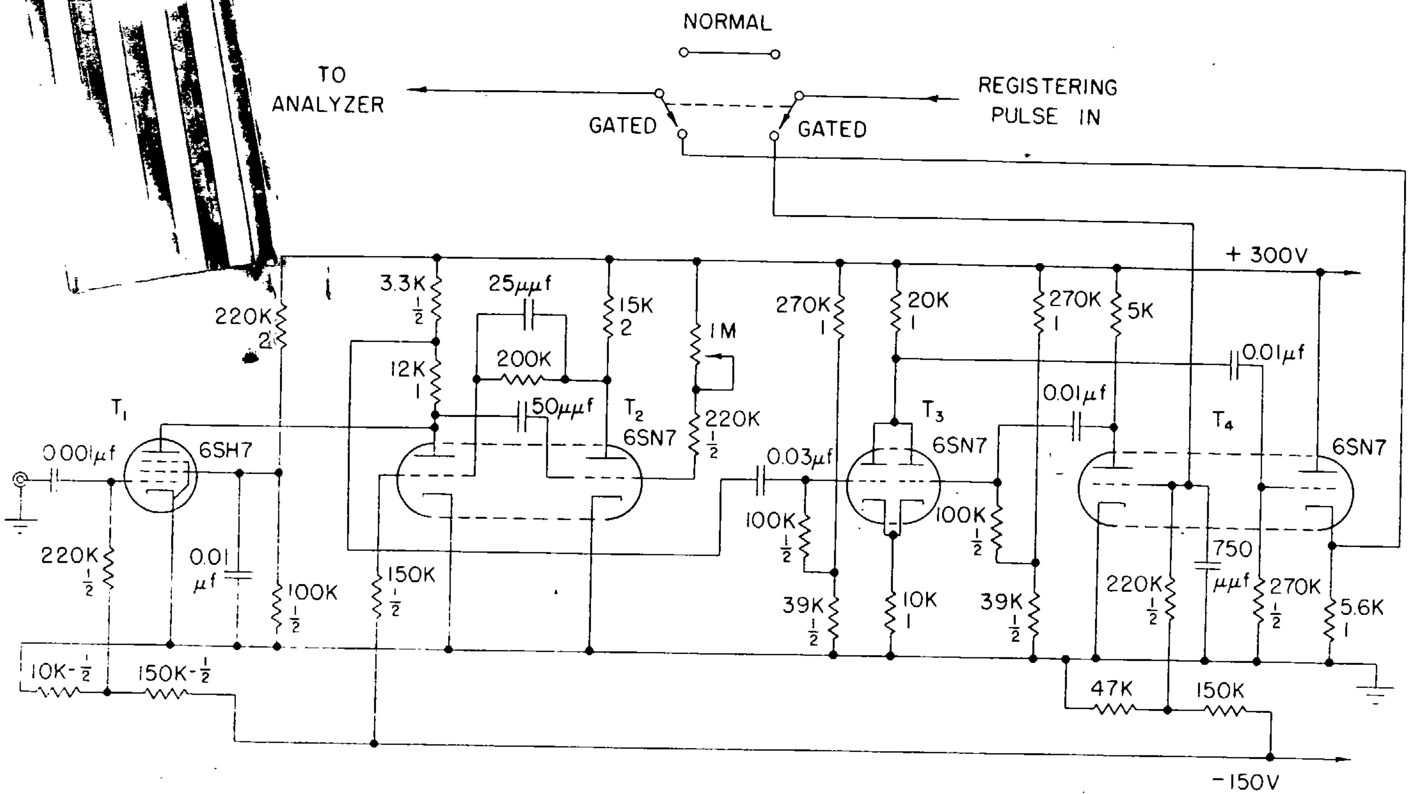


FIG. 8

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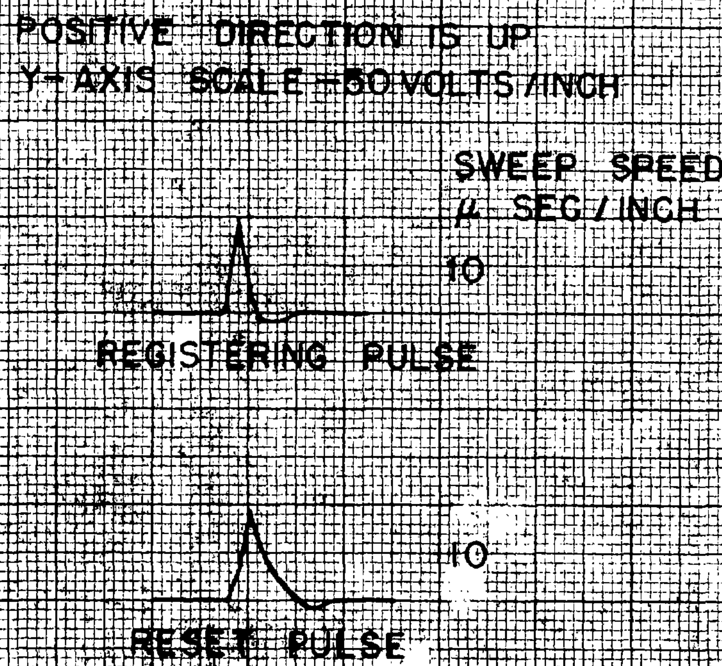
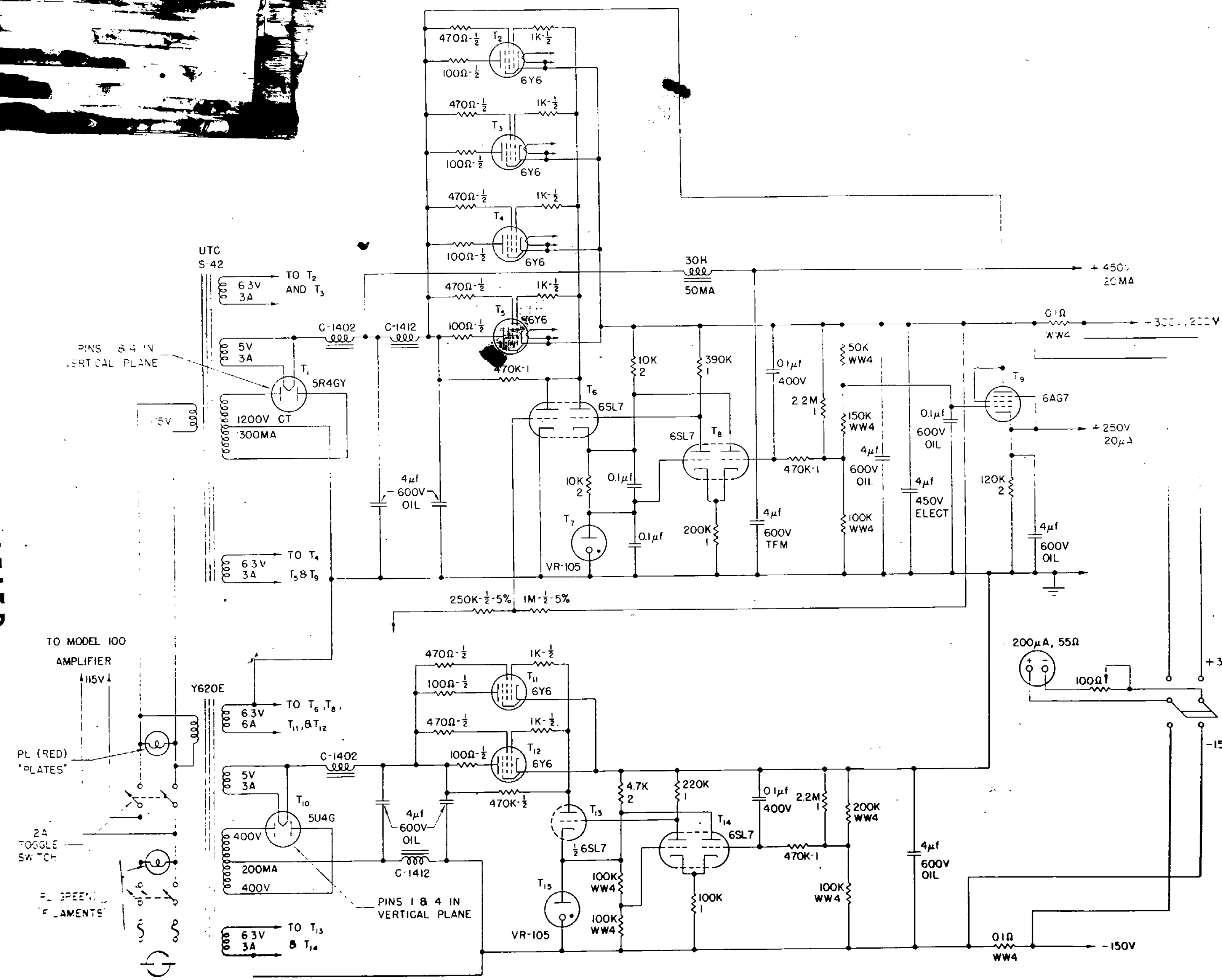

POSITIVE DIRECTION IS UP
Y-AXIS SCALE - 50 VOLTS/INCH
SWEEP SPEED
μ SEC/INCH
10
REGISTERING PULSE
10
RESET PULSE

FIG 9

[redacted]



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[redacted]

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