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NRL REPORT 3568

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AN INVESTIGATION OF HIGH-RESOLUTION RADAR PHENOMENA

PART II, HIGH-SPEED OSCILLOSCOPY

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AN INVESTIGATION OF HIGH-RESOLUTION RADAR PHENOMENA

PART II, HIGH-SPEED OSCILLOSCOPY

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November 10, 1949

Approved by:

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DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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ABSTRACT

A research project on high-speed oscilloscopy has resulted in the construction of an oscilloscope with sweep rates as high as 100 in/microsecond and possessing sufficient brilliance to allow single traces to be photographed. Controllable delay circuits have been developed which are stable to less than 500 micro-microseconds jitter for delays of a few microseconds. Complete analysis of the circuitry involved and a description of the construction of the oscilloscope is included.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem R12-02R
NR 512-020

AN INVESTIGATION OF HIGH-RESOLUTION RADAR PHENOMENA, PART II, HIGH-SPEED OSCILLOSCOPY

INTRODUCTION

A high-speed oscilloscope has been designed and constructed at the Laboratory. This work is one component development of a long-range research project on High-Resolution Radar. Other work on this project has been reported previously.[1]

Performance Requirements

The use to be made of this particular oscilloscope placed conditions on its design which required that the oscilloscope:

1. Provide uniform amplitude frequency response to 200 megacycles (within 10 percent).
2. Have brilliance sufficient to observe recurrent pulses from 20 cps to 5000 cps.
3. Have a maximum sweep speed of 100 in/μsec (0.01 μsec/inch) and a minimum sweep speed of 20 in/μsec.
4. Provide a keying pulse to the external circuit under examination of suitable voltage and impedance characteristics for keying a hydrogen thyratron type 5C22.
5. Provide a delay between external keying pulse and sweep, adjustable from zero to at least two microseconds.

Choice of Cathode-Ray Tube

Conditions 1, 2, and 3 combine to limit rather narrowly the type of cathode-ray tube that can be used. Since the maximum writing speed of the scope is 100 in/μsec, it is immediately apparent that a high-intensity tube must be used. The Dumont types 5RP-A and K-1030 tubes are high intensity trace tubes employing electrostatic deflection, while

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[1] *Olson, Carl O., "An Investigation of High-Resolution Radar Phenomena, Part I, Short Pulse Transmitter," NRL Report 3501, September 1949*

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the 5TP4 used in projection television service is a high intensity tube using electromagnetic deflection. The Dumont tubes have been used for photographic recording using single traces having writing speeds in the neighborhood of 100 in/μ sec.

Since this particular oscilloscope was to be used for recurrent pulses (Condition 2) the brilliance problem is helped somewhat over the single trace case. However, at repetition rates as low as 20 cycles, the brilliance of the post-deflection-acceleration tubes is demanded. Post-deflection acceleration furnishes a means of maintaining fairly reasonable deflection factors combined with a high-energy beam.

Condition 1 specifying the range of frequencies to be viewed brings up two important factors concerning the cathode-ray tube.

(a) The Input Circuit to the Deflection Plate.

In order to display frequencies as high as 200 megacycles without distortion, it is necessary to keep the lead lengths to the deflection plates short and also to keep to a minimum the capacitance of the deflection plates to ground. By keeping the capacitance of the deflection plate to ground low, the impedance of the line or amplifier feeding the deflection plates can be made higher over a given frequency range.

(b) The Effect of Transit Time.

The transit time through the deflection plates places an upper frequency limit on a given deflection system.[2]

$$A = A_0 \; \frac{\sin \pi ft}{\pi ft} .$$

Where A = amplitude of deflection at frequency f,

A_0 = amplitude of deflection at low frequencies, and

t = transit time through the deflecting system.

The value of t depends upon the effective length of the deflecting plates and the velocity of the electrons as they pass through the deflection system. This velocity in turn depends upon the second anode voltage. Values of this velocity for various voltages are presented in tabular form:

Voltage (kilovolts)	Velocity (cm/sec)
1.0	1.88×10^9
1.5	2.30 "
2.0	2.66 "
3.0	3.29 "
4.0	3.75 "
5.0	4.03 "
7.0	4.93 "
10.0	5.86 "
20.0	8.11 "
30.0	9.86 "

Figure 1 - Electron velocities in terms of accelerating voltage

The Dumont tubes previously mentioned were designed for high-speed oscillography and as such furnish the necessary high intensity and low capacitance input with short leads. The electrical characteristics of these two tubes are compared in the Appendix. The K-1030 tube can be operated at a higher frequency than the 5RP-A, and has further advantage of providing co-axial connection to the deflecting plates which reduces the amount of cross coupling between plates. However, the 5RP-A satisfies the brilliance and frequency

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[2] *"Cathode-Ray Tube Displays," MIT Radiation Laboratory Series, Vol. 22, McGraw-Hill, 1948*

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limits imposed by Conditions 1, 2, and 3 and was decided upon because of its availability.

Once the cathode-ray tube has been chosen, Condition 3 determines the amplitude of sweeps that must be used to obtain full deflection.

Generation of Sweeps

The problem of high-speed sweep generation will be considered using the lowest deflection sensitivity figure (highest intensity, shortest transit time) of the 5RP-A tube as a guide.

From the characteristics itemized above the lowest deflection sensitivity can be considered as approximately 0.005 in/volt so that for five inches of deflection about 1000 volts of sweep voltage is required. If the fastest sweep (100 in/μ sec) is considered, a voltage slope of 20,000 V/μ sec must be developed.

Two general methods of generating these sweeps were investigated: namely, the modified raster scan method using vacuum tubes and the hydrogen thyratron method. In the former method, a two-megacycle oscillator was keyed to provide either sine wave sweeps directly or to produce a series of linear sawtooth sweeps starting at t_0 (Figure 2).

The cathode-ray tube was unblanked at t_1, the interval from t_0 to t_1 being adjustable. Coinciding with the unblanking pulse, a small expansion sweep voltage was applied to the vertical deflection system so that several consecutive sweeps would be distinguishable. This corresponds to a raster type of scan in that several sweeps can be made available at a given time.

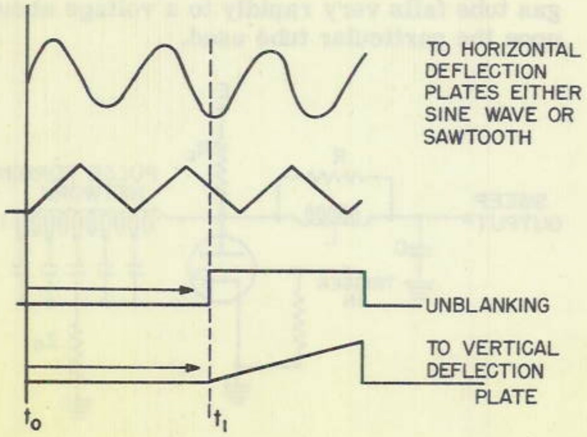

Figure 2 - Modified raster scan

One advantage of this type of sweep is that of providing stable delayed sweeps with no other stable delay pulse generation necessary. The time jitter of any sweep depends upon the variation in the amplitude and frequency of the two-megacycle oscillator. It is apparent that jitter in the delay of the unblanking pulse used in this system does not result in time jitter of the trace itself, but is seen only as fluctuations in the ends of the interval being examined.

This method worked quite satisfactorily for sweeps longer than about 0.5μsec. Above this speed the generation of steep voltage slopes demands higher currents than can be conveniently obtained from vacuum tubes.

The rate of rise in volts per second of the voltage across a condenser can be considered equal to the current divided by the capacitance.

$$\frac{i \text{ (amperes)}}{c \text{ (farads)}} = \frac{V \text{ (volts)}}{t \text{ (seconds)}}$$

[redacted]

If the sweeps are developed across the lowest possible capacitance consisting of the output capacitance of the sweep generator tube in parallel with wiring and cathode-ray tube capacities, the current that must be handled by the vacuum tube becomes objectionably high. For example, given a minimum capacity of $30 \mu\mu f$ and rate of rise of 20,000 volts/μ sec, the current becomes 600 milliamperes.

In addition, the amount of cross coupling from one deflection plate to the next right-angle plate increases as the capacitance from plate to ground is lowered. This is due in part to the capacitance divider formed by the capacitance to ground, and the plate-to-plate capacitance of the cathode-ray tube. If the capacity from the deflection plate to ground is deliberately made as high as $100 \mu\mu f$ to minimize cross-coupling effects, the current is increased to two amperes. This magnitude of current leads to the selection of a gas filled tube such as the thyratron as a sweep generation source.

The use of the hydrogen thyratron for generation of high speed sweeps is described in the literature,[3] and several variations of this circuit will be discussed. Figure 3 shows one form of a thyratron used for generating a linear sweep voltage. The tube can take the form of a 2D21, 2050, 3C45, or 4C35 depending upon factors such as the voltage or current required. The circuit operates as follows.

When the tube is keyed by means of a positive pulse at the grid the charged line is discharged through Z_0 in series with the thyratron. This produces a negative square pulse across Z_0 of amplitude E/2 and length equal to twice the delay of the line. The plate of the gas tube falls very rapidly to a voltage about 20-50 volts above ground potential depending upon the particular tube used.

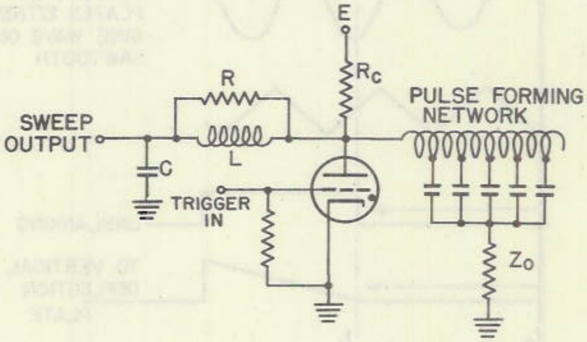

Figure 3 - Thyratron used for generating a linear sweep voltage

This circuit provides a negative square pulse across Z_0 that can be used as an unblanking pulse for the cathode-ray tube. The sharp drop at the plate is integrated by the R,L,C circuit to provide a substantially linear sweep voltage about equal to the supply voltage.

The values of R, L, and C are obtained from the relationships

$$L = KR^2 C, \text{ and}$$

$$t = RC.$$

The variation of condenser voltage as a function of K is presented by Winters.[4] For K = 0.8 and t = RC, the voltage across the condenser will be nearly linear up to about 0.9 of the supply voltage.

In order to prevent the defocusing effects which result from an unbalanced sweep, two methods of producing balanced sweeps were used (Figure 4).

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[3] *Winters, D. F., "Winterscope or Fast Sweep Synchroscope," MIT Radiation Laboratory Report No. 1001, April 12, 1946.*

[4] *Winters, ibid.*

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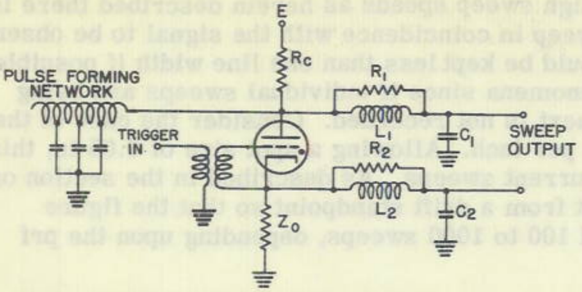

NOTE: HEATER CURRENT SUPPLIED THROUGH SUITABLE CHOKES

Figure 4 - Method of obtaining balanced sweep voltages using a thyratron

(a) One method considered for use employed a thyratron to obtain the balanced sweeps desired. The operation of this circuit (Figure 4) is similar to that previously described. In this case when the thyratron is triggered the cathode of the gas tube rises rapidly to a voltage V/2. In this way C_2 charges to V/2 through L_2 and R_2 to provide a positive linear sweep approximately equal to V/2. C_1 discharges from V to V/2 to provide a negative sweep approximately equal to V/2. A positive square pulse of amplitude E/2 is developed across Z_0 so that an unblanking pulse can be obtained from the circuit.

(b) Another method considered for use employed a transformer to obtain the balanced sweeps desired. In this circuit, (Figure 5) the cathode of the gas tube is grounded, eliminating the necessity of filament chokes and also of a pulse transformer for keying purposes. The unblanking pulse is obtained from Z_0. The sharp voltage step at the plate is capacitively coupled into the phase inverting transformer. This voltage step is integrated from the secondary of the transformer to develop the balanced sweeps. The linearity of these sweeps depends upon the frequency response of the transformer used. This method is used in the oscilloscope described in the latter part of this report.

Phasing or Delay of Sweeps

Before discussing the problem of phasing or delaying sweeps it is desirable to define what is meant by the "stability" of firing of a thyratron. For the purpose of this report, stability will be defined in detail as follows.

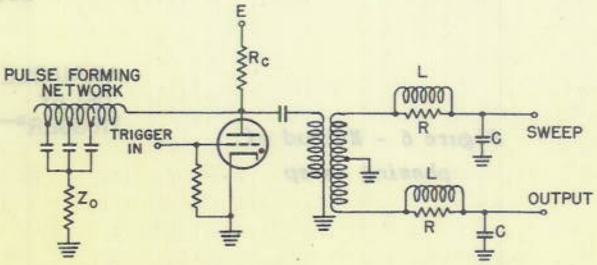

Figure 5 - Sweep generator using a transformer to obtain balanced sweep voltages

Pulse Delay - The time difference from an arbitrary time reference to the leading edge of a pulse is called the delay of the pulse.

Jitter - The variation in pulse delay measured over any one-second interval will be defined as jitter.

Average Delay - The delay to the most probable pulse in a jitter interval will be defined as average delay.

Drift - The variation in average delay over any time interval will be defined as the drift over that time interval.

It is readily apparent that the term jitter includes rapid fluctuations of delay resulting from noise effects, ripple voltages or effect of sixty cycle fields present within or near the thyratron. Instability in firing time, a-c fields, pickup, etc. contribute primarily to jitter. Slow fluctuations of d-c voltages, thermal changes in gas temperature or components will contribute to drift.

When using an oscilloscope which has high sweep speeds as herein described there is considerable difficulty in maintaining the sweep in coincidence with the signal to be observed. To obtain a good presentation, the jitter should be kept less than one line width if possible. This naturally applies only to recurrent phenomena since if individual sweeps are being photographed, jitter from one sweep to the next is not recorded. Consider the case of the fastest sweep described: namely, 0.01 μsec per inch. Allowing a spot size of 0.05 in, this demands a jitter less than 500 $\mu\mu$sec for recurrent sweeps. As described in the section on stability, this restriction is eased somewhat from a drift standpoint so that the figure 500 $\mu\mu$ sec represents jitter over a range of 100 to 1000 sweeps, depending upon the prf used.

To obtain coincidence of sweep and signal, means must be provided to delay the sweep over the interval being examined. This may be accomplished by several methods.

Winters[5] describes one such system, which operates as follows. A sharp pulse is generated by a 3D21 tube and applied to taps along the line as shown in Figure 6. This keying pulse travels down the line in both directions, at one end the sweep thyratron is triggered while at the other end a trigger pulse is obtained for an external circuit. In order to provide complete coverage of delay over an interval, a variable delay line was inserted in series with the line to fill in between the steps of the switch.

A modification of this circuit was used in the first high-speed oscilloscope constructed by the group at NRL. The circuit (Figure 7) operates in the following manner:

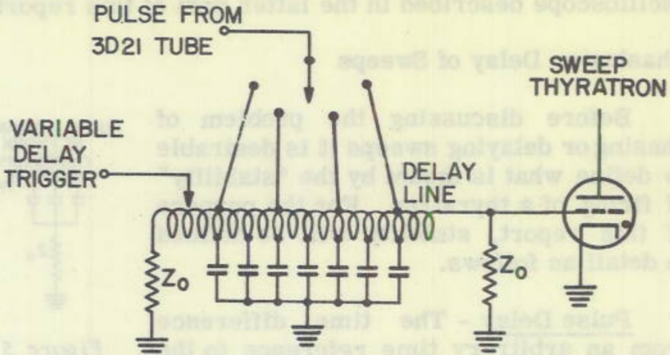

Figure 6 - Method of phasing sweep

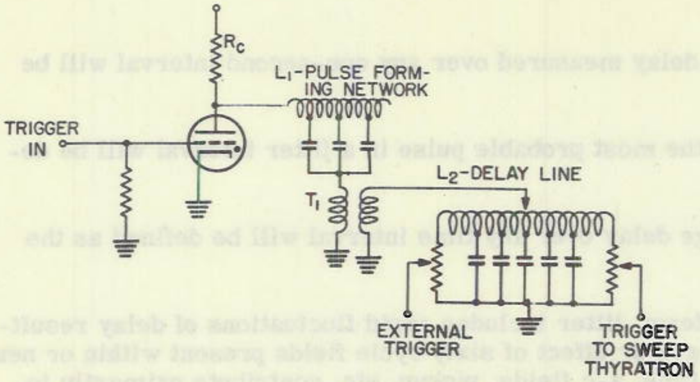

Figure 7 - Adjustable delay circuit for phasing of sweep

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[5] *Winters, ibid.*

Tube 3C45 was triggered so that the line L_1 was discharged through the pulse transformer T_1 developing a 3 microsecond, positive, square pulse across the secondary of the transformer. This pulse was applied to taps along the line L_2 providing rough adjustment in delay. Fine delay was obtained by means of amplitude control of the pulse at each end of the line.

Further experimentation with this circuit indicated that when direct current was used in the heater supply, rapidly rising keying voltages were not necessary to provide stable keying of the thyratrons used, namely, 2050, 3C45, 4C35, and 5C22. Consequently, the circuit was modified so that instead of a square pulse forming line a single series R,L, and C circuit was used for pulse forming, providing an approximate half-sine-wave pulse (Figure 8).

The constants were chosen so that L,C, and resistance, R, reflected by the transformer formed an underdamped or oscillatory circuit. The delay line was a lumped constant line having a delay of 5 microseconds and 100 ohms impedance.

The stability of firing of the thyratron with these types of pulses indicated that the delay time could be controlled by amplitude alone over a range of at least two microseconds with the jitter less than $500\mu\mu$ sec.

Since the delay time could be controlled by amplitude alone a longer keying pulse (about 20μsec) was needed at low impedance in order to extend the delay range. Figure 9 was used to furnish the required positive keying pulse.

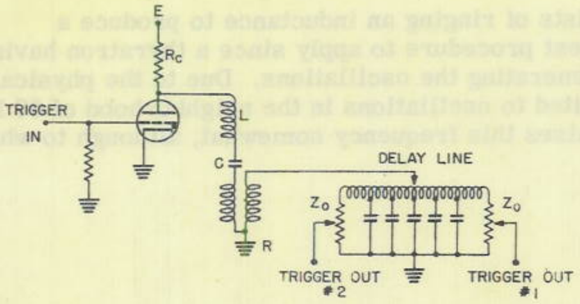

Figure 8 - Modified sweep phasing circuit

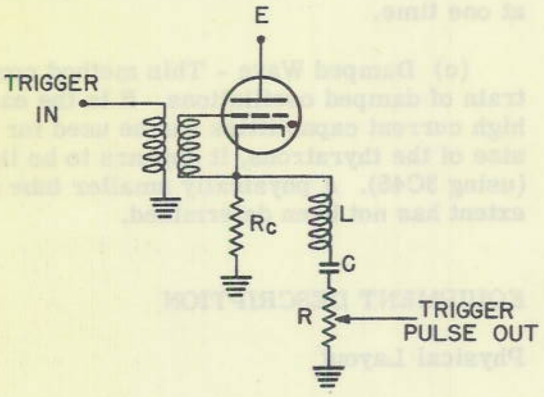

Figure 9 - Positive trigger pulse generator

In this circuit, the condenser, C, charges to +E through R and L. Values of R, L, and C are obtained from the relationships:

$$R = \sqrt{\frac{L}{C}}$$

$$t \cong \pi\sqrt{LC}$$

R - ohms
L - henries
C - farads
t - seconds

The pulse obtained approximates a half-sine-wave pulse of width t. The gas tube acts as damping so that no overshoot is obtained even though the R, L, and C circuit is oscillatory. R_L is made as low as permissible with a given voltage, V, so that the condenser, C, recovers as rapidly as possible without allowing the thyratron to stay in conduction. Filament voltage was obtained from the 60-cycle supply with negligible amplitude modulation of the output pulse.

A detailed study of this type of delay and stability of this delay for various thyratrons has been undertaken and will be reported at a later date. By the method just outlined, it is possible to obtain small jitter delays out to about 20 microseconds. By suitable compensation within the gas tube circuit as well as changes in the design of the thyratron it is hoped that the stable delay interval can be increased.

Calibration of a High-Speed Scope

The high-speed sweeps herein described were calibrated by several methods in an attempt to find one method which was accurate, and at the same time available for both visual and photographic use.

(a) Crystal Controlled CW Transmitter - Perhaps the most accurate method tried consisted of using a crystal controlled CW transmitter as the timing wave source. This timing wave was applied to the vertical deflection plates and single trace photographs taken. It has the disadvantage of not being synchronized with the sweeps and cannot be used to measure time intervals directly when viewing recurrent phenomena.

(b) Keyed Oscillator - A 200-megacycle oscillator was keyed and photographed. This circuit demanded considerable build-up time for oscillations but was very stable and easily photographed since a considerable number of sweeps could be photographed at one time.

(c) Damped Wave - This method consists of ringing an inductance to produce a train of damped oscillations. It is the easiest procedure to apply since a thyratron having high current capabilities can be used for generating the oscillations. Due to the physical size of the thyratrons, it appears to be limited to oscillations in the neighborhood of 60 Mc (using 3C45). A physically smaller tube raises this frequency somewhat, although to what extent has not been determined.

EQUIPMENT DESCRIPTION

Physical Layout

The oscilloscope described in this report housed in a four-foot Parmetal cabinet, (Figures 10 and 11) has its component parts placed at three levels within the cabinet. The upper level, consisting of two chassis, contains the following circuits and components:

1. Type 5RP-A tube and shield.
2. High voltage bleeder for providing proper post-deflection accelerating voltages.
3. Shielded transformer for cathode-ray tube insulated for 5000 volts.
4. Bleeder for obtaining focus and bias voltages for cathode-ray tube.
5. Marker circuit employing a 2D21 thyratron.

6. Multivibrator with frequency range 0.25 to 25 kc in five steps for initiating trigger pulses.

7. Two pulse generating circuits each supplying two low impedance keying pulses.

8. Sweep circuit furnishing sweeps and unblanking for CRT.

The middle level contains:

1. High-voltage RF supply - 0 to 20 kilovolts for post deflection acceleration.

2. Second anode RF supply negative 1.0 to 4.5 kilovolts.

3. Centering voltage supply furnishing positive and negative 300 volts.

4. D.C. heater supply 6.5 volts at 3 amperes.

The lower level contains:

1. Power supply furnishing 600 volts at 165 ma.

2. Two power supplies each furnishing +300 volts at 165 ma.

3. Filament voltage supply.

Schematic diagrams of the oscilloscope are shown as Figures 23, 24, and 25.[6]

Cathode-Ray Tube Chassis

The cathode-ray tube is mounted as shown in Figure 12. The front of the tube is maintained at the final intensifier voltage by means of a copper band, encircling the tube. In order to prevent corona as well as provide a physical support for the tube, a lucite collar is fastened to the front panel which supports the front of the cathode-ray tube. A sheet of 1/8 inch thick lucite protects the observer from the high voltage. Magnetic shielding is provided by a mu-metal shield.

Figure 13 shows a close-up view of the high voltage bleeder used for obtaining the proper voltages for the intensifier elements. The bleeder is made up of half-watt, 1.8 megohm resistors wound in a spiral groove cut into a polystyrene rod to minimize corona effects. The total resistance is 100 megohms so that a 200 microampere meter can be used with the bleeder to read twenty kilovolts full scale.

Since the cathode of the oscilloscope is operated at a negative potential of four kilovolts with respect to ground, an isolation filament transformer is necessary. This transformer, mounted beneath the chassis, is surrounded by two iron shields to minimize the sixty-cycle field external to it.

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[6] *Figures 23, 24, and 25 will be found at end of report.*

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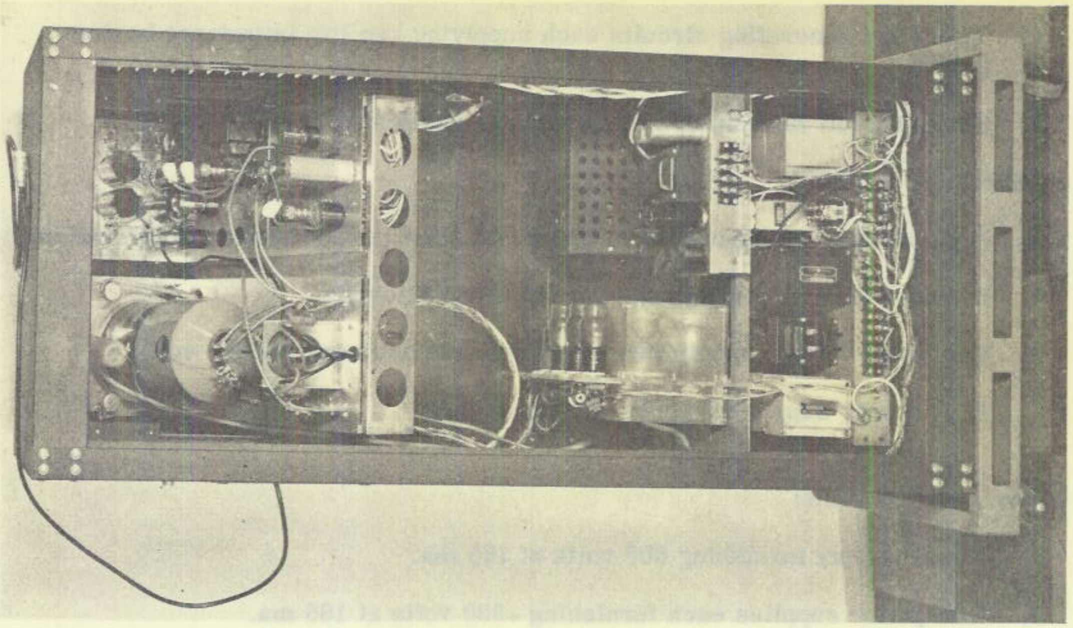

Figure 11 - Rear view

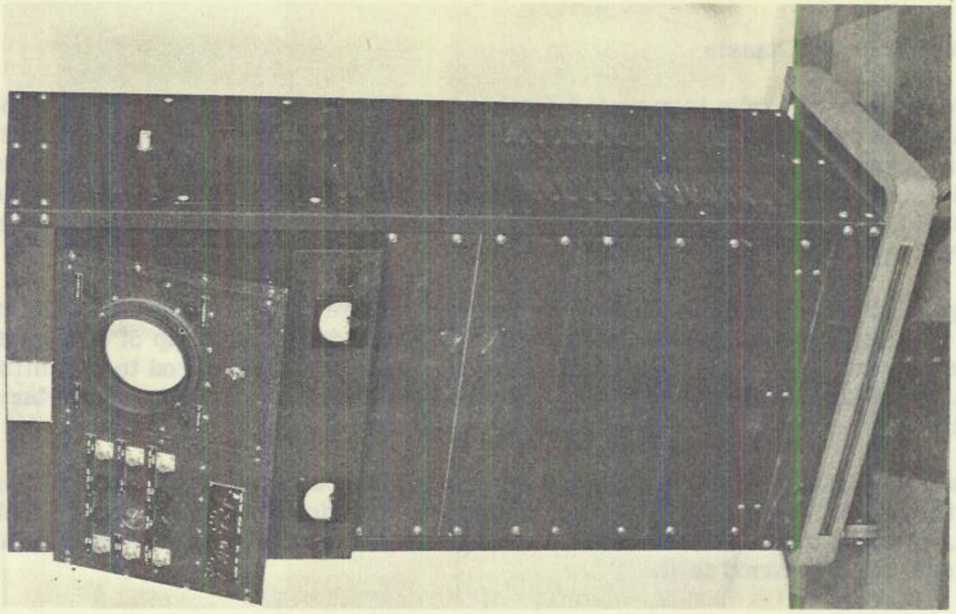

Figure 10 - Front view

High-speed oscilloscope

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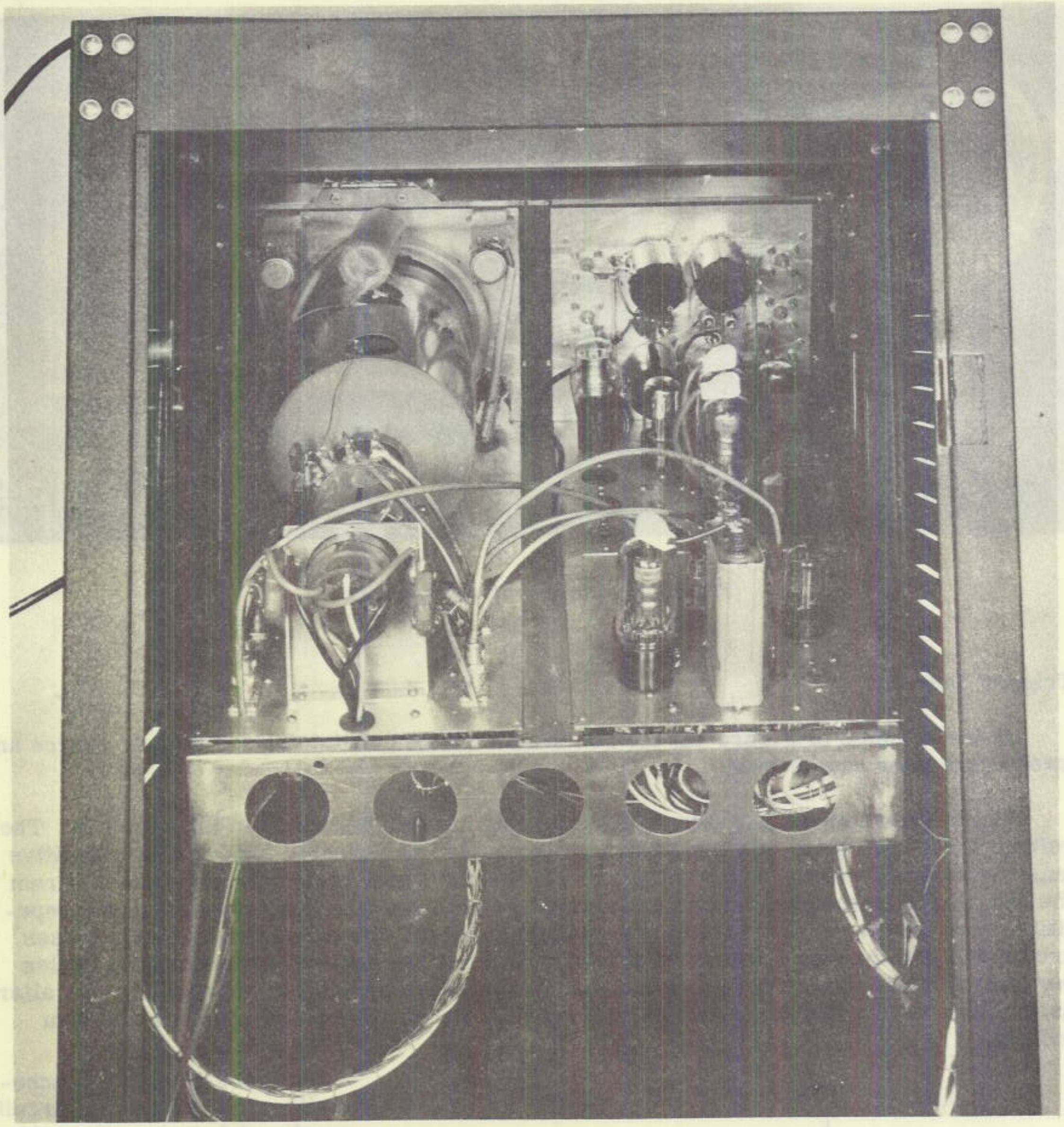

Figure 12 - Cathode-ray tube mount and trigger generator

A ringing circuit used for generating a timing wave is placed close to the deflection plates. Figure 14 shows a schematic of the circuit used.

The 2D21 thyratron is triggered to start a damped oscillation of fifty megacycles in the coil. In this manner sine waves of two hundred volts peak-to-peak amplitude are generated. A miniature positive grid type thyratron such as a miniature 3C45 would be useful for this application.

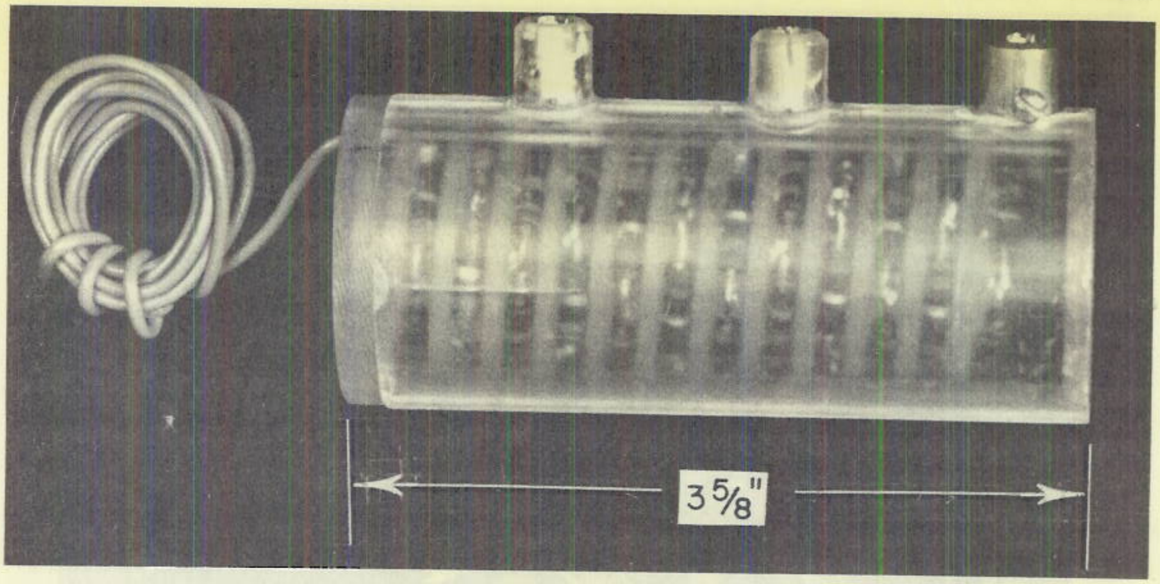

Figure 13 - High-voltage bleeder

Trigger Source

At the left side of Figure 12, the removable chassis containing the trigger source and sweep generator can be seen.

The trigger source operates in the following manner as indicated in Figure 15. The voltage from each plate of a multivibrator is coupled to a ringing tube so that a positive pulse is obtained whenever the voltage at the multivibrator plate goes downward. From the two ringing circuits two identical pulses are obtained which occur at the same repetition rate but which alternate in time with each other. These alternate keying pulses are provided to furnish a means of obtaining an effective repetition rate of 8000 cycles per second while operating two circuits at 4000 cycles per second. Each of the two alternate pulses keys a thyratron that in turn generates a positive pulse across a 500 ohm helipot.

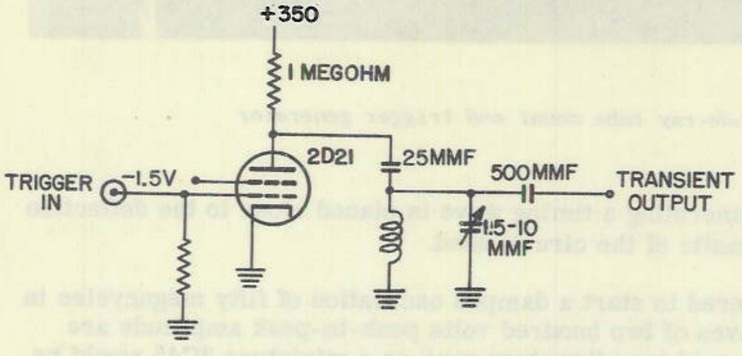

Figure 14 - Schematic of marker generator

Figure 16 shows a schematic of the thyratron circuit employed for generating the low impedance keying pulses used in the oscilloscope. The operation is identical to that of Figure 8 except that two pulses are obtained simultaneously, one from R_1 and the other from R_2. One of these can be used as a trigger for the sweep thyratron and the other for an external circuit trigger.

[redacted]

The multivibrator is designed to cover the range of repetition rates from 0.25 to 25,000 cycles per second in five steps. The dionization time of the thyratrons and the recovery of the associated condensers, however, restrict the maximum repetition rate to about 5000 cycles per second. By either choke charging or charging through a cathode follower the maximum repetition rate can be increased. However, since the 3C45 tubes used in the trigger circuit are operating at their maximum average current rating it was decided to use resistance charging rather than change to larger tubes such as 4C35 or 5C22.

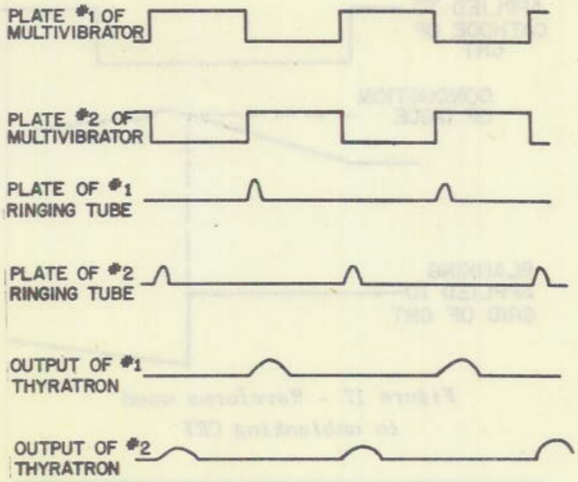

Figure 15 - Operation of triggering system of high-speed oscilloscope

Sweep Circuit

The sweep circuit consists of a 3C45 thyratron employing a 0.5 microsecond pulse forming line to develop unblanking and sweep voltage. A transformer is used to provide balanced deflection as described previously (Figure 5). In order to prevent the trace from striking the sides of the tube after deflection and at the same time avoid the necessity of switching pulse forming networks, the following method of blanking is used. A biased diode, 6X5, and an amplifier 6AG7, are used to give the waveforms shown in Figure 17. Positive sweep voltage is applied to the biased diode which does not conduct until the sweep voltage has reached a value determined by the adjustable bias control. When it does conduct, the positive slope is coupled to the 6AG7 and amplified to furnish a rapidly falling voltage. This negative voltage is fed to the grid of the cathode-ray tube and serves as a blanking pulse.

The sweep speeds in the oscilloscope can be switched from 20 to 120 inches per microsecond. Since the oscilloscope can be used under different deflection sensitivity conditions, a timing wave generator is used to calibrate the sweep for a given set of conditions (Figure 14).

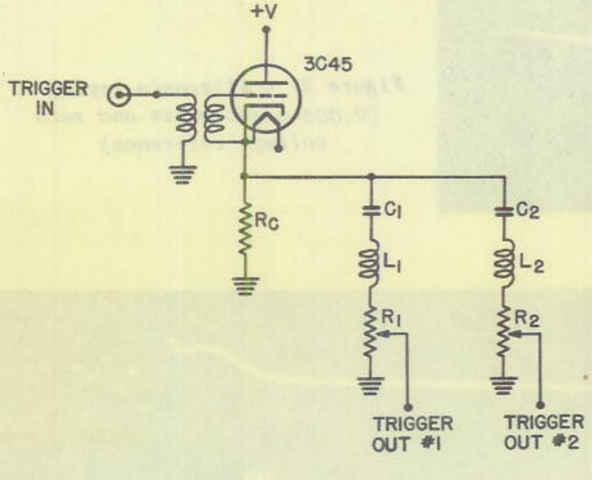

Figure 16 - Schematic of a low-impedance trigger pulse output circuit

Figure 18 through 22 are oscillograms taken from the oscilloscope at various sweep speeds. All exposures were taken with a two second exposure and a repetition rate of 1000 cycles per second so that the time jitter can be estimated by comparing the vertical to horizontal line widths.

Figure 18 shows a 120-megacycle keyed oscillator taken on a sweep of 0.05 μsec per inch.

Figure 19 shows the same oscillator output taken on a sweep of .1μsec per inch.

Figure 20 presents a 50-megacycle timing wave obtained from a ringing circuit superimposed by alternate keying on a short pulse (0.005μsec).

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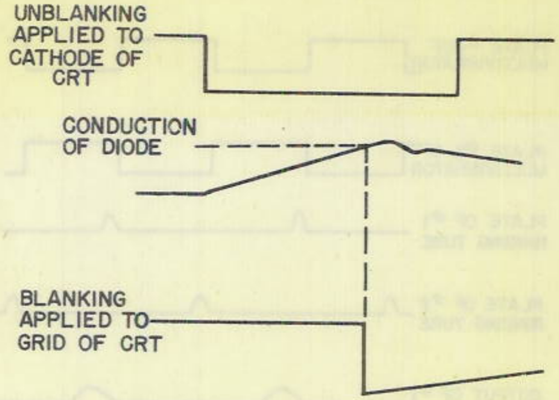


Figure 17 - Waveforms used in unblanking CRT

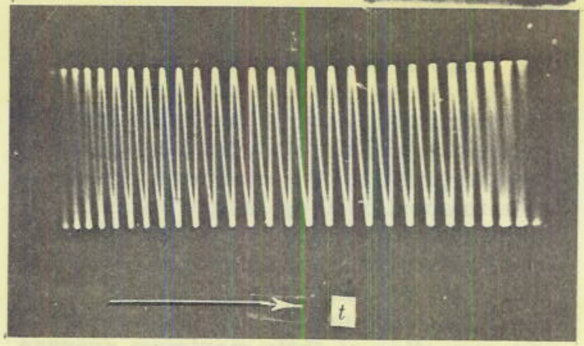


Figure 18 - 120 megacycle keyed oscillator sweep (0.05 μ sec per inch)

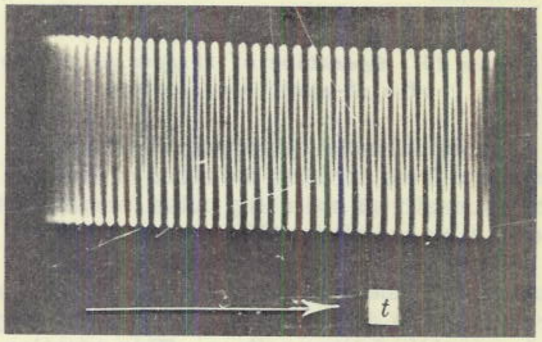


Figure 19 - 120 megacycle keyed oscillator sweep (0.1 μ sec per inch)

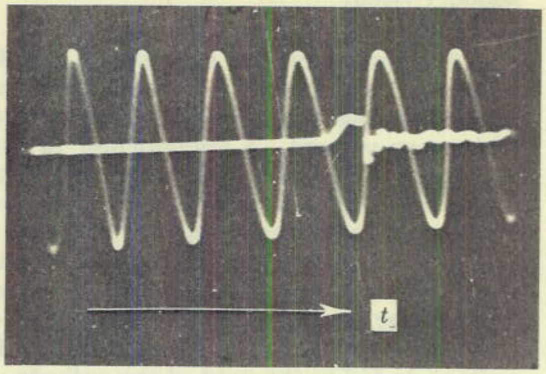


Figure 20 - Alternate keying (0.005 μ sec pulse and 50 megacycle timing wave

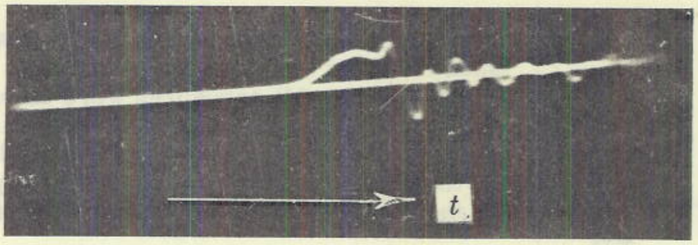
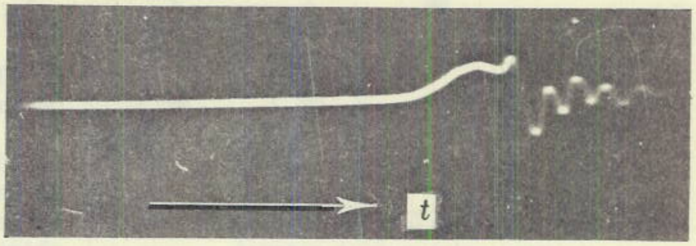


Figure 21 - Alternate keying (0.005 μ sec pulse and zero voltage reference)

Figure 22 - Single trace (0.005 μ sec pulse)



The same pulse is shown again in Figure 21 on a faster sweep and the timing wave replaced by a zero voltage reference.

Figure 22 shows the 0.005μsec pulse taken on the same sweep as Figure 21 but without alternate keying.

CONCLUSIONS

The Dumont type 5RP-11A cathode-ray tube is satisfactory for use up to 300 megacycles. The brilliance obtained with this type tube is satisfactory for visual observation of low, recurrent-rate phenomena (less than 100 cps) at writing speeds of 2000 inches per microsecond.

For sweep lengths shorter than 0.25 microseconds at repetition rates less than 10,000 cycles per second a sweep circuit using thyratrons is more satisfactory than that employing vacuum tubes. At higher repetition rates a type of sweep which uses vacuum tubes appears to be necessary.

A low impedance, half-sine-wave pulse can be used to provide keying for the thyratron type sweep with jitter less than 1000 micro-microseconds. By varying the amplitude of this pulse a variable delay of at least five microseconds can be obtained with very little jitter.

For stable operation of the oscilloscope, voltage regulation should be used on the accelerating potentials applied to the cathode-ray tube. In order to minimize jitter, the d-c voltages used in the sweep circuit and trigger generator should also be regulated. For the heater power of the thyratron sweep tube to keep jitter a minimum, d-c is necessary.

ACKNOWLEDGMENTS

An acknowledgment is made to D. F. Winters, author of the Radiation Laboratory report titled "Winterscope," who described sweep circuits using hydrogen thyratrons.

Acknowledged also is the work of members of the Radar II Branch, especially I. W. Fuller and C. O. Olson for their assistance in thyratron circuitry, and to E. Nan,Jr., M. L. Burnett and J. R. Conlon for their contribution in the construction and testing of the circuits used in the oscilloscope.

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APPENDIX
COMPARISON OF TWO HIGH INTENSITY TUBES

CATHODE-RAY TUBE CHARACTERISTICS

Direct Interelectrode Capacitances	Dumont Type K-1030	 5RP-A
Grid to all other electrodes	3.80	5.40 $\mu\mu$fd
Cathode to all other electrodes	5.05	5.00 $\mu\mu$fd
Deflection plate D_1 to deflection plate D_2	.52	1.8 $\mu\mu$fd
Deflection plate D_3 to deflection plate D_4	.39	1.80 $\mu\mu$fd
D_1 to all other electrodes except D_2	2.25	2.30 $\mu\mu$fd
D_2 to all other electrodes except D_1	2.35	2.10 $\mu\mu$fd
D_3 to all other electrodes except D_4	2.25	2.40 $\mu\mu$fd
D_4 to all other electrodes except D_3	2.20	2.20 $\mu\mu$fd

Ratings (Design-Center Values)		
Anode 2 to final intensifier	30,000	22,000 Max. Volts d-c
Anode 2 voltage E_{b_2}	4,100	3,500 Max. Volts d-c
Anode 1 E_{b_1}	2,000	1,550 Max. Volts d-c
Grid voltage E_{c_1}	Never positive	
Peak potential between accelerating electrode and any deflection plate	750	1,200 Max. Volts
Heater-cathode potential	125	125
Grid circuit resistance	1.5	1.5 Megohms
Impedance of deflecting electrode at heater supply frequency	1.0	1.0 Megohms
$\frac{E_{b_3}}{E_{b_2}}$ RATIO	5	10

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TYPICAL OPERATING CHARACTERISTICS

CATHODE-RAY TUBE CHARACTERISTICS

Direct Interelectrode Capacitances	Dumont Type	
	K-1030	5RP-A
Heater	6.3	6.3 Volts
Anode 3	15,000	20,000 Volts d-c
Anode 2	3,000	2,000 Volts d-c
Anode 1 voltage for focus when E_{C_1} is 75 percent of cut-off	865 ± 20 percent	575 ± 20 percent
Grid voltage for beam cut-off	-90 ± 50 percent	-60 ± 50 percent
Deflection factor D_1 D_2	128 V/inch ± 20 percent	175 V/inch ± 20 percent
Deflection factor D_3 D_4	137 V/inch ± 20 percent	164 V/inch ± 20 percent
Frequency for 10 percent reduction deflection factor due to transit time	1000 Mc	265 Mc

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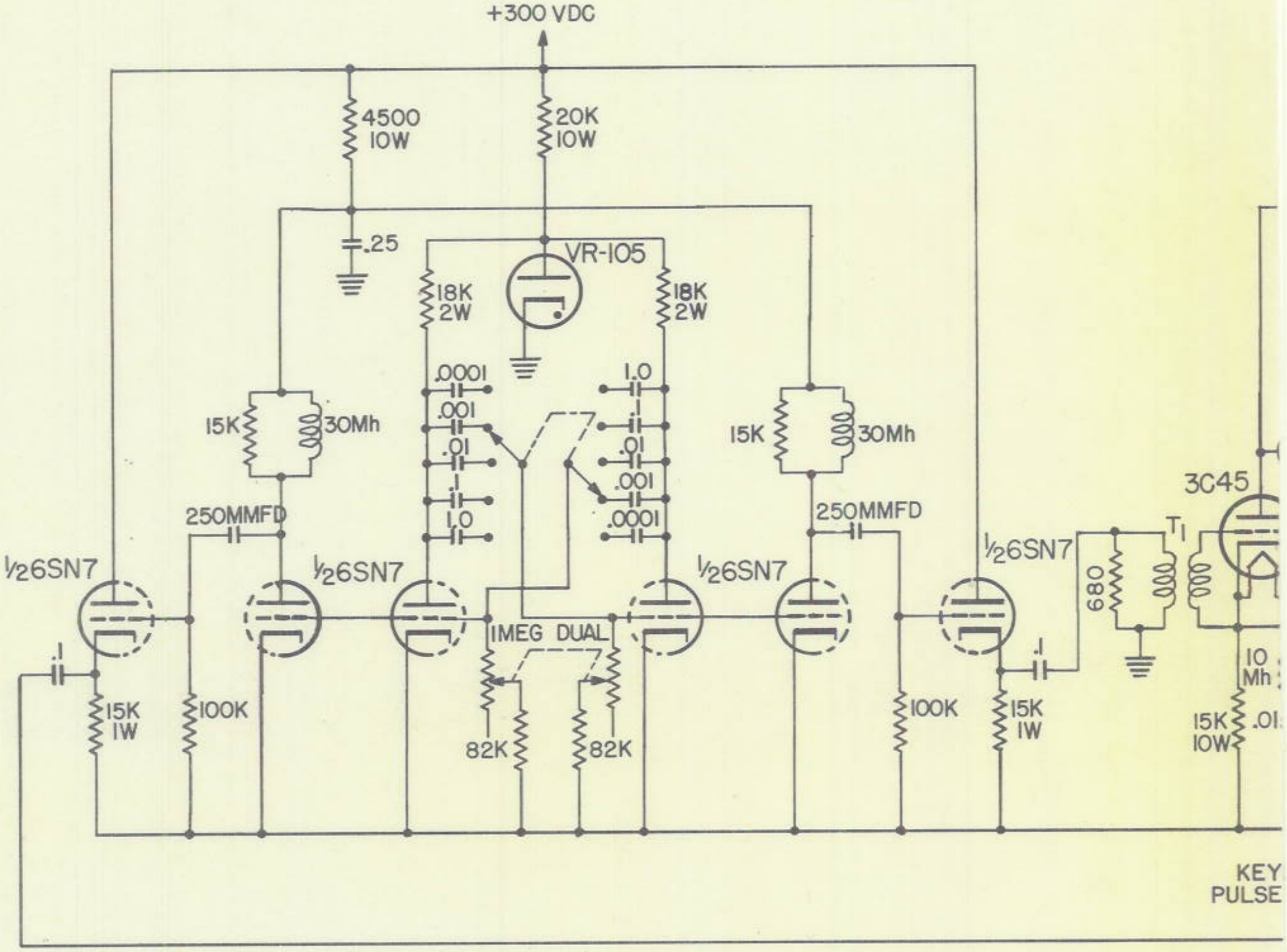
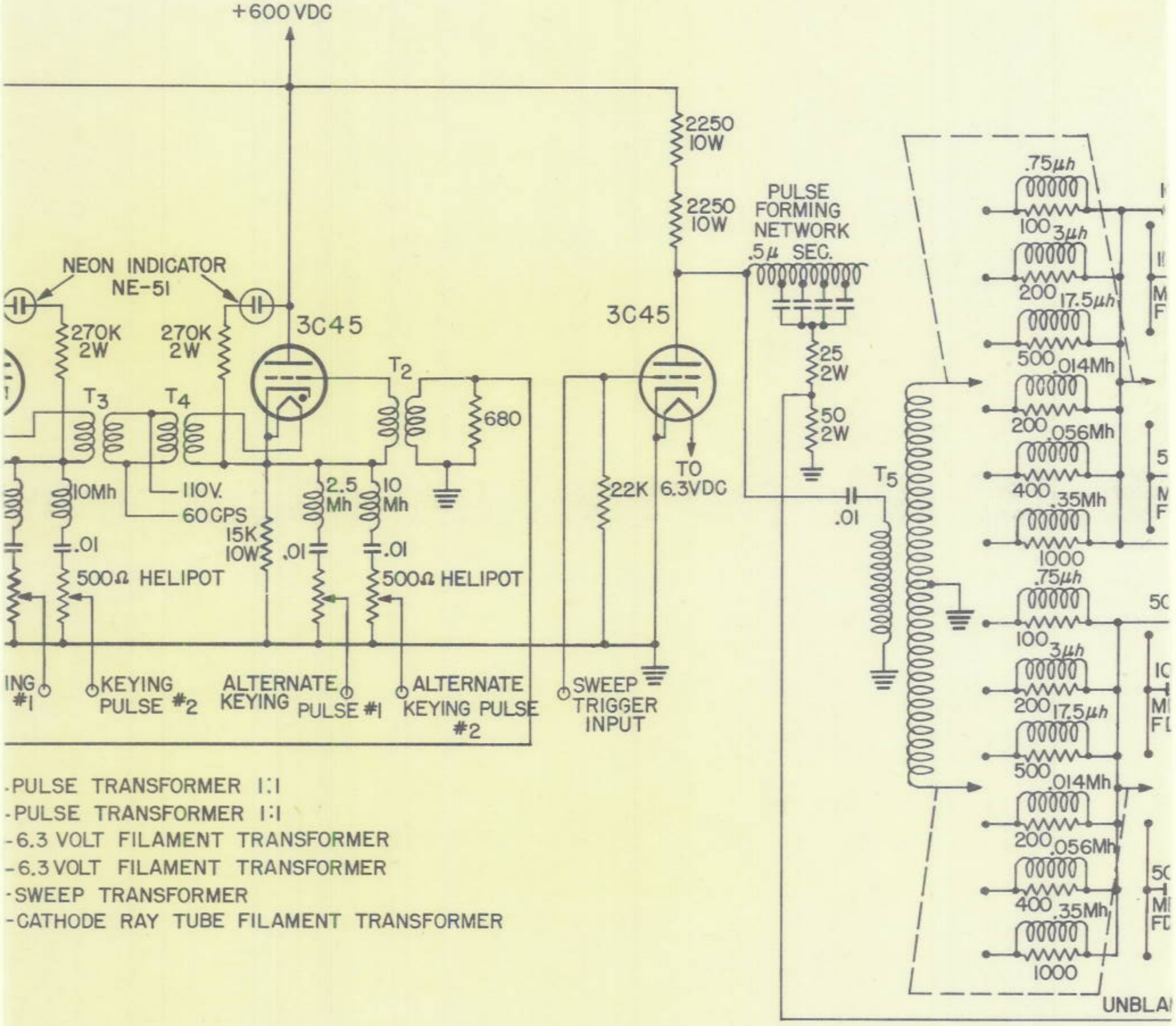


T_1-
T_2-
T_3-
T_4-
T_5-
T_6-

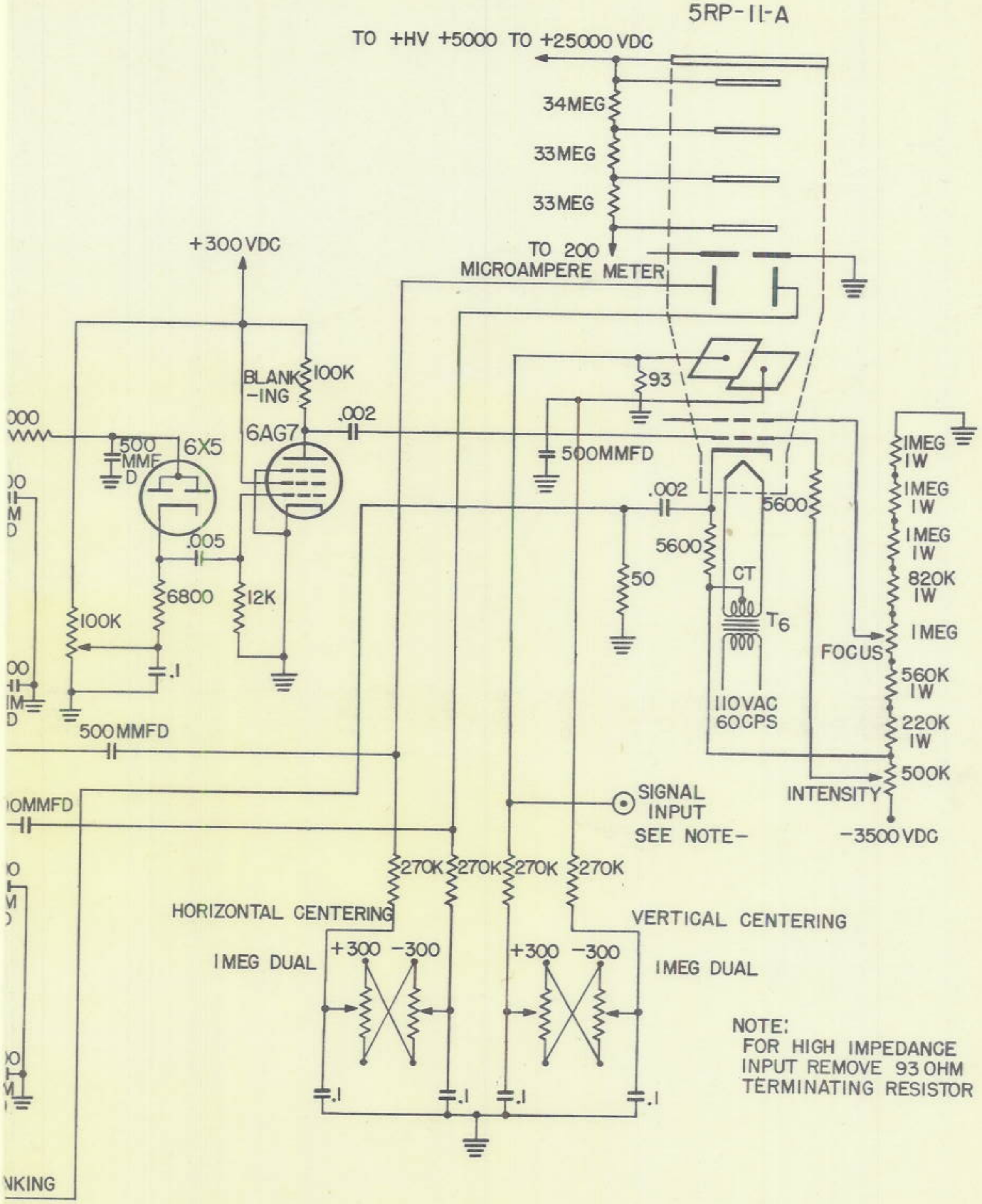
RESISTANCE IN OHMS UNLESS OTHERWISE INDICATED.
CAPACITANCE IN MICROFARADS UNLESS OTHERWISE INDICATED.

[redacted]



-PULSE TRANSFORMER 1:1
-PULSE TRANSFORMER 1:1
-6.3 VOLT FILAMENT TRANSFORMER
-6.3 VOLT FILAMENT TRANSFORMER
-SWEEP TRANSFORMER
-CATHODE RAY TUBE FILAMENT TRANSFORMER

Figure 23 - Schematic of trigger and sweep generators



NOTE:
FOR HIGH IMPEDANCE INPUT REMOVE 93 OHM TERMINATING RESISTOR

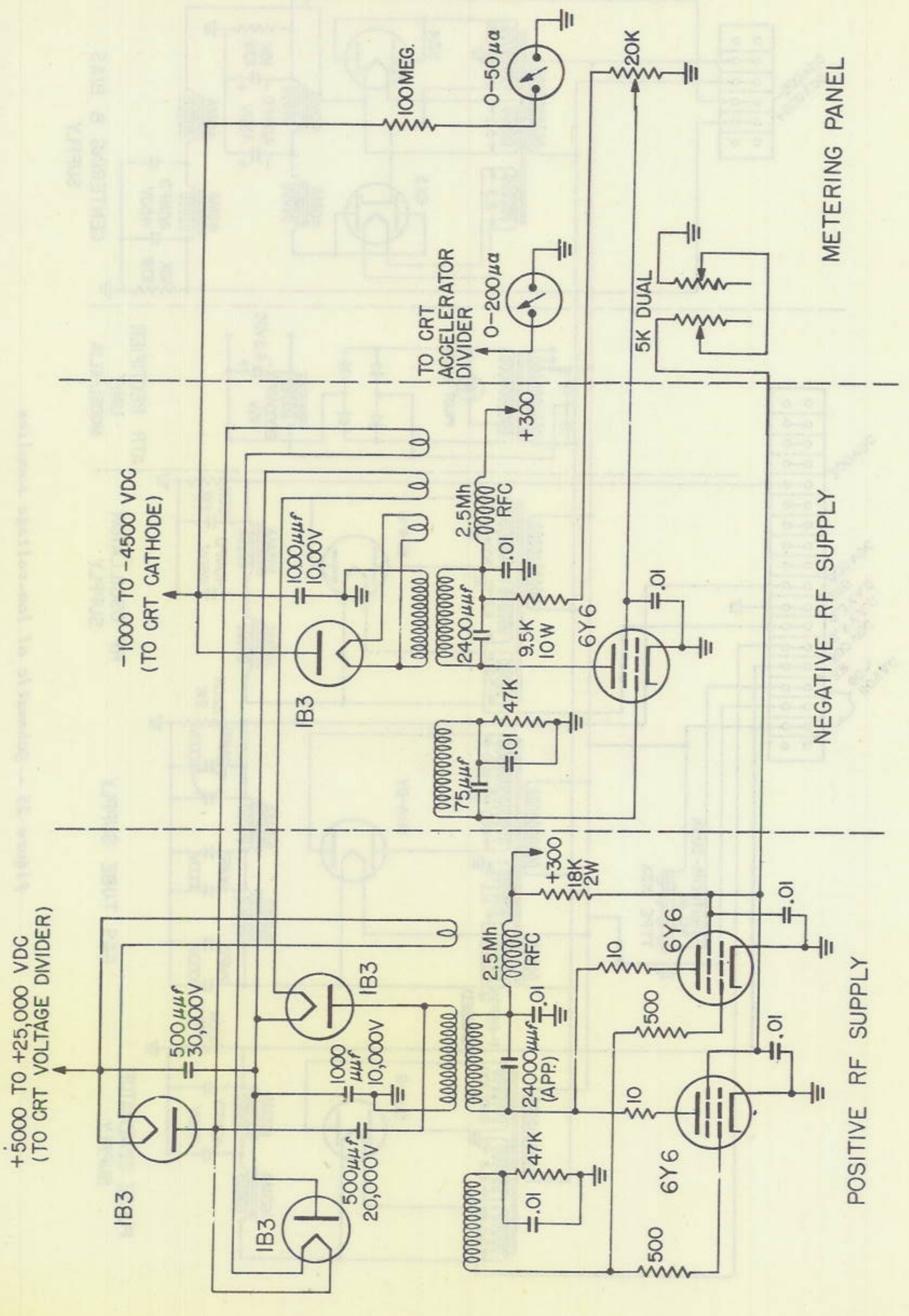


Figure 24 - Schematic of high-voltage supplies

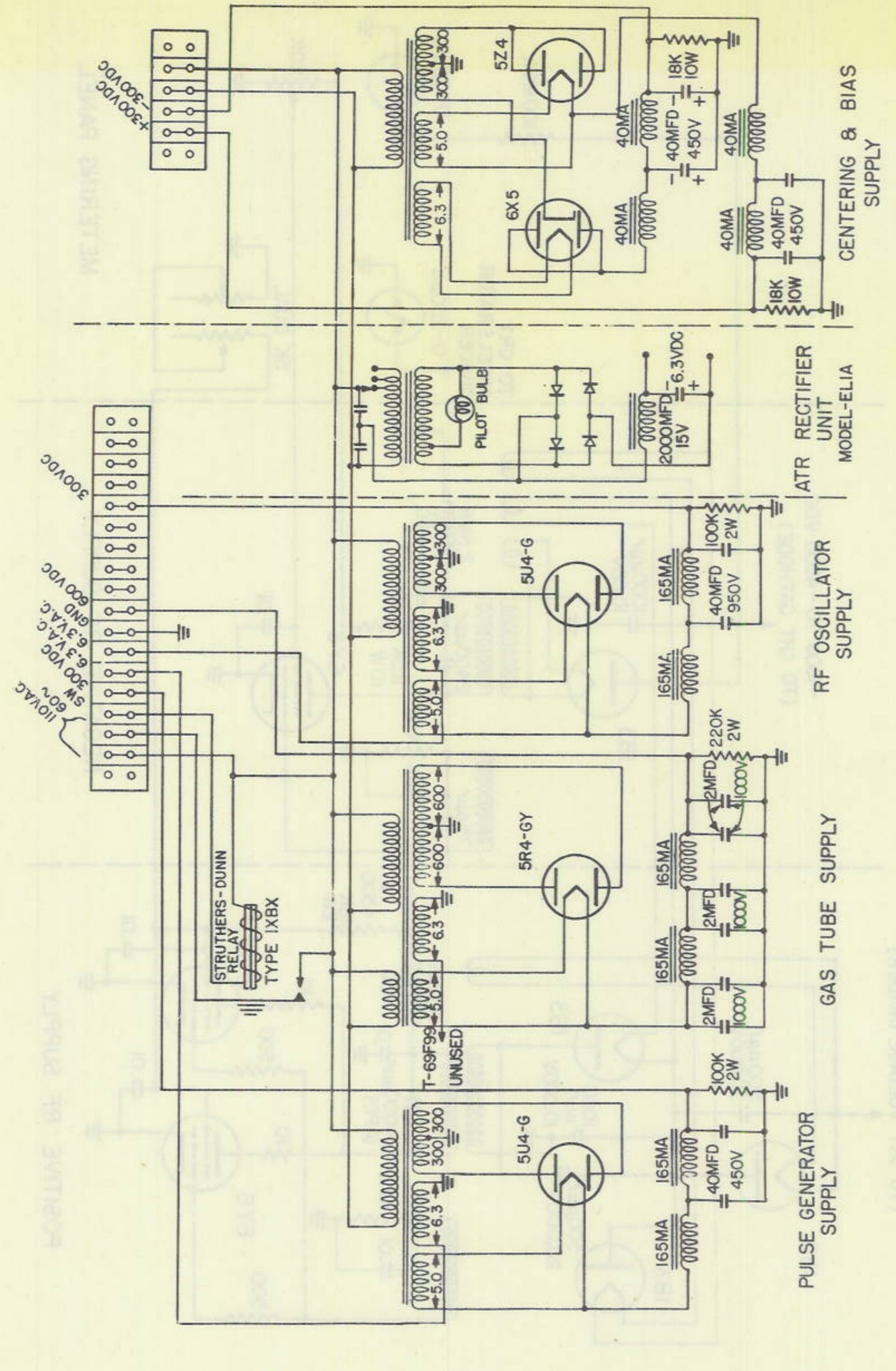


Figure 25 - Schematic of low-voltage supplies