APPLICATION OF FAST SWEEP SYNCHROSCOPE TO MEASUREMENT OF RAPIDLY RISING PULSES

D. F. WINTER AND O. T. FUNDINGSLAND

TECHNICAL REPORT NO. 27

JANUARY 21, 1947

RESEARCH LABORATORY OF ELECTRONICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

The research reported in this document was made possible through support extended the Massachusetts Institute of Technology, Research Laboratory of Electronics, jointly by the Army Signal Corps, the Navy Department (Office of Naval Research), and the ~~Army~~ Air Force~~s~~ (Air Materiel Command), under the Signal Corps Contract No. W-36-039 sc-32037.

Please Return to
David F. Winter

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Research Laboratory of Electronics

Technical Report No. 27 January 21, 1947

APPLICATION OF FAST SWEEP SYNCHROSCOPE TO MEASUREMENT OF RAPIDLY RISING PULSES

by

D. F. Winter and O. T. Fundingsland

Abstract

This report is concerned primarily with performance and applications of ~~the~~ Fast Sweep ~~Oscilloscope (or~~ Synchroscope) which was first described in M.I.T. Radiation Laboratory Report No. 1001 entitled "Winterscope or Fast Sweep Synchroscope". The salient features of the instrument are reviewed briefly. The sweep-phasing circuit has been modified to reduce time jitter between the sweep voltage and the output trigger pulse. In the improved circuit, phasing is accomplished at high level (1000 volts) by means of a tapped delay network, thereby eliminating all electronic stages between the trigger voltage source, a biased blocking oscillator, and the points of utilization which are the sweep thyratron grid and the output trigger voltage. With this circuit the output trigger pulse has no observable jitter on the 75 in./μsec sweep if the filament of the sweep thyratron is heated from a d-c supply. To demonstrate the utility of the Fast Sweep Synchroscope for studying magnetron starting behavior, a pulse generator has been built which produces an output pulse rising to 14 kv in less than 0.01 μsec on a 1000-ohm resistance load. A hydrogen thyratron driver is used with four 5D21's (tetrodes) to obtain this fast build-up of output pulse voltage. This pulser was used to modulate a 725A magnetron (3-cm wavelength) and the resulting plate current and plate voltage pulses were observed. Representative photographs are presented which show a form of magnetron instability indicated by time variations in plate current build-up. Other photographs show samples of individual successive voltage, current, and r-f envelope pulses from an unstable 10-cm magnetron. Also included are photographs of random noise generated in a 30-Mc/sec amplifier.

APPLICATION OF FAST SWEEP SYNCHROSCOPE TO MEASUREMENT OF RAPIDLY RISING PULSES

1. Introduction

The Fast Sweep Synchroscope originally described in RL Report No. 1001, "Winterscope or Fast Sweep Synchroscope", was designed to study individual voltage transients in the millimicrosecond region. To demonstrate the utility of this synchroscope for studying magnetron starting behavior, it was necessary first to modify the sweep phasing circuit to reduce time jitter between the sweep voltage and the output trigger pulse, and second, to build a special pulse generator. The salient features of the synchroscope ~~and certain improvements which have been made in the~~ sweep phasing circuit are presented ~~covered~~ in Sec. 2. Section 3 discusses the problems of designing a pulser circuit capable of generating rapidly rising high voltage pulses, synchronized precisely from the synchroscope output trigger pulse. Results are given in Sec. 4 in the form of photographs. Some of these show short, rapidly rising pulses obtained with both resistance and magnetron loads, while others illustrate additional applications including records of random noise generated in a 30-mc/sec amplifier.

2. The Oscilloscope

This oscilloscope is suitable for making photographic records of voltage transients in the millimicrosecond region. The time of transit of the electrons through the deflecting plates is computed to be between 2 and 3×10^{-10} seconds, which insures a signal amplitude reduction of less than 10 per cent at 1000 Mc/sec compared to a d-c deflecting voltage. Conventional low-voltage cathode-ray tubes are not satisfactory for measurements in this region as their transit times are in the range of 10^{-9} seconds or greater. Furthermore, the trace intensity of low-voltage tubes is not sufficient to record a single transient with a spot writing speed of more than 20 to 30 in./µsec. It can be shown (from consideration of spot size, deflection sensitivity, and time interval to be resolved) that a spot writing speed of 200 in./µsec is desirable to record photographically millimicrosecond transients. A special tube (type K1017) was designed for this oscilloscope by the A. B. Dumont Laboratory, Passaic, New Jersey. When operated with the cathode at -5 kv and the screen at +20 kv a signal of about 180 volts amplitude produces a deflection of one inch on the screen. Careful electron optical design and post deflection acceleration results in a finely focused spot of high intensity. The tube has its horizontal and vertical deflecting plate systems isolated from one another. Electrical contact with each plate in the shielded deflecting chamber is made through co-axial connectors in the neck of the tube. This precaution effectively eliminates electrostatic coupling between the horizontal and vertical deflecting plates at 1000 Mc/sec. Taking into account the spot size of this cathode-ray tube we find that a sweep speed greater than 50 in./µsec is needed to measure time intervals of 10^{-9} seconds to a precision of ±10 per cent.

Figure 1 is a block diagram showing the component circuits of the oscilloscope. The most important features of these circuits are described in some detail below.

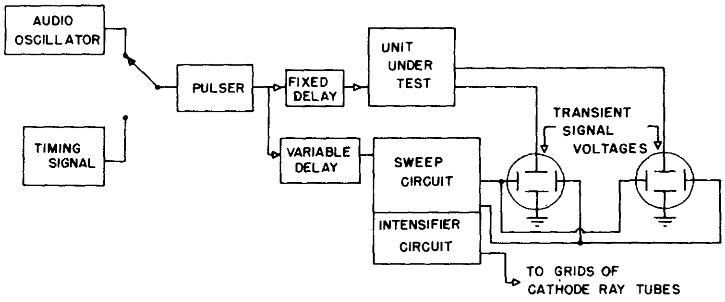


Figure 1. Block diagram of High Speed Oscilloscope.

The circuit employed to develop linear sweep speeds of 50-100 in./µsec is shown in Fig. 2. With $L = 0.8 R^2C$, the voltages of opposite sign at Ⓐ and Ⓒ will be linear functions within 5 per cent from $t = 0$ to $t = RC$. The value of the time constant RC is

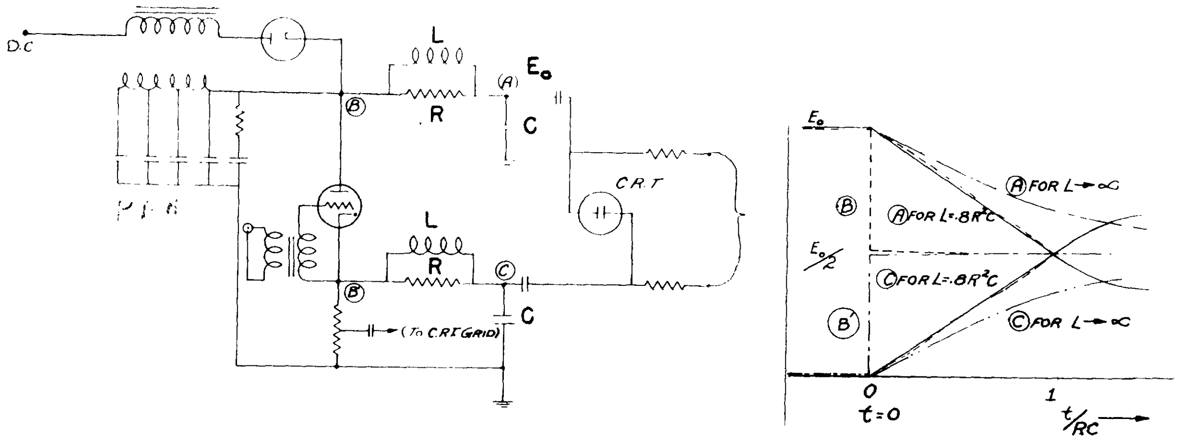


Figure 2. Sweep and intensifier circuit.

determined by the sweep speed required, the voltage sensitivity of the cathode-ray tube, and the supply voltage E_0. The voltage at (B') is a pulse of amplitude equal to $\frac{E_0}{2}$ which is coincident with the start of the sweep so that an appropriate portion may be used to gate the electron beam during the sweep. This pulse is applied to the cathode-ray tube grid and drives it almost to zero bias to obtain the maximum light output from the trace on the screen. After each sweep the circuit is recharged through the resonant choke and hold-off diode shown at the upper left. Linear sweeps from 0.1 to 100 in./µsec have been generated with this circuit. Repetitive sweeps to 2000 per second (or higher) as well as single sweeps can be obtained.

To synchronize the sweep and the voltage transient being studied, two trigger voltages are needed which are free of time jitter with respect to one another. In the experimental model of the synchroscope the phasing of these two trigger pulses was accomplished at low level. After being phased these two pulses triggered two independent, biased blocking oscillators, one to supply a voltage pulse to the sweep thyratron and the other to supply an output trigger pulse to initiate the transient. It was found necessary to reduce the time jitter in this scheme and after testing several other methods we decided to use a one-pulse source and do the phasing at high level by means of a tapped delay network. Figure 3 shows a 1500-volt biased blocking oscillator which may be run repetitively or used for a single pulse. The output of the transformer is fed into a lumped constant delay network which has a 0.25-μsec delay per section. The pulse coming out of the right end triggers the thyratron in the sweep circuit. The pulse reaching the left end is fed into a continuously wound delay line having a total delay of 0.8 μsec. The sliding contact on the continuously wound line, together with the switch on the lumped network, allow the two pulses to be continuously varied ± 5 μsec with respect to one another. High level phasing eliminates the difficulties of bias ripple, heater pickup, etc., which are present in electronic phasing schemes. With the circuit shown in Fig. 3 there is no observable time jitter between the sweep and the synchroscope output trigger pulse on a 75-in./μsec sweep, if d-c heater power is used on the sweep thyratron. For a-c thyratron heater power there is a small time variation, due to heater or cathode conditions, which amounts to about 1 or 2 x 10^{-9} seconds.

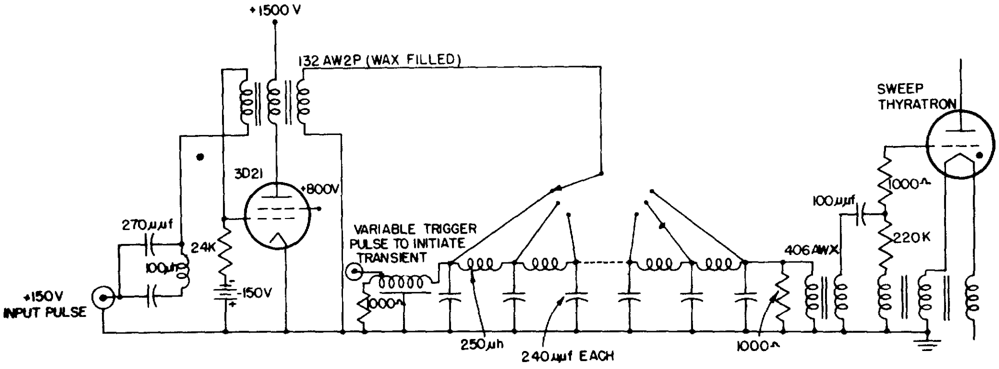


Figure 3. Sweep-phasing circuit.

~~Several~~ A picture~~s~~ of the completed oscilloscope ~~are~~ is shown in Figs. 13 and ~~14 and~~ a complete circuit ~~diagram is shown in Fig. 15~~. Photographic records are obtained on 35-mm Eastman Orthochromatic film No. 5211 by means of an f1.5 coated lens. Individual successive traces are obtained by running the film continuously and thus obtaining a record every time the beam is on. (The decay time constant of the screen is about 10^{-5} seconds and there is practically no smearing of the trace for the film speed needed to record 500 pulses per second). If it is desired to show two or more pulses superimposed, the camera can be momentarily stopped. The sample photographs shown in Figs. 7 through 12 have been enlarged from the 35-mm film; Eastman Kodabromide F5 paper was used to obtain maximum contrast.

This synchroscope may be used to study transient voltages which occur at repetition frequencies up to 2000 per second or it may be used for single transients as well. A six-position internal audio oscillator is provided as well as connections for an external oscillator and/or trigger pulse. There are four sweep speeds: (1) $\approx$ 1.3 in./μsec, (2) $\approx$ 7 in./μsec, (3) $\approx$ 17 in./μsec, and (4) $\approx$ 75 in./μsec. With new film and new cathode-ray tubes, single trace writing speeds up to 300 inches per μsec have been recorded.

3. Experimental Pulser

The need for a suitable instrument to study the starting behavior of a pulsed magnetron and the interaction between modulator and magnetron constituted the original motivation for the design and construction of the Fast Sweep Synchroscope described above. In order to demonstrate the utility of this synchroscope for observing magnetron starting behavior and for other applications involving measurements in the millimicrosecond region, we decided to build a pulser capable of generating high voltage pulses ($\doteq$ 12 kv) having a leading edge which approaches an ideal step function. Specifically, we ~~hoped~~ wanted to obtain a pulse having a rise time $\lesssim$ 0.01 μsec, with a linear rising edge and a sharp leading corner and with spurious ripples and other irregularities reduced to a minimum. Expediency dictated the use of a pulser switch which could be synchronized precisely from the synchroscope trigger pulse and a circuit as near to conventional design as practicable.

The basic problem in the design of a pulser for generating a fast rising voltage pulse is to obtain high current immediately after closing the switch, in order to charge the output capacitance to full value within the desired time of rise. Intrinsic limitations of the switch are therefore the first consideration. Spark gap switches generally Cannot be synchronized precisely with the leading edge of the trigger pulse. ~~do not satisfy synchronization requirements~~. To the best of our knowledge, enclosed triggered gaps cannot be synchronized to less than 0.01 μsec. Hydrogen thyratrons can be synchronized satisfactorily but have an inherent ionization time of the order of 0.02 μsec. Ionization time is also a limitation of spark gap switches but probably to a lesser extent in those of the open-air non-synchronous type. The objections to the above types of switches, the pulse-shaping limitations of lumped parameter pulse-forming networks (with a reasonable ~~finite~~ number of sections), and the imperfect response of iron core pulse transformers are significant factors which precluded the use of a line-type pulser for our purpose.

A conventional hard tube pulser[1] output circuit consisting of a high voltage storage capacitor and a vacuum tube switch (preferably a tetrode) proved to be suitable. The chief limitations of this type of switch for obtaining rapidly rising pulses are that the tube cannot be turned on instantly with any practically designed driver circuit, and that the plate current obtainable from the tube cannot exceed a certain maximum value.

If, as a first approximation, we assume that the switch can be turned on instantly to full current, the value of the current required for a given rise time of the output pulse can be estimated from the relation

$$I \approx \frac{CV}{t} + \frac{V}{2R} \qquad (1)$$

---

[2] G. N. Glasoe and J. V. Lebacqz, "Pulse Generators", MIT RL Series, Vol. 5, McGraw-Hill, 1947.

where C = the output shunt capacitance (including that of the load)
R = the load resistance
V = the maximum pulse voltage across the load
t = the time of rise.

For example, with C reduced to a minimum of say 30 μμf and R = 1000 ohms, the current required for a rise time of 0.01 μsec and maximum voltage of 12 kv is approximately

$$I \approx \frac{30 \times 10^{-12} \times 12 \times 10^{3}}{10^{-8}} + \frac{12 \times 10^{3}}{2 \times 10^{3}}$$

$$\approx 42 \text{ amp.}$$

The rate of build-up of plate current, however, depends directly upon the rate of rise of grid voltage which in turn is determined by the instantaneous power delivered from the driver circuit to the grid input conductance and susceptance of the switch tube. During the positive swing of grid voltage the grid current may become excessive, thus requiring a driving voltage source with very low internal impedance to maintain a rapid rise of grid voltage. In a practical circuit the time required for the plate current to build up may be comparable to the rise time desired for the load voltage pulse. Hence, the actual current required in the output circuit to give a specified time of rise is greater than the value indicated by Eq. (1), the correction factor depending upon the characteristics of the driver and the equivalent input circuit of the vacuum tube switch.

Because of this high current requirement and other considerations we decided to build a hard-tube pulser, using several 5D21 tubes in parallel for the pulser switch. With the 5D21's biased considerably beyond cut-off only a small fraction of the driver pulse amplitude is effective in producing positive grid swing on that part of the e_g-i_p characteristic which corresponds to the steep rise of plate current (i.e. where $\frac{\partial i_p}{\partial e_g}$ is high), hence the total time of rise of the driver pulse may be appreciably greater than the rise time of the output pulse to the load.

For our driver circuit, we therefore decided to use a line-type pulser circuit with a 3C45 hydrogen thyratron switch. To avoid the use of a pulse transformer a positive pulse was obtained from a 1000-ohm resistor connected between ground and the thyratron cathode which was capacity coupled to the 5D21 grids. The choice of optimum number of output switch tubes depends upon several factors:

(1) For these short times, the instantaneous current needed to charge the distributed capacity of the load is more than one tube can supply.

(2) Adding more tubes to obtain more output current necessarily increases the loading of the driver by the grid input circuit of the 5D21's.

(3) The exact nature of the e_g-i_p curves for these short pulses is not known and one can only extrapolate from data obtained with longer pulses.

(4) The variation of thyratron impedance as a function of time is not known accurately, and most reasonable assumptions add a non-linear element to the circuit problem.

It is difficult to establish criteria for determining experimentally the optimum number of switch tubes. For example, a very rapidly rising pulse can be obtained with two or three tubes when the grid drive is excessive. The leading corner of the pulse is not square, however, but has a spike of about 10-20 per cent amplitude and several millimicroseconds' duration. If a flat top pulse is desired, the grid drive must be reduced, and a slower rising pulse results. Depending on the particular shape desired, the optimum number of tubes is somewhere between two and six.

After some preliminary tests with one and two 5D21 tubes on a breadboard model, the circuit shown in Fig. 4 seemed satisfactory, and we decided to construct a large unit with provision to use a maximum of eight 5D21's in parallel, with a single 3C45 driver. It should be pointed out that the various circuit constants indicated in the figure are not necessarily considered to be optimum values. We did not pursue analysis and experimentation with the circuit more than was necessary to meet our design objectives, and we were not particularly concerned with economy in power and other engineering refinements which are of secondary importance in a temporary laboratory unit.

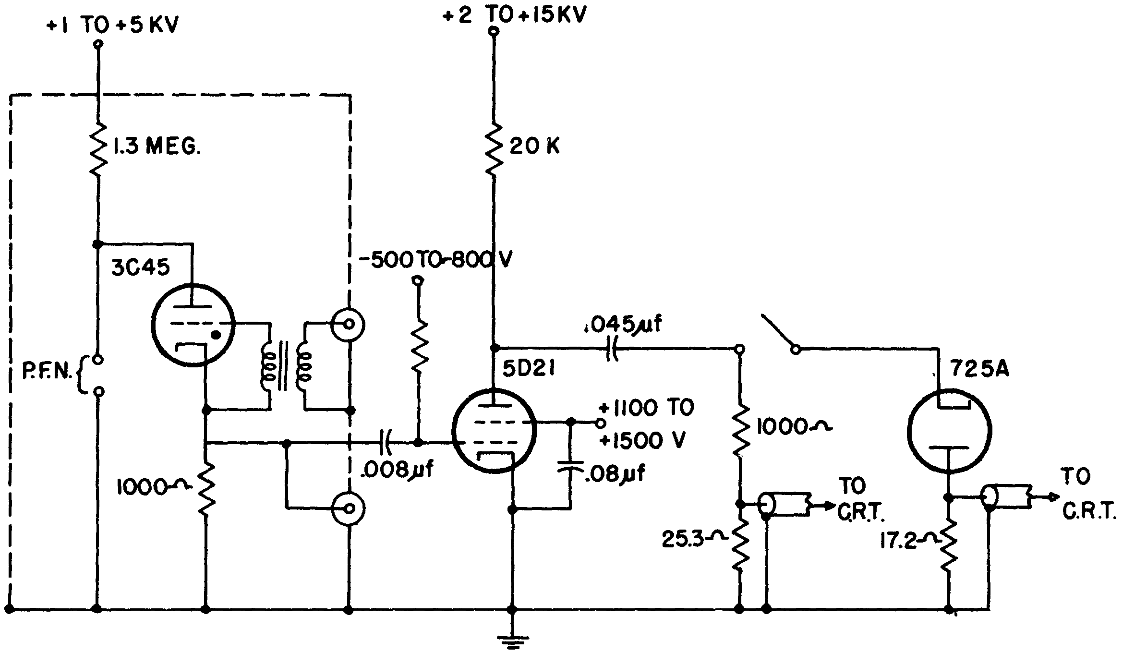


Figure 4. Pulser circuit.

The driver is enclosed in a separate copper housing to insure adequate shielding against "pick-up" in the viewing system. Several pulse-forming networks were tried. For long pulses best results were obtained with a length of Federal Telephone and Radio cable RG71/U with a small capacitance connected in parallel with the cable output. For very short ($\approx$0.01 µsec) pulses we used a capacitance of 100-500 µµf connected in series with a parallel L-R corrective network[2].

Inductance of connecting leads is minimized by the symmetrical arrangement

---

[2] O. T. Fundingsland and G. J. Wheeler, "Constant Current Circuits", Electronics, 19, pp. 130-133, November 1946.

illustrated in the sketch of Fig. 5. The control grids of the 5D21 tubes are connected through individual small resistors to a common "drive" ring. The screen grids are likewise connected to a common ring and a mica capacitor bypasses each screen to cathode as close to the tube as possible. The plates are all connected to a single conductor which supports the output high voltage capacitor.

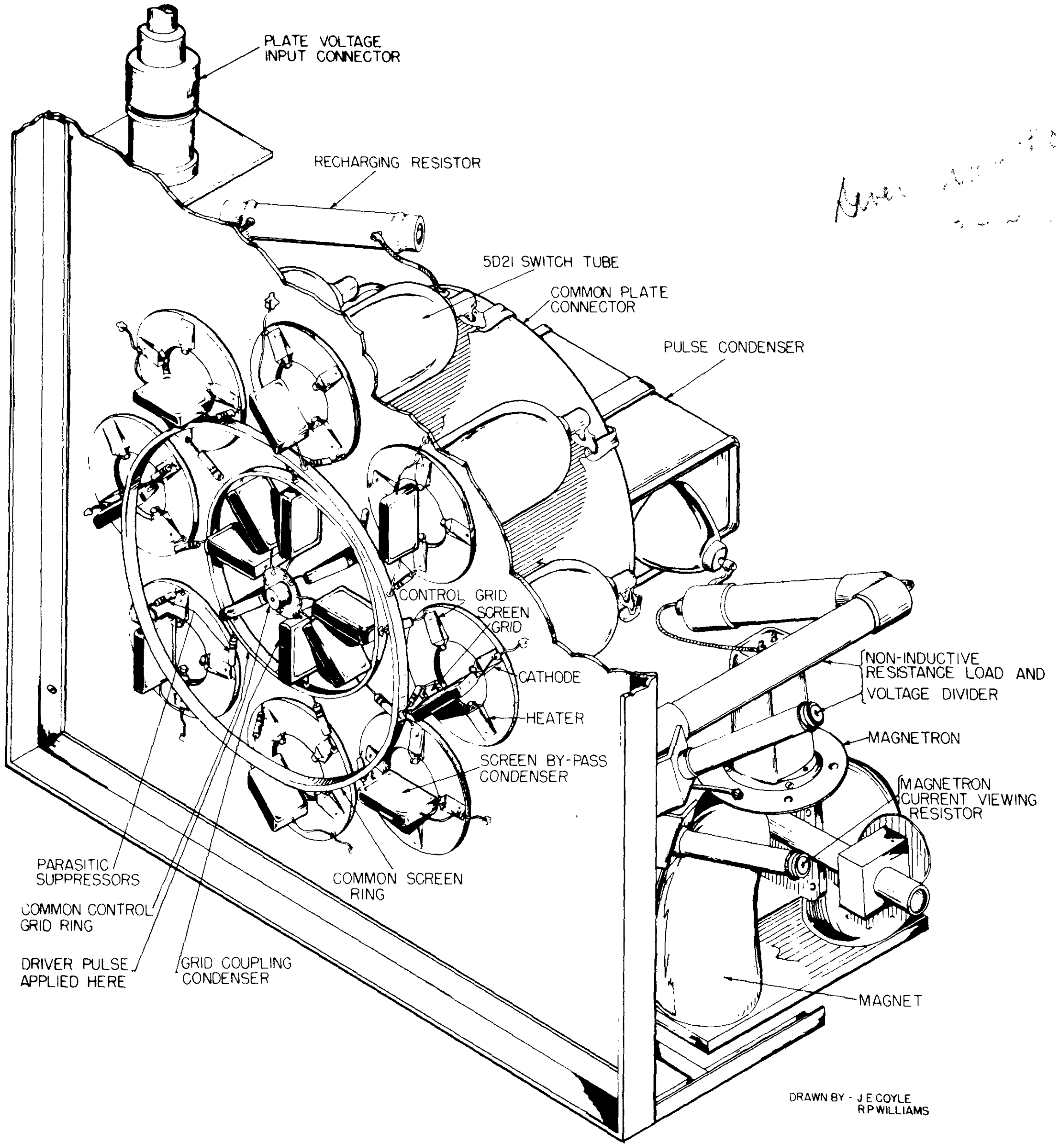


Figure 5. Pulse generator and load.

The resistance load consists of two 500-ohm WE six-inch tubular carbon-ceramic resistors in series with a 25-ohm BTL coaxial "current-viewing" resistor [3].

A similar coaxial current-viewing resistor is connected in series with the ground return of the magnetron. When the magnetron is connected the resistance load also serves as a voltage divider for viewing the magnetron voltage.

The pulses are transmitted to the synchroscope through three-foot lengths of shielded coaxial cable (Federal Telephone and Radio RG71/U). The signal delay in such a cable is comparable to the rise times to be measured. Therefore, in order to avoid undesirable reflections, it was necessary to match closely the characteristic impedance of the cable, by means of a shunt resistance at the cathode-ray tube. The cable impedance measured under pulse conditions was found to be 95 ± 1 ohms.

4. Experimental Results

Figure 6 shows a 15-kv pulse obtained with two 5D21 tubes operating into a 1000-ohm resistance load. This pulse was viewed on a MIT Radiation Laboratory Model 5 synchroscope which had been modified to produce a sweep speed of about 9 in./μsec. The rise time appears to be less than 0.005 μsec (measured from 10 per cent to 90 per cent amplitude) and the duration at 90 per cent amplitude is about 0.01 μsec. The pulse repetition frequency was 2000 per second. This photograph, however, may not be a true representation of the actual pulse because we were crowding the upper frequency limit for which low voltage cathode-ray tubes are considered satisfactory. For example, there may have been high frequency oscillations or other irregularities on the actual pulse which were smoothed out in this presentation. Furthermore, the coupling between signal plates and sweep plates on the cathode-ray tube may be sufficient to affect the apparent rate of rise of the pulse even though no gross "cross talk" involving backward motion of the sweep is obvious.

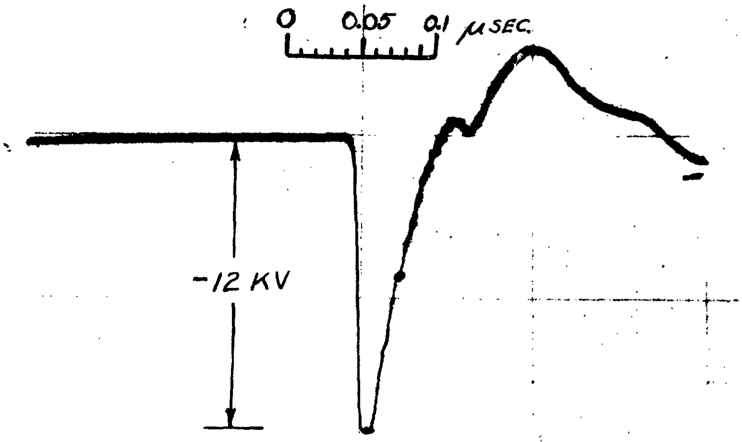


Figure 6. Voltage pulse on 1000-ohm load (leading edge retraced because of low intensity of trace on Model 5 synchroscope).

---

[3] Glasoe and Lebacqz, op. cit., Appendix A.

A 725A magnetron (3-cm band) was connected in parallel with the resistance load without otherwise changing the circuit or the operating voltages. The added capacitance of the magnetron and its filament transformer caused some decrease in the voltage rate-of-rise, but the magnetron failed to "fire"; i.e. no conduction current flowed and no r-f output radiation was detectable. Apparently the magnetron behaved only as a capacitance. The only observable current was proportional to the rate-of-rise of applied voltage and when the amplitude of the applied voltage was varied the current did not change in accordance with the dynamic impedance characteristic for normal conduction current during oscillation. Even with appreciably higher voltage than is normally applied to the tube it was necessary to increase the pulse duration to more than 0.02 μsec at 90 per cent amplitude before a true conduction current appeared and r-f radiation was detectable.

The remaining photographs (Figs. 7 through 12) were obtained with the fast sweep synchroscope. The pulser was adjusted to produce pulses of longer duration to insure normal magnetron operation. Figure 7 shows the voltage pulse with the resistance load only, on both slow and fast sweeps. The pulse repetition frequency was 60 per second.

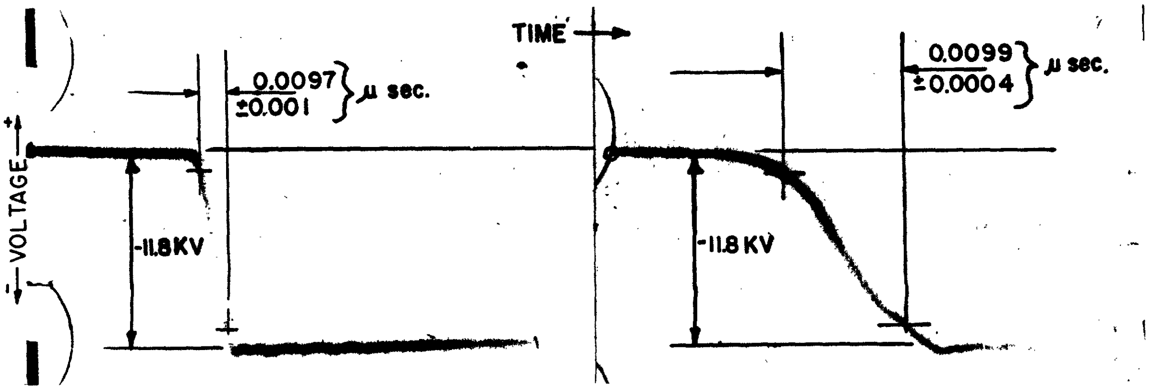


Figure 7. Voltage pulse on 1000-ohm load.

Figure 8 shows corresponding magnetron current and voltage pulses with the same circuit condition. The amplitudes and rise times are indicated on the photographs. Measurements were made from full size prints with the aid of a drafting machine.

Reducing the grid drive effected a slower rising pulse, and induced the magnetron instability illustrated in Fig. 9. This instability does not appear to be mode jumping, because the final amplitudes of voltage and current are the same on all pulses. However, it is clear that the main build-up of conduction current occurs at two distinct times on different cycles, with reference to the applied voltage pulse. The lower left photograph of this figure gives a much better resolution of the fine structure in the region where the current differs on different cycles. Small variations in the leading corner of the voltage pulse are also apparent. Other forms of magnetron instability were observed when the circuit conditions were varied over a wider range.

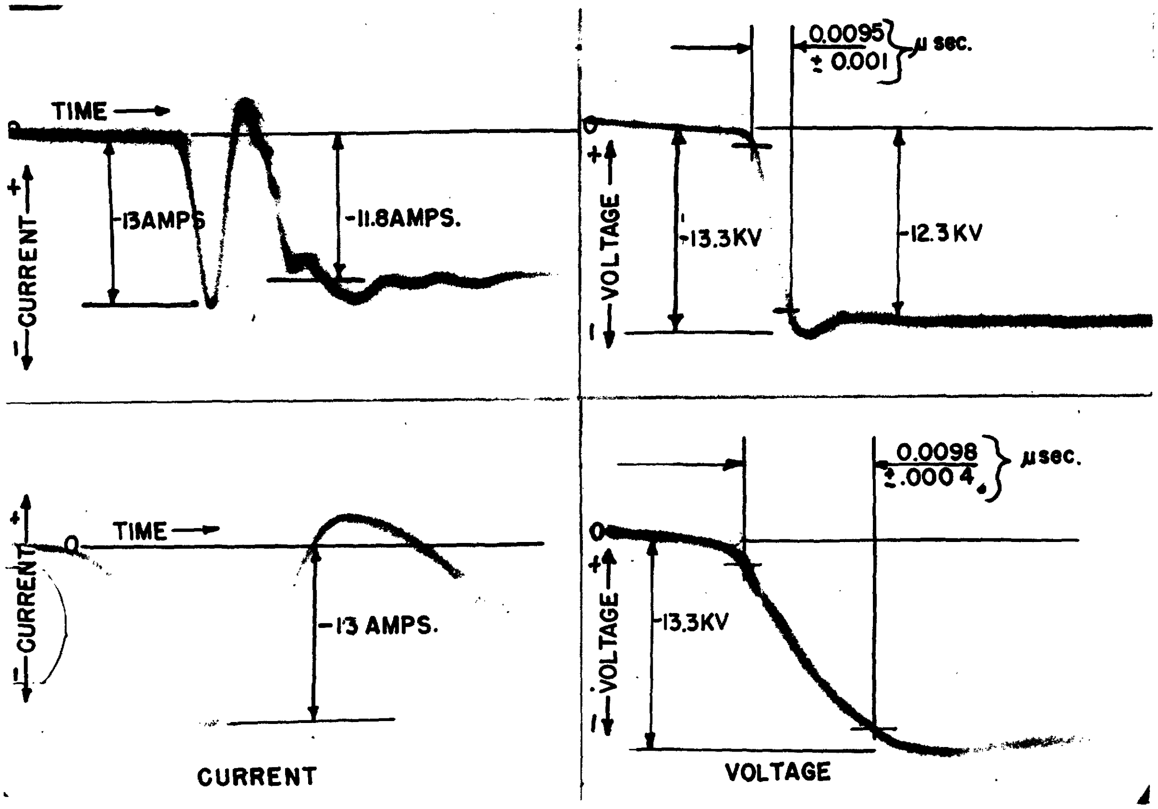


Figure 8. Pulses on 725A magnetron load.

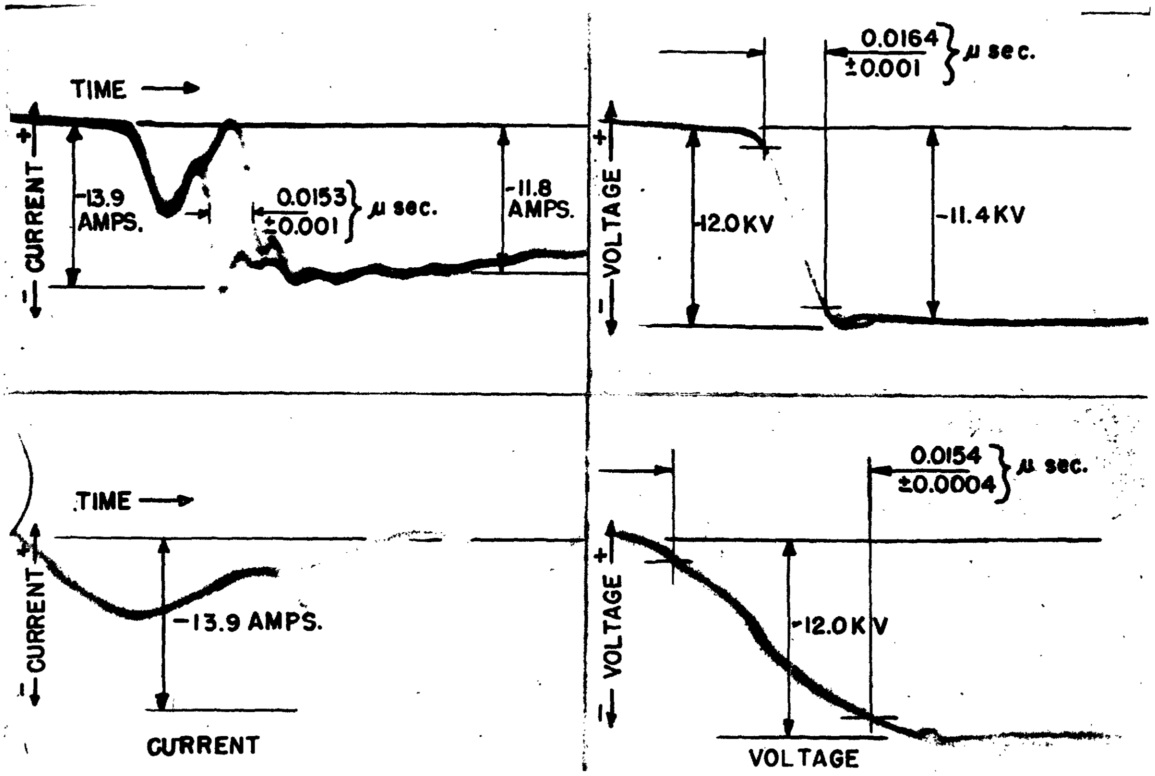


Figure 9. Pulses on 725A magnetron load with reduced grid drive.

Figure 10 is a sample of records of individual successive pulses from a modified line-type pulser applied to a 10-cm magnetron. Pulses shown in Columns 1 and 3 are magnetron plate current, those in Column 2 are magnetron plate voltage, and those in Column 4 are 10-cm radio-frequency envelopes. These pulses recur at 3300-microsecond intervals. Marked differences in plate voltage and current due to sparking and variations in r-f build-up are apparent. [Some work on magnetron [illegible] is being done at present (by a group at the M.I.T. Research Laboratory of Electronics)]

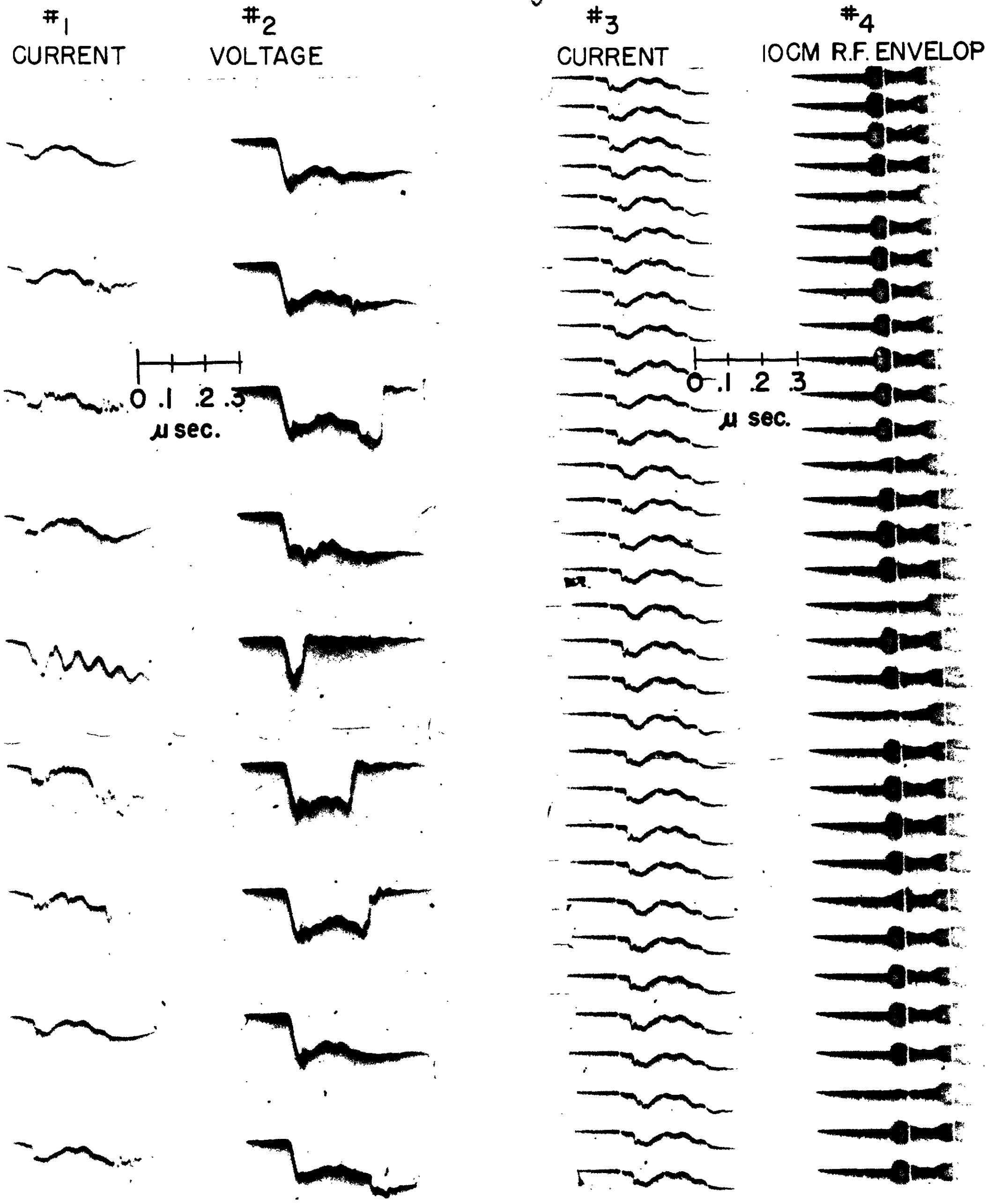


Figure 10. Pulses on HK7 magnetron load.

Figure 11 shows how the output of a 30-Mc/sec amplifier is affected by random noise generated in the first stage. The 30-Mc/sec equipment was supplied by G. E. Duvall (MIT Research Laboratory of Electronics).

amplifier is in constant operation and the sweep was run at a 60-cycle/sec repetition frequency.

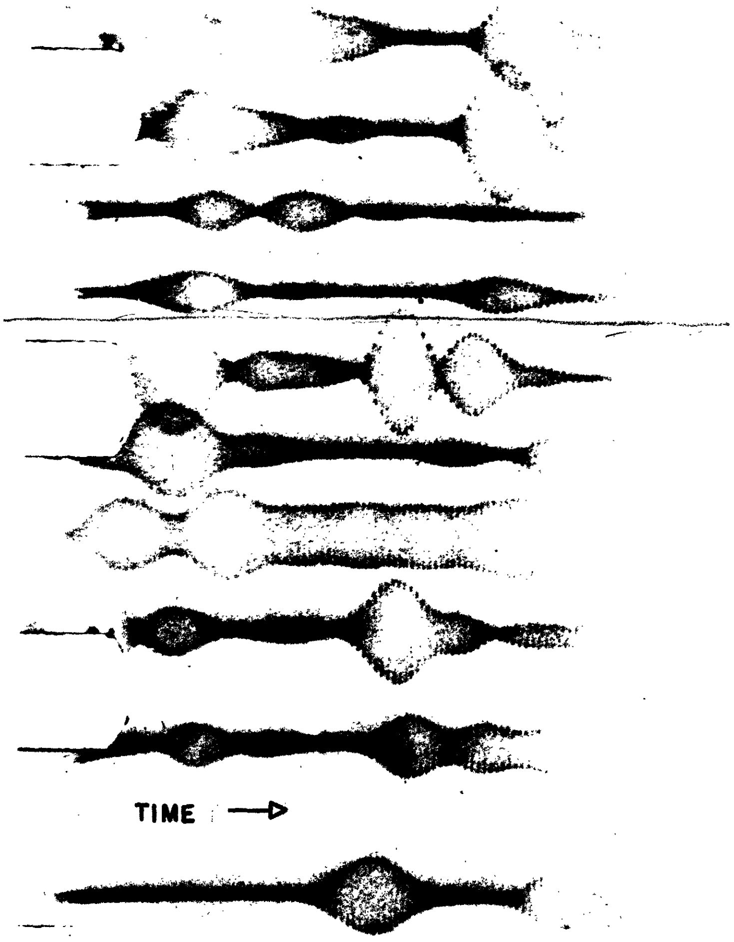


Figure 11. Output of a 30-Mc/sec amplifier modulated by random noise.

This oscilloscope can also be used to study repetitive transients which occur at irregular intervals. Figure 12 shows several sweeps on which no signal appears and only two where the transient happened to occur during the sweep interval. These pictures were obtained from a capacitor which was discharged by a mechanical switch into a resistance load. The oscilloscope sweep and mechanical switch were run from the same 600-cycle source but the mechanical switch had an inherent time jitter of ± 2 μsec.

5. Conclusion

The photographs of voltage transients presented here serve as an indication of some of the types of problems which can be studied with the aid of the Fast Sweep Synchroscope. While the primary objective in the design of the synchroscope was to

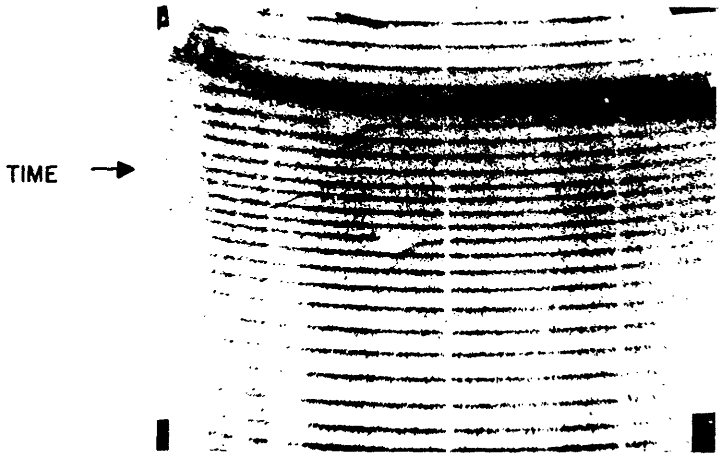


Figure 12. Non-synchronous pulses
(condenser discharged by a mechanical switch)

provide a method of recording high speed voltage transients such as those encountered in radar transmitters, an attempt has been made to make this instrument as flexible as possible and already several applications outside of the original field have been made. Provisions for direct access to the cathode-ray tube deflecting plates and control grids make possible a wide variety of applications where sweep voltages other than those already available might be used.

In their present form, the synchroscopes show some trace defocussing at sweep repetition frequencies above 2000 per second. This difficulty can probably be eliminated by readjusting time constants of circuits associated with the control grid. There is a small amount of vertical centering modulation (0.01 to 0.03 in.) at 60 cycles whose source we have been unable to determine.

Although the calculated transit time is small enough to give a 95 per cent response to a 1000-Mc signal, we have not tested the synchroscope to its limit of time resolution in pulse measurements because of the inherent limitations of pulse generators and auxillary pulse-viewing equipment. Specifically no video amplifier has yet been designed with a 1000-Mc bandwidth for amplifying low voltage signals, and in order to construct high voltage pulse attenuators with adequate frequency response (balanced time constants), it would be necessary to design special high voltage resistors and capacitors which have small physical size and whose distributed inductance and capacitance are made negligibly small. Other considerations include the viewing cable frequency characteristics and the impedance-matching problem. Our experiments have demonstrated satisfactory performance of the Fast Sweep Synchroscope within the limitations of the auxiliary apparatus described in this report and conventional pulse-viewing systems.

The assistance of Mr. L. A. Harris in the development of the sweep-phasing circuit and the work of Messrs. S. R. Ames and A. M. Belinski in the construction and testing of these two synchroscopes are gratefully acknowledged. We also wish to express our appreciation of the friendly interest of many others both inside and outside the Research Laboratory of Electronics.

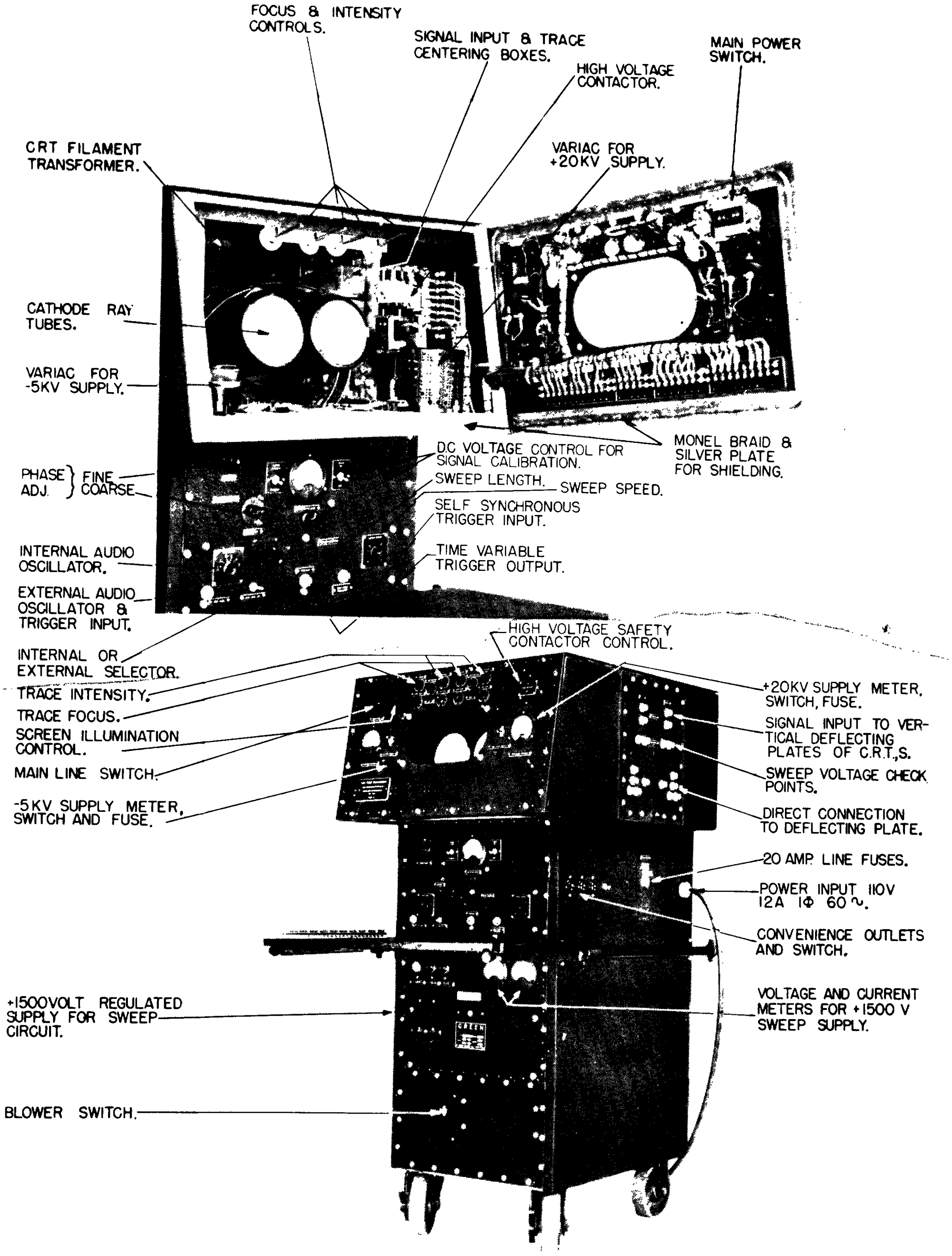


Figure 13. Fast Sweep Synchroscope, front view.

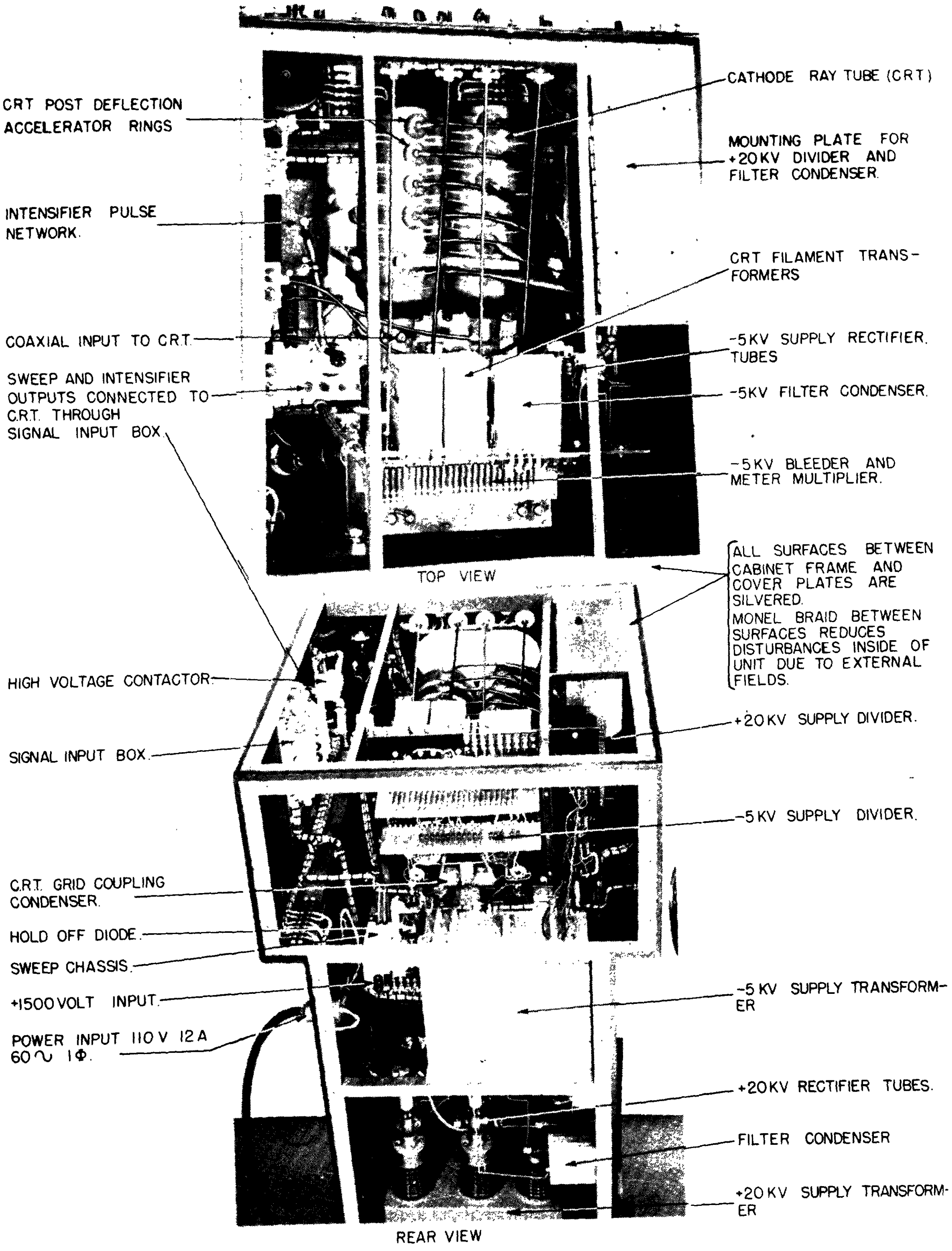
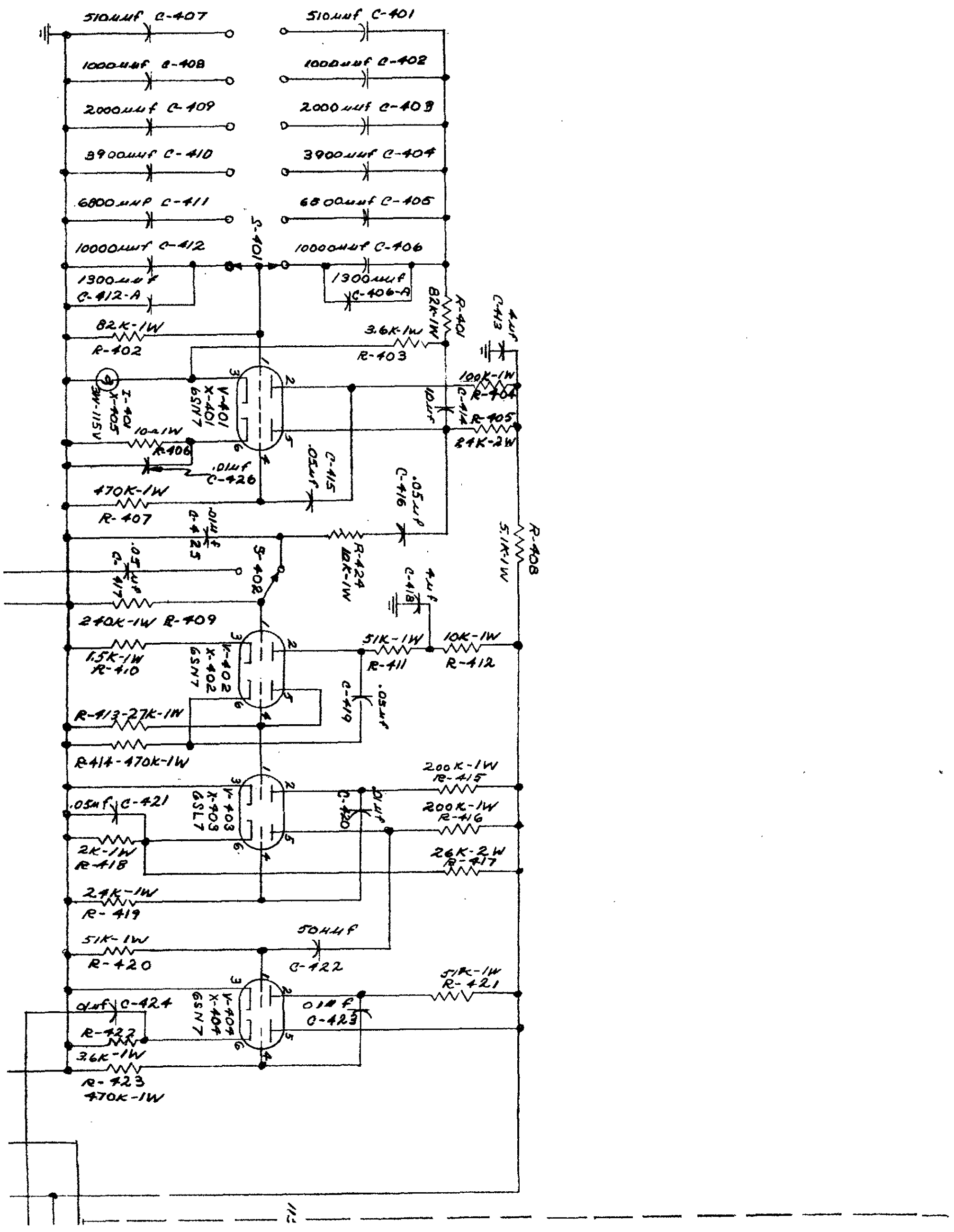
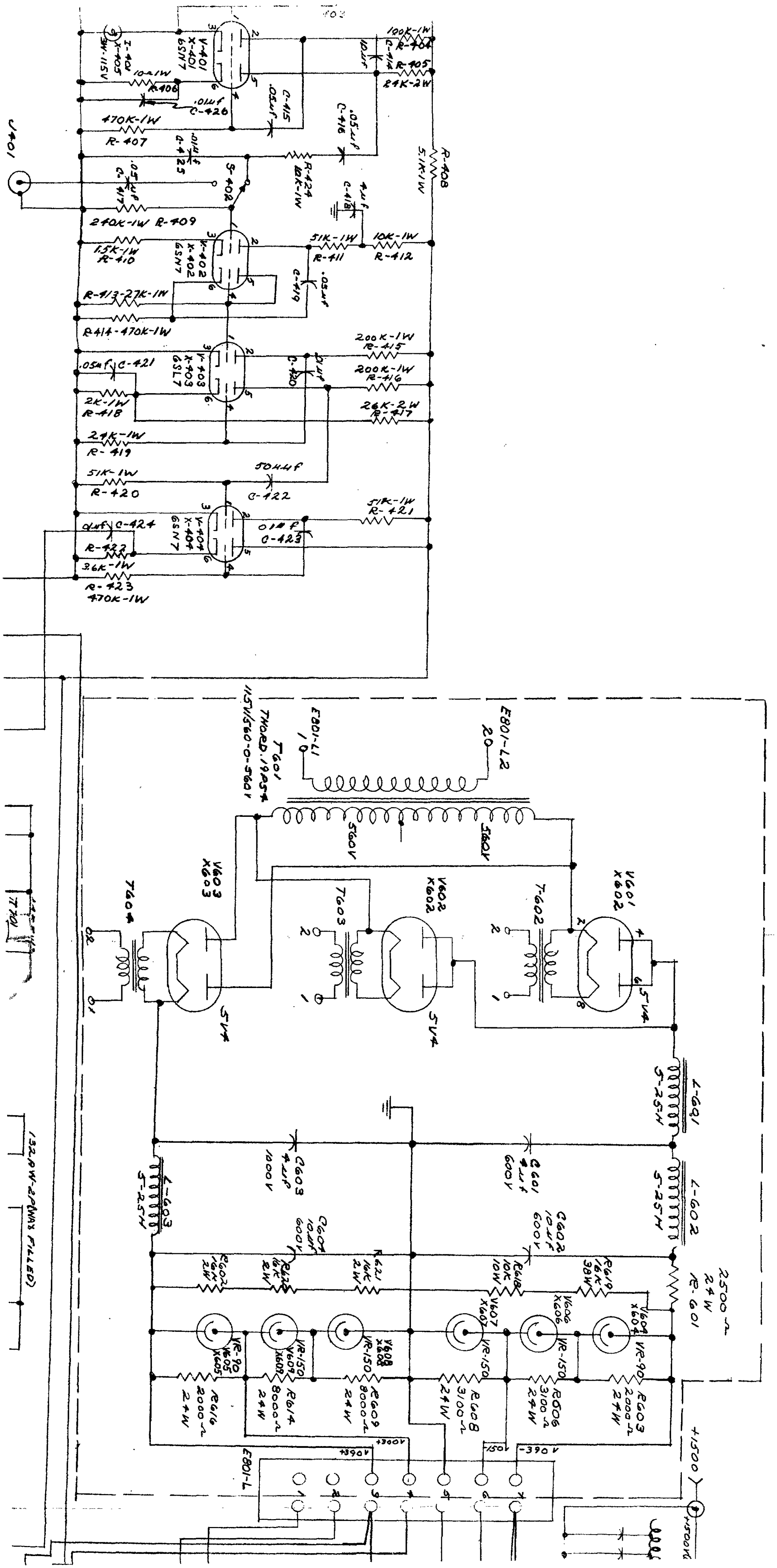


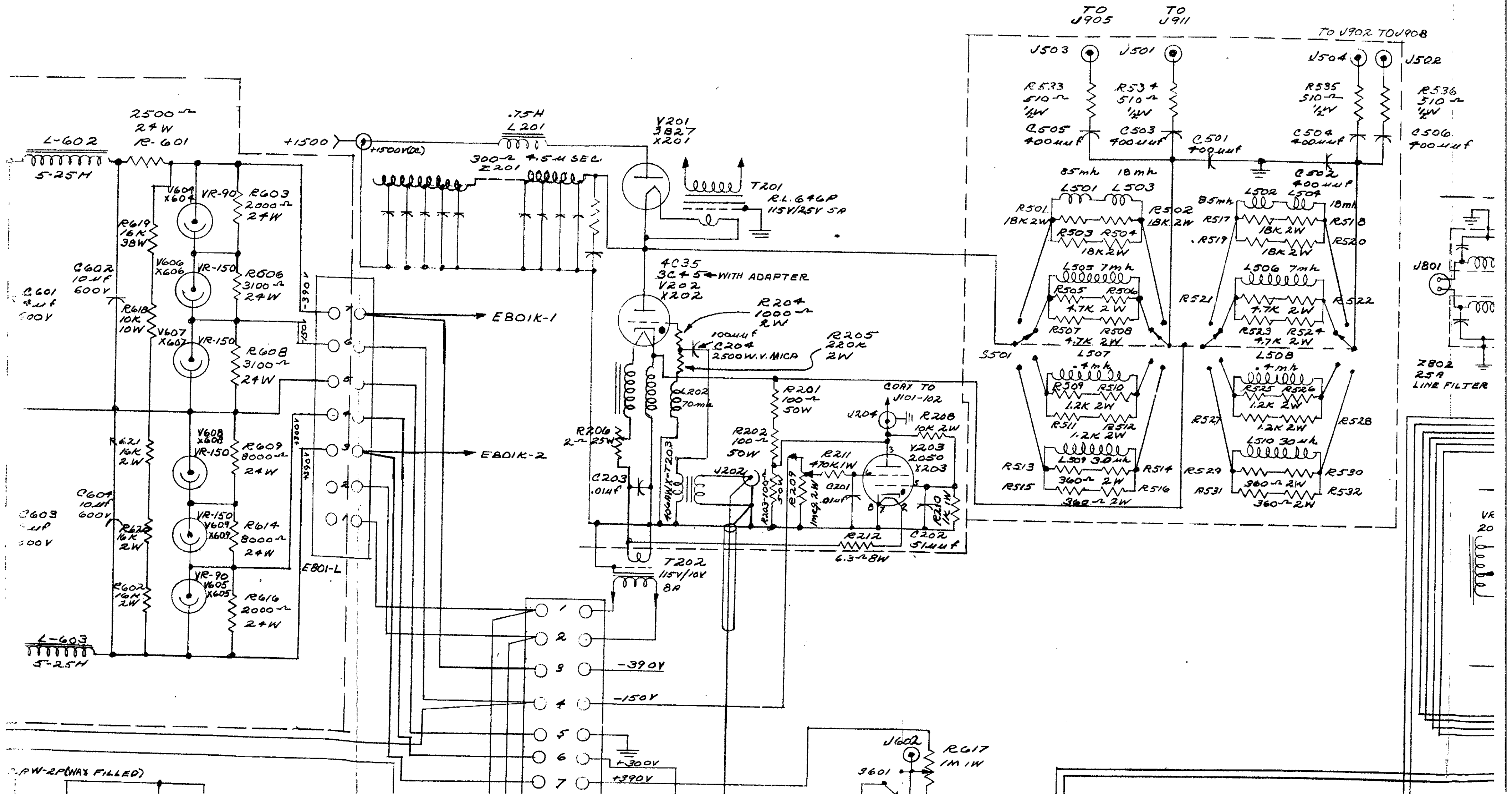
Figure 14. Fast Sweep Synchroscope, top and rear views.

TOP-1


510μμf C-407
1000μμf C-408
2000μμf C-409
3900μμf C-410
6800μμf C-411
10000μμf C-412
1300μμf C-412-A
510μμf C-401
1000μμf C-402
2000μμf C-403
3900μμf C-404
6800μμf C-405
10000μμf C-406
1300μμf C-406-A
S-401
82K-1W R-401
82K-1W R-402
3.6K-1W R-403
4μf C-413
100K-1W R-404
10μf C-414
R-405 24K-2W
I-401 X-405 115V-6W
V-401 X-401 6SN7
10Ω-1W R-406
.01μf C-426
.05μf C-415
470K-1W R-407
.01μf C-425
.05μf C-416
R-424 12K-1W
R-408 5.1K-1W
.05μf C-417
S-402
4μf C-418
240K-1W R-409
1.5K-1W R-410
V-402 X-402 6SN7
51K-1W R-411
10K-1W R-412
.05μf C-419
R-413-27K-1W
R-414-470K-1W
200K-1W R-415
200K-1W R-416
26K-2W R-417
V-403 X-403 6SL7
.05μf C-421
.01μf C-420
2K-1W R-418
24K-1W R-419
51K-1W R-420
50μμf C-422
V-404 X-404 6SN7
51K-1W R-421
.01μf C-424
.01μf C-423
R-422 3.6K-1W
R-423 470K-1W
1
2
3
4
5
6

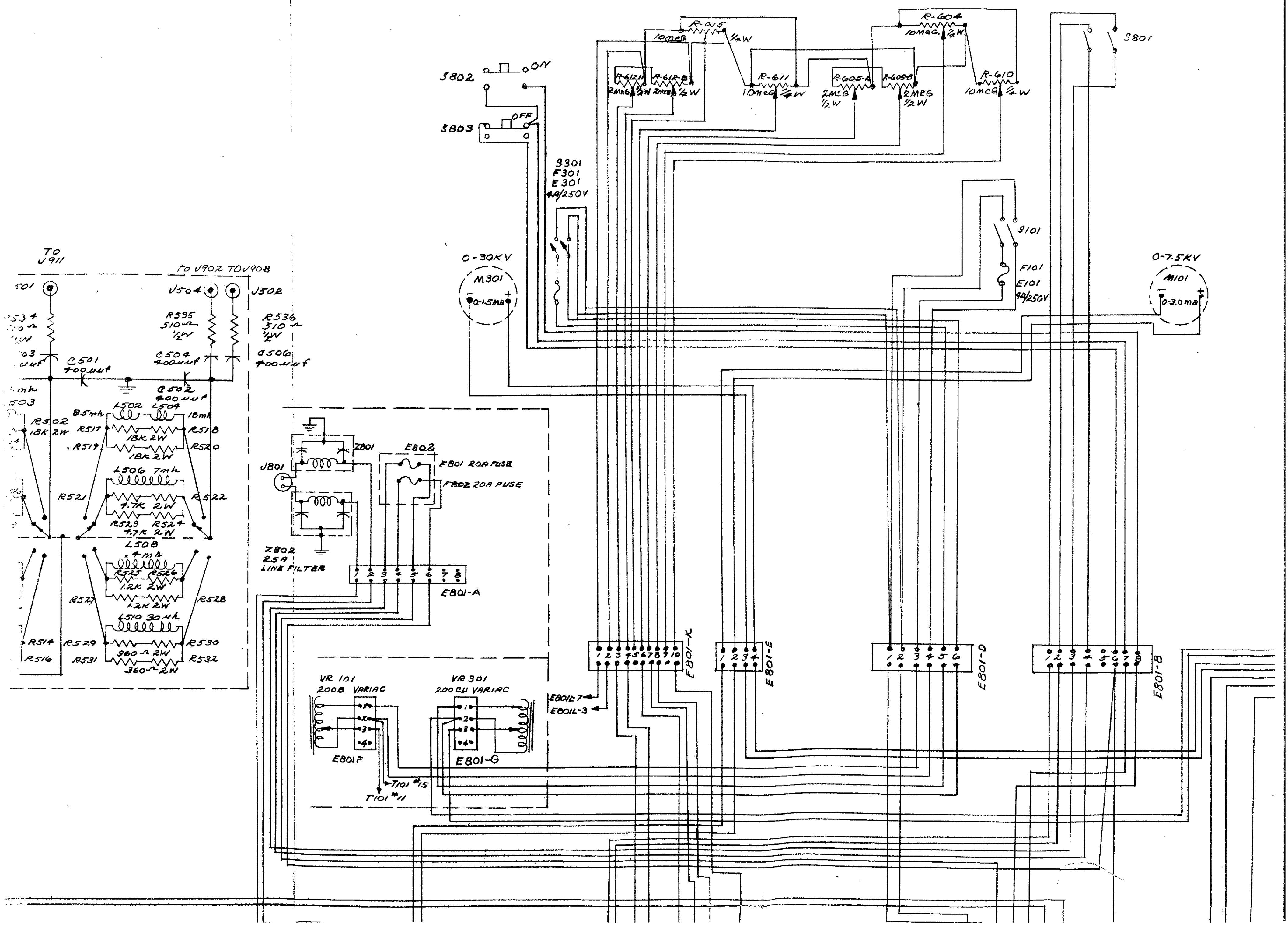

TOP-2
J401
V-401 X-401 6SN7
I-401 X-405 115V-W
10Ω-1W
R-406
.01uf C-426
C-415 .05uf
470K-1W
R-407
.01uf C-425
.05uf C-416
100K-1W R-404
10uf C-414
R-405
24K-2W
R-408 5.1K-1W
S-402
R-424 82K-1W
4uf C-418
.05uf C-417
240K-1W R-409
V-402 X-402 6SN7
1.5K-1W R-410
51K-1W R-411
10K-1W R-412
C-419 .05uf
R-413-27K-1W
R414-470K-1W
V-403 X-403 6SL7
.05uf C-421
.01uf C-420
200K-1W R-415
200K-1W R-416
2K-1W R-418
26K-2W R-417
24K-1W R-419
51K-1W R-420
50uuf C-422
V-404 X-404 6SN7
.01uf C-424
R-422
3.6K-1W
R-423 470K-1W
51K-1W R-421
.01uf C-423
T-601 THORD. 19P54 115V/560-0-560V
E801-L1 10
E801-L2 20
560V
560V
T604
V603 X603 5V4
T603
V602 X602 5V4
T-602
V601 X602 5V4
L-601 5-25H
L-602 5-25H
L-603 5-25H
C603 4uf 1000V
C601 4uf 600V
C607 10uf 600V
C602 10uf 600V
R602 16K 2W
R612 16K 2W
R621 16K 2W
R618 10K 10W
R619 16K 38W
2500Ω 24W R-601
VR-90 V605 X605
VR-150 V609 X609
VR-150 V608 X608
VR-150 V607 X607
VR-150 V606 X606
VR-90 V604 X604
R616 2000Ω 24W
R614 8000Ω 24W
R609 8000Ω 24W
R608 3100Ω 24W
R606 3100Ω 24W
R603 2000Ω 24W
+390V
+300V
-150V
-390V
+1500V
E801-L
1 2 3 4 5 6 7
+1500V
T701
132,0W-2 (WAS FILLED)

TOP-3



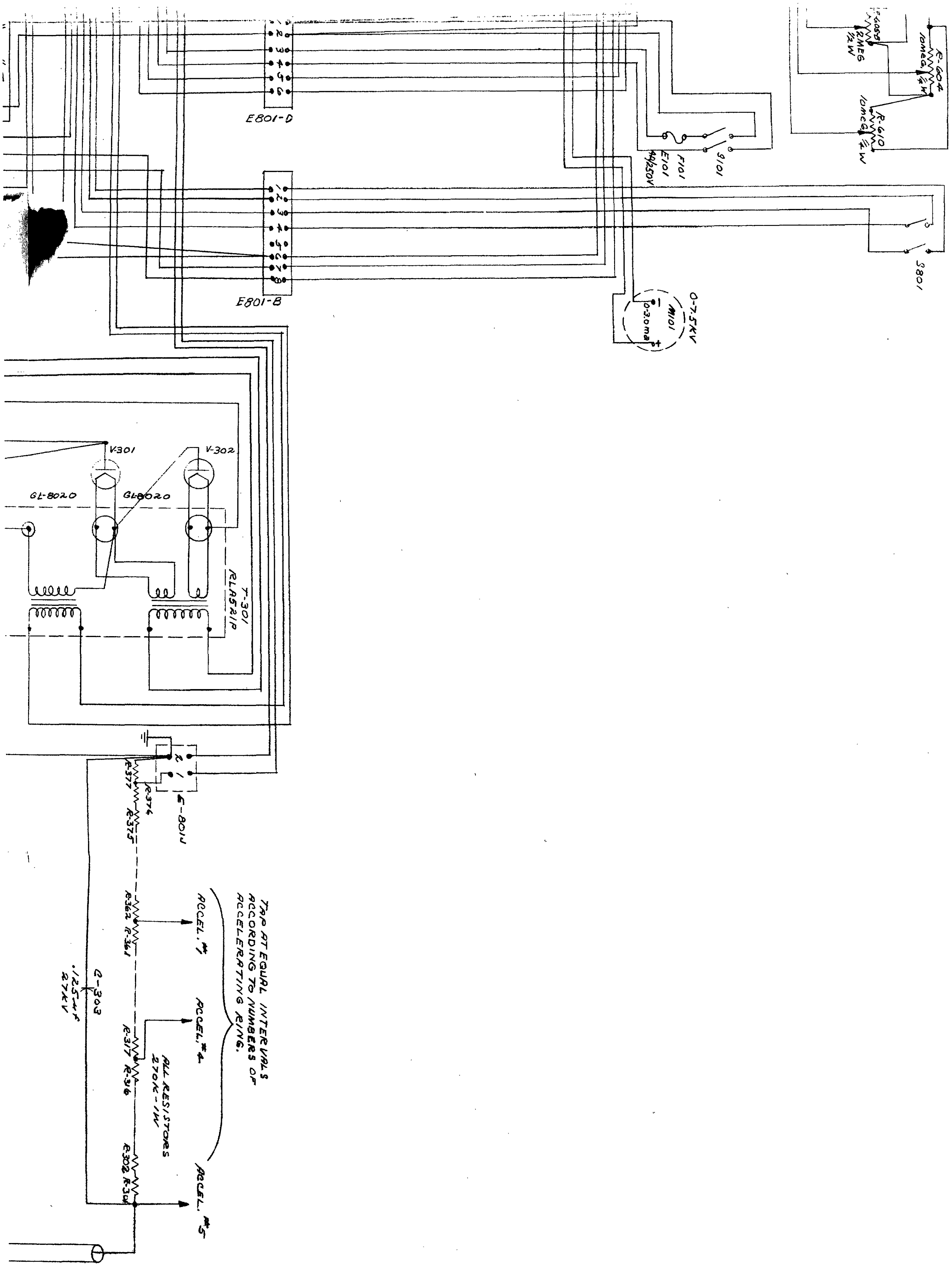
L-602
5-25H
2500-Ω
24W
R-601
+1500
+1500V(DC)
.75H
L201
300-Ω 4.5-H SEC.
Z201
V201
3B27
X201
T201
R.L.646P
115V/25V 5A
V604
X604
VR-90
R603
2000-Ω
24W
R619
16K
38W
C602
10μf
600V
C601
600V
V606
X606
VR-150
R606
3100-Ω
24W
R618
10K
10W
V607
X607
VR-150
R608
3100-Ω
24W
-390V
-150V
+300V
+390V
EB01K-1
EB01K-2
EB01-L
R621
16K
2W
V608
X608
VR-150
R609
8000-Ω
24W
C604
10μf
600V
C603
600V
R622
16K
2W
VR-150
V609
X609
R614
8000-Ω
24W
R602
16K
2W
VR-90
V605
X605
R616
2000-Ω
24W
L-603
5-25H
4C35
3C45 ← WITH ADAPTER
V202
X202
R204
1000-Ω
2W
100μμf
C204
2500W.V. MICA
R205
220K
2W
L202
70mh
R206
2-Ω 25W
C203
.01μf
406AWX-T203
J202
R202
100-Ω
50W
R203-100-Ω
50W
R201
100-Ω
50W
COAX TO
J101-102
J204
R208
10K 2W
V203
2050
X203
R209
1meg 2W
R211
470K 1W
C201
.01μf
R210
1K 1W
R212
6.3-Ω 8W
C202
51μμf
T202
115V/10V
8A
1
2
3
4
5
6
7
-390V
-150V
+300V
+390V
J602
R617
1M 1W
S601
RW-2P (WAX FILLED)
TO
J905
TO
J911
TO J902 TO J908
J503
J501
J504
J502
R533
510-Ω
½W
R534
510-Ω
½W
R535
510-Ω
½W
R536
510-Ω
½W
C505
400μμf
C503
400μμf
C501
400μμf
C504
400μμf
C506
400μμf
C502
400μμf
85mh
18mh
L501
L503
R501
18K 2W
R502
18K 2W
R503
R504
18K 2W
85mh
L502
L504
18mh
R517
R518
R519
R520
18K 2W
18K 2W
L505 7mh
R505
R506
4.7K 2W
R507
R508
4.7K 2W
L506 7mh
R521
R522
4.7K 2W
R523
R524
4.7K 2W
S501
L507
.4mh
R509
R510
1.2K 2W
R511
R512
1.2K 2W
L508
.4mh
R525
R526
1.2K 2W
1.2K 2W
R527
R528
R513
R514
L509 30mh
360-Ω 2W
R515
R516
360-Ω 2W
L510 30mh
R529
R530
360-Ω 2W
R531
R532
360-Ω 2W
J801
Z802
25A
LINE FILTER
VR
20

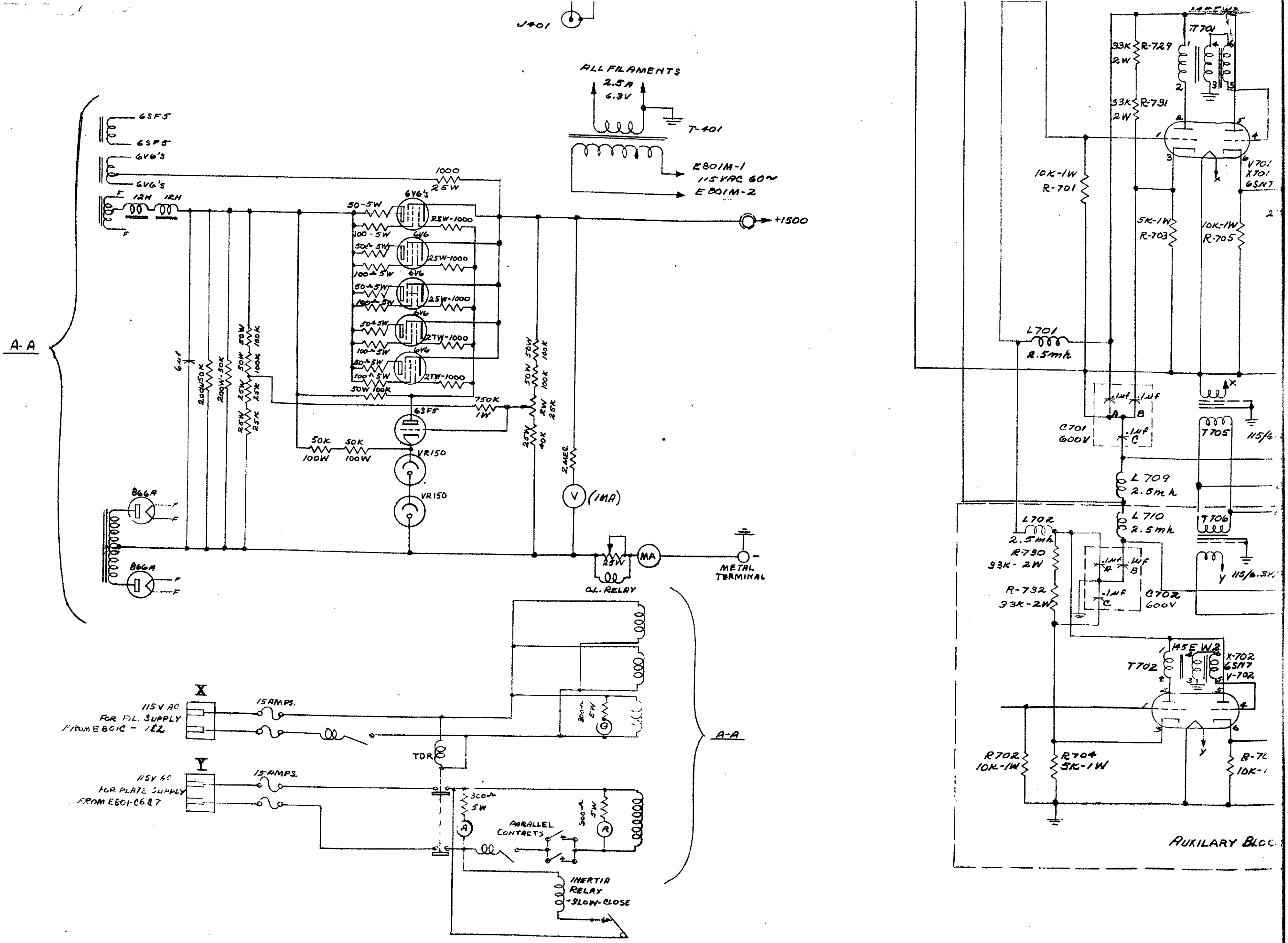
TOP-4



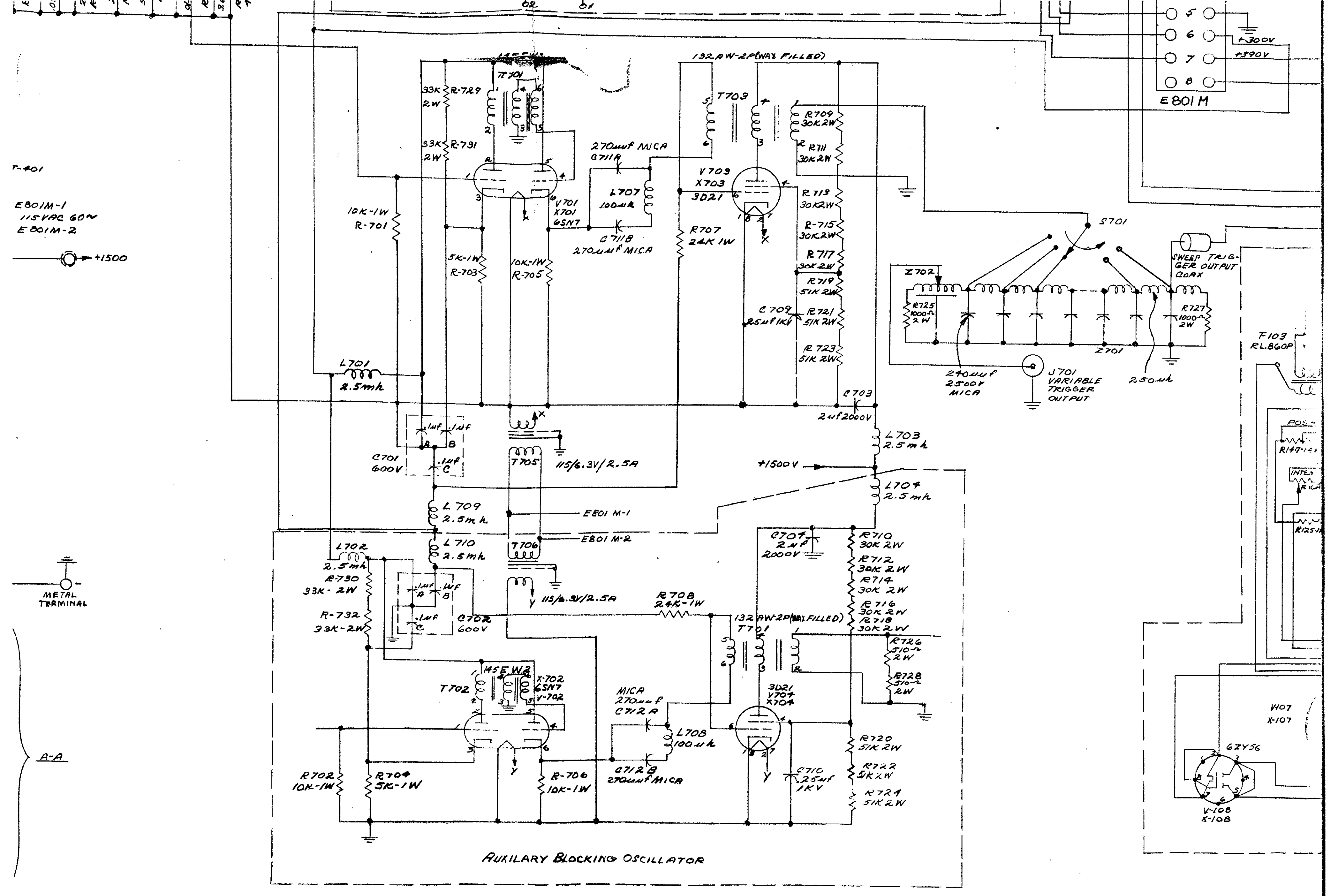
TO J911
TO J902 TO J908
J501
J504
J502
R534 510Ω ½W
R535 510Ω ½W
R536 510Ω ½W
C503 400uuf
C501 400uuf
C504 400uuf
C506 400uuf
C502 400uuf
L503
L502 85mh
L504 18mh
R502 18K 2W
R517
R518
R519
R520
18K 2W
18K 2W
L506 7mh
R521
R522
4.7K 2W
R523
R524
4.7K 2W
L508 4mh
R525
R526
1.2K 2W
1.2K 2W
R527
R528
L510 30mh
R514
R516
R529
R530
R531
R532
360Ω 2W
360Ω 2W
J801
Z801
Z802 25A LINE FILTER
E802
F801 20A FUSE
F802 20A FUSE
E801-A
VR 101 200B VARIAC
E801F
VR 301 200CU VARIAC
E801-G
T101 #15
T101 #11
E801L-7
E801L-3
E801-K
E801-E
E801-D
E801-B
S802 ON
S803 OFF
S301 F301 E301 4A/250V
0-30KV M301 0-1.5MA
R-615 10MEG ½W
R-612A 2MEG ½W
R-612-B 2MEG ½W
R-611 1.0MEG ¼W
R-605-A 2MEG ½W
R-605-B 2MEG ½W
R-604 10MEG ¼W
R-610 10MEG ¼W
S801
S101
F101 E101 4A/250V
0-7.5KV M101 0-3.0ma

TOP-5

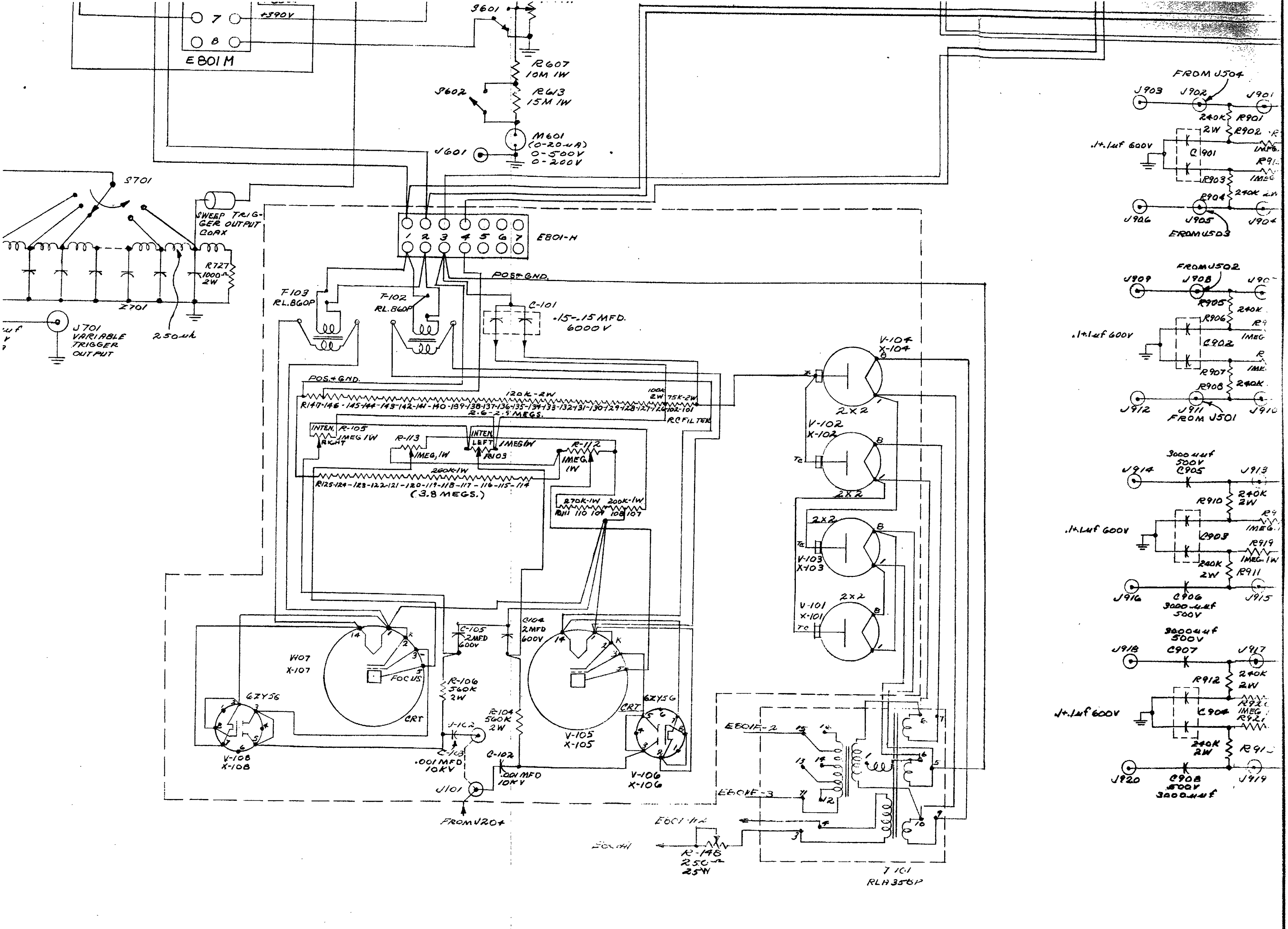

E801-D
E801-B
F101
E101
40/250V
S101
R-605
2MEG
1/2W
R-604
10MEG
1/4W
R-610
10MEG
1/4W
S801
M101
0-7.5KV
0-3.0ma
V-301
V-302
GL-8020
GL8020
T-301
RLA5Z1P
E-801J
R-377
R-376
R-375
R-362
R-361
R-317
R-316
R-302
R-301
C-303
.125mf
27KV
ACCEL. #1
ACCEL. #4
ACCEL. #5
TAP AT EQUAL INTERVALS ACCORDING TO NUMBERS OF ACCELERATING RING.
ALL RESISTORS 270K-1W


J401
ALL FILAMENTS
2.5A
6.3V
T-401
E801M-1
115VAC 60~
E801M-2
+1500
A-A
6SF5
6SF5
6V6's
6V6's
F
12H
12H
F
1000
25W
6V6's
50-5W
100-5W
25W-1000
6V6
50Ω-5W
25W-1000
100Ω-5W
6V6
50Ω-5W
100Ω-5W
25W-1000
6V6
50Ω-5W
2TW-1000
100Ω-5W
6V6
50Ω-5W
100Ω-5W
2TW-1000
50W 100K
6μf
200W 50K
200W-50K
25W 25K
25W 25K
50W 100K
50W 100K
750K
1W
6SF5
50K
100W
50K
100W
VR150
VR150
50W 100K
50W 100K
2W 25K
25W 40K
2 MEG.
V
(1MA)
866A
F
F
866A
F
F
25W
O.L. RELAY
MA
METAL TERMINAL
-
X
115V AC
FOR FIL. SUPPLY
FROM E601C - 1&2
15AMPS.
300Ω
5W
G
TDR
Y
115V AC
FOR PLATE SUPPLY
FROM E601-C6&7
15AMPS.
300Ω
5W
A
PARALLEL CONTACTS
300Ω
5W
R
INERTIA RELAY
-SLOW-CLOSE
A-A
T701
33K
2W
R-729
33K
2W
R-791
1
2
3
4
5
6
V701
X701
6SN7
10K-1W
R-701
5K-1W
R-703
10K-1W
R-705
X
L701
2.5mh
.1μf
.1μf
A
B
C701
600V
.1μf
C
T705
115/6.
L709
2.5mh
L710
2.5mh
T706
L702
2.5mh
R-730
33K-2W
.1μf
A
.1μf
B
R-732
33K-2W
.1μf
C
C702
600V
Y
115/6.3V
T702
145EW2
X-702
6SN7
V-702
1
2
3
4
5
6
Y
R702
10K-1W
R704
5K-1W
R-7
10K-
AUXILARY BLOC

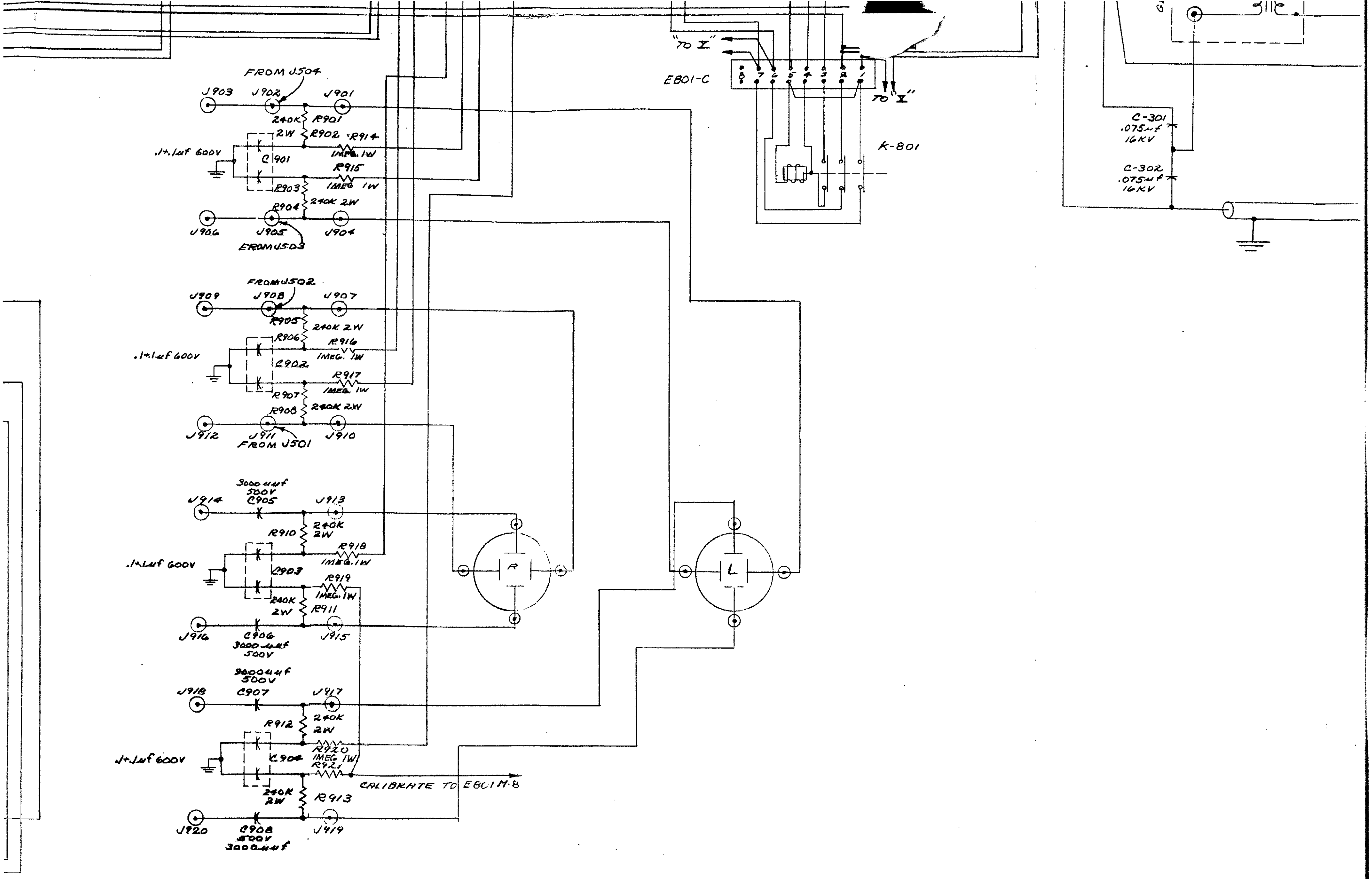
BOTTON - 1


T-401
E801M-1
115VAC 60~
E801M-2
+1500
METAL TERMINAL
A-A
33K 2W R-729
33K 2W R-731
T701
V701 X701 6SN7
10K-1W R-701
5K-1W R-703
10K-1W R-705
270µµf MICA C711A
L707 100µh
C711B 270µµf MICA
132AW-2P(WAX FILLED)
T703
V703 X703 3D21
R707 24K 1W
R709 30K 2W
R711 30K 2W
R713 30K 2W
R-715 30K 2W
R717 30K 2W
R719 51K 2W
C709 25µf 1KV
R721 51K 2W
R723 51K 2W
C703 2µf 2000V
L701 2.5mh
C701 600V
.1µf A
.1µf B
.1µf C
T705
115/6.3V/2.5A
L703 2.5mh
+1500V
L704 2.5mh
L709 2.5mh
E801 M-1
L710 2.5mh
E801 M-2
T706
115/6.3V/2.5A
L702 2.5mh
R730 33K-2W
R-732 33K-2W
C702 600V
R708 24K-1W
132AW-2P(WAX FILLED)
T701
C707 2µf 2000V
R710 30K 2W
R712 30K 2W
R714 30K 2W
R716 30K 2W
R718 30K 2W
R726 510Ω 2W
R728 510Ω 2W
T702
145EW2
X-702 6SN7 V-702
MICA 270µµf C712A
L708 100µh
C712B 270µµf MICA
3D21 V704 X704
R720 51K 2W
R722 51K 2W
R724 51K 2W
C710 .25µf 1KV
R702 10K-1W
R704 5K-1W
R-706 10K-1W
AUXILARY BLOCKING OSCILLATOR
S701
Z702
R725 1000Ω 2W
Z701
R727 1000Ω 2W
SWEEP TRIGGER OUTPUT COAX
240µµf 2500V MICA
J701 VARIABLE TRIGGER OUTPUT
250µh
E801M
5
6
7
8
+300V
+390V
F103 RL.860P
POS
R147
INTEN
R125
W07 X-107
6ZY56
V-108 X-108
X
Y

Bottom 2


E801M
+390V
S601
R607 10M 1W
S602
R613 15M 1W
M601 (0-20-uA) 0-500V 0-200V
J601
S701
SWEEP TRIGGER OUTPUT COAX
R727 1000Ω 2W
Z701
250uh
J701 VARIABLE TRIGGER OUTPUT
E801-H
T-103 RL.860P
T-102 RL.860P
C-101 .15-.15 MFD. 6000V
POS.+GND.
120K-2W
100K 2W
75K-2W
R147-146-145-144-143-142-141-140-139-138-137-136-135-134-133-132-131-130-129-128-127-126-102-101
2.6-2.9 MEGS.
RC FILTER
INTEN. R-105 1MEG 1W RIGHT
R-113 1MEG, 1W
INTEN. LEFT 1MEG 1W R103
R-112 1MEG. 1W
260K-1W
R125-124-123-122-121-120-119-118-117-116-115-114
(3.8 MEGS.)
270K-1W 200K-1W
R111 110 109 108 107
V-104 X-104
2X2
V-102 X-102
2X2
V-103 X-103
2X2
V-101 X-101
C-105 2MFD 600V
C104 2MFD 600V
V107 X-107
FOCUS
CRT
6ZY56
V-108 X-108
R-106 560K 2W
R-104 560K 2W
J-102
C-103 .001 MFD 10KV
C-102 .001 MFD 10KV
J101
FROM J204
V-105 X-105
6ZY56
V-106 X-106
E801F-2
E801F-3
E801-11
R-148 250Ω 25W
T101 RLH356P
FROM J504
J903
J902
J901
240K 2W
R901
R902
.1+.1uf 600V
C901
R903
R904
240K
J906
J905
J904
FROM J503
FROM J502
J909
J908
R905
240K
R906
.1+.1uf 600V
C902
1MEG
R907
R908
240K
J912
J911
J910
FROM J501
3000uuf 500V
J914
C905
J913
R910
240K 2W
.1+.1uf 600V
C903
1MEG.
R919
1MEG. 1W
240K 2W
R911
J916
C906 3000uuf 500V
J915
3000uuf 500V
J918
C907
J917
R912
240K 2W
.1+.1uf 600V
C904
1MEG.
240K 2W
J920
C908 500V 3000uuf
J919

BOTTOM-3


FROM J504
J903
J902
J901
240K R901
2W R902
R914
1MEG 1W
.1+.1uf 600V
C901
R915
1MEG 1W
R903
R904
240K 2W
J906
J905
J904
FROM U503
FROM U502
J909
J908
J907
R905
240K 2W
R906
R916
1MEG. 1W
.1+.1uf 600V
C902
R917
1MEG. 1W
R907
R908
240K 2W
J912
J911
J910
FROM U501
3000uuf
500V
C905
J914
J913
R910
240K
2W
R918
1MEG. 1W
.1+.1uf 600V
C903
R919
1MEG. 1W
240K
2W
R911
J916
C906
3000uuf
500V
J915
R
L
3000uuf
500V
J918
C907
J917
R912
240K
2W
R920
1MEG 1W
R921
.1+.1uf 600V
C904
CALIBRATE TO EB01 M-8
240K
2W
R913
J920
C908
500V
3000uuf
J919
"TO X"
EB01-C
8
7
6
5
4
3
2
1
TO "X"
K-801
C-301
.075uf
16KV
C-302
.075uf
16KV

Bottom-4

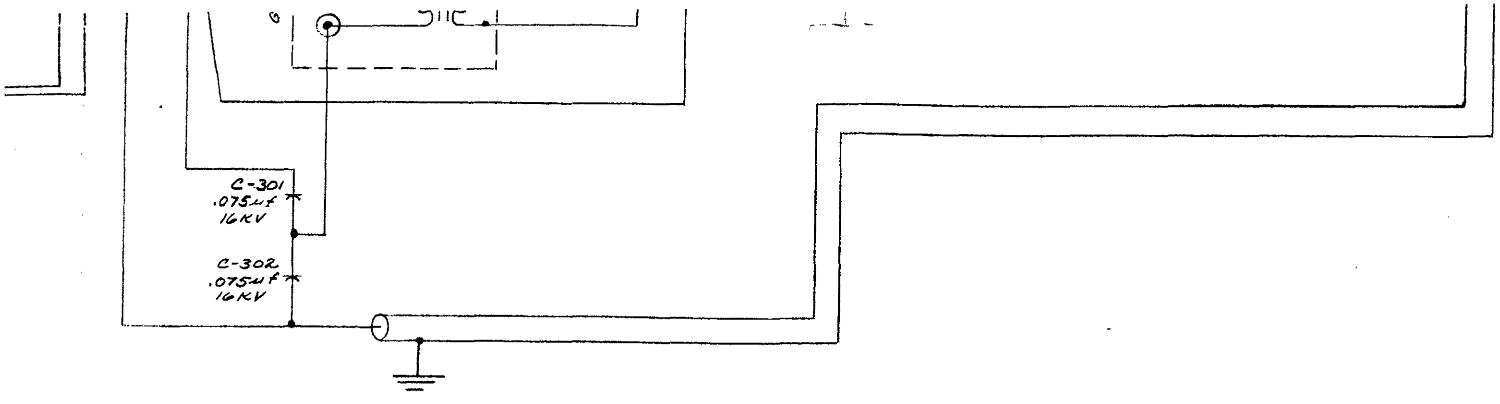


FIG. 15 COMPLETE CIRCUIT DIAGRAM OF FAST SWEEP SYNCHROSCOPE

Research Laboratory of Electronics MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMBRIDGE, MASS.	DRAWN FOR D.WINTER APPROVED BY J. B.W. DRAWN BY R.P.WILLIAMS CHECKED BY DATE 12-13-46
	TITLE FAST SWEEP SYNCHROSCOPE
	DWG. NO. S-90-A

Bottom-5