DESIGN AND CONSTRUCTION OF AN ELECTRONIC SWITCH

by

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INTRODUCTION

An electronic switch is a versatile instrument which doubles the utility of a cathode ray oscilloscope. It is used to study phase relationships of voltage waveforms in electronic circuits and in many applications where it is necessary to observe two patterns, apparently simultaneously, upon a single oscilloscope screen. The control leads of the oscilloscope are transferred rapidly from one test position to another, while a simultaneous alteration of bias changes the vertical location upon the screen. The cycle of observation is repeated so swiftly that each pattern appears to be present continuously. One pattern may be observed directly above the other, or the two patterns may be superimposed for easy comparison.

For example, in television practice, the composite synchronizing signal represents the combined output of a number of generators, each having control of the output channel for an allotted number of microseconds during each sixtieth of a second. In certain types of pre-war directive devices, built for Coast Guard use, a single receiving set produced two different records upon a common oscilloscope screen, the receiver input being shifted rapidly back and forth between two directional antennas. Exact balance of these "split-beam" patterns produced a sharp indication of direction.

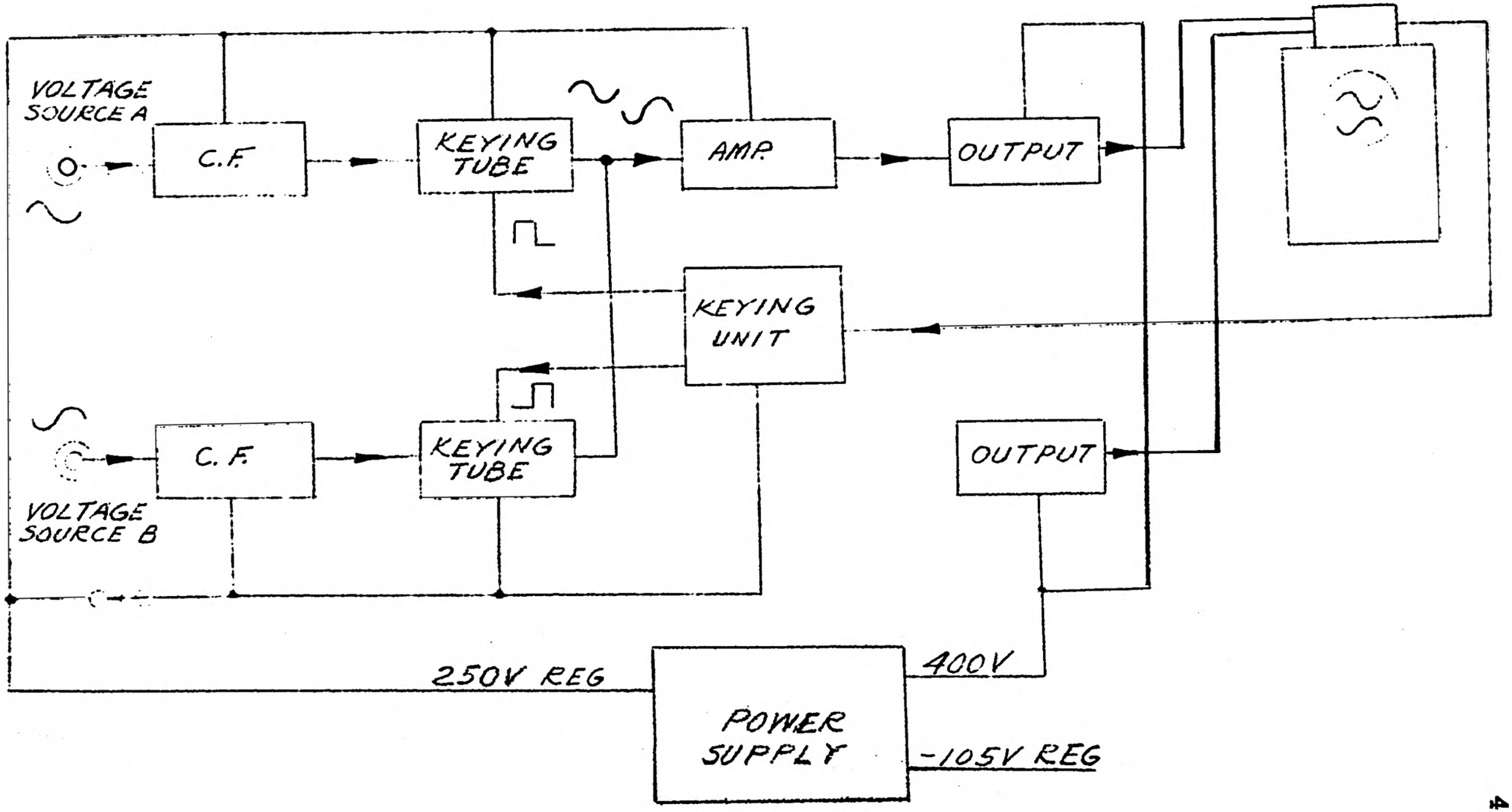
To open and close an electronic switch, the electron stream in a normal amplifier tube is interrupted and later re-established. This tube is sometimes referred to as a keying tube. Each voltage source provides a continuous signal present at all times on the control grid of the respective keying tube. When the bias is normal on this tube the signal is allowed to pass through the amplifier and appear on the screen. Thus, this signal may be said to be keyed in. Meanwhile, the electron stream in the other keying tube is interrupted by a controlling voltage from the keying unit and the signal on the grid of this tube is blocked, or keyed out. After a time interval corresponding to the period of a sweep on the oscilloscope, the conditions of operation of the keying tubes are reversed. The transition must occur instantly; steepness and precise timing of the keying signal are of major importance.

Plate I is a simplified block diagram of the instrument which illustrates the function of the three main units. The power supply furnishes a regulated 250 volts plate supply voltage for the amplifier tubes, 400 volts plate supply voltage for the push-pull output stage and -105 volts regulated for bias voltages. The keying unit blocks first one signal, then the other, in synchronization with the sweep from the oscilloscope. The respective signals are amplified in the voltage amplifier which at the same time produces the separation of the signals on the screen.

EXPLANATION OF PLATE I

Simplified block diagram of the instrument

PLATE I



VOLTAGE SOURCE A
C.F.
KEYING TUBE
AMP.
OUTPUT
KEYING UNIT
VOLTAGE SOURCE B
C. F.
KEYING TUBE
OUTPUT
250V REG
POWER SUPPLY
400V
-105V REG

THE KEYING UNIT

The phase inverter, half of tube V2, is used to accommodate either a positive or negative sawtooth from the oscilloscope. If this sawtooth synthronizing signal has a negative edge the Synch Phase switch should be in the minus position; if it has a positive edge the switch should be in the plus position. With the switch in the minus position, the grid of the phase inverter is returned to ground and the output is from the cathode. If the switch is in the plus position, the grid is returned to the cathode and the output is from the plate. Thus, the maximum possible grid swing is utilized without danger of clipping occurring for large signals. In either case, the output is a sawtooth having a negative edge.

Since the time constant of R5 and C3 is small, the sawtooth is differentiated by the combination, a sharp negative pulse of voltage appearing on the grid of the cathode follower, the other half of tube V2. The pulse is then amplified and inverted by the 6AC7, V3.

One half of the following tube, V4, is used as a blocking oscillator; the other half is used as a trigger stage which is plate coupled to the blocking oscillator. The grid of this stage is biased below cutoff as is the blocking oscillator grid. The positive pulse output from V3 raises the grid of the trigger stage above cutoff causing a flow of

EXPLANATION OF PLATE II

Schematic diagram of the phase inverter, cathode follower, 6AC7 amplifier, trigger stage and blocking oscillator

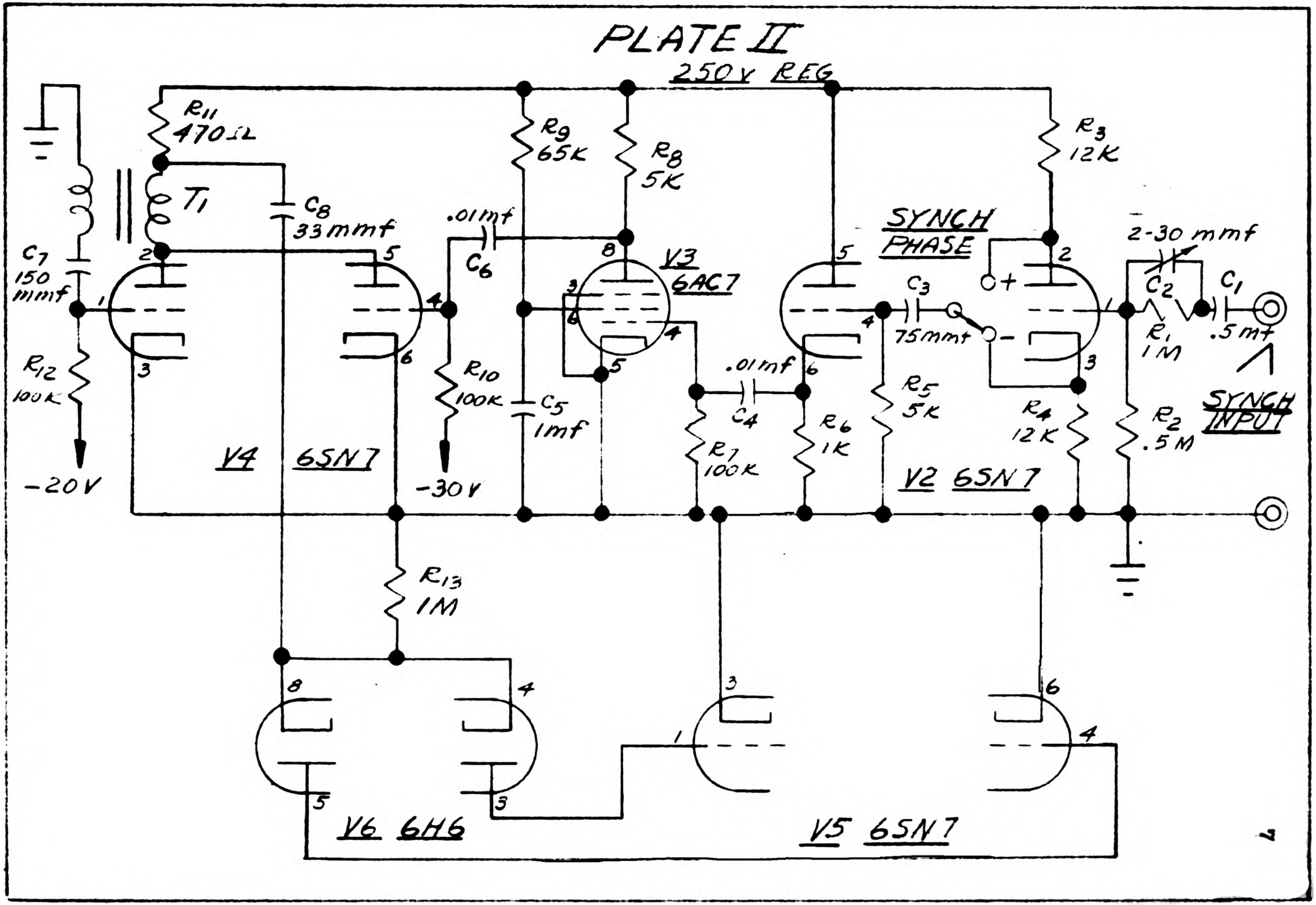


PLATE II
250v REG
R11 470Ω
T1
C8 33mmf
C7 150 mmf
R12 100K
-20V
R9 65K
R8 5K
.01mf
C6
V3 6AC7
R10 100K
-30V
C5 1mf
V4 6SN7
.01mf
C4
R7 100K
R6 1K
SYNCH PHASE
C3
75mmf
R5 5K
R3 12K
2-30 mmf
C2
C1
R1 1M
.5mf
R4 12K
R2 .5M
SYNCH INPUT
V2 6SN7
R13 1M
V6 6H6
V5 6SN7

plate current in the blocking oscillator transformer winding which initiates the action of the blocking oscillator.

The negative pulse output from the blocking oscillator is then coupled through the diode, V6, to the grids of V5, the square wave generator or flip-flop circuit, as it is commonly named. The output from this circuit is a square wave of approximately 100 volts amplitude synchronized with the sawtooth from the oscilloscope.

Tubes V7 and V8 are cathode followers which are cathode coupled to the respective keying tubes, V11 and V12. The grids of the cathode followers are returned to -60 volts; the value of cutoff for this tube is -50 volts. The square wave from the flip-flop is averaged about -60 volts on the grids of V7 and V8. The top of the square wave raises the grid of one cathode follower, say V8, to -10 volts while the other cathode follower grid is lowered to -110 volts by the opposite phase. The plate current through V8 is 25 milliamperes, the cathode voltage is 10 volts, the grid-cathode voltage is -20 volts as shown in Plate IV. The value of 10 volts on the cathode of V12 is sufficient to cut this tube off provided the grid signal does not exceed about 4 volts. Meanwhile, the other cathode follower is cut off, allowing its keying tube, V11, to amplify any signal present on the control grid in the usual manner. During the next half cycle of the square wave, the roles of the keying tubes are interchanged.

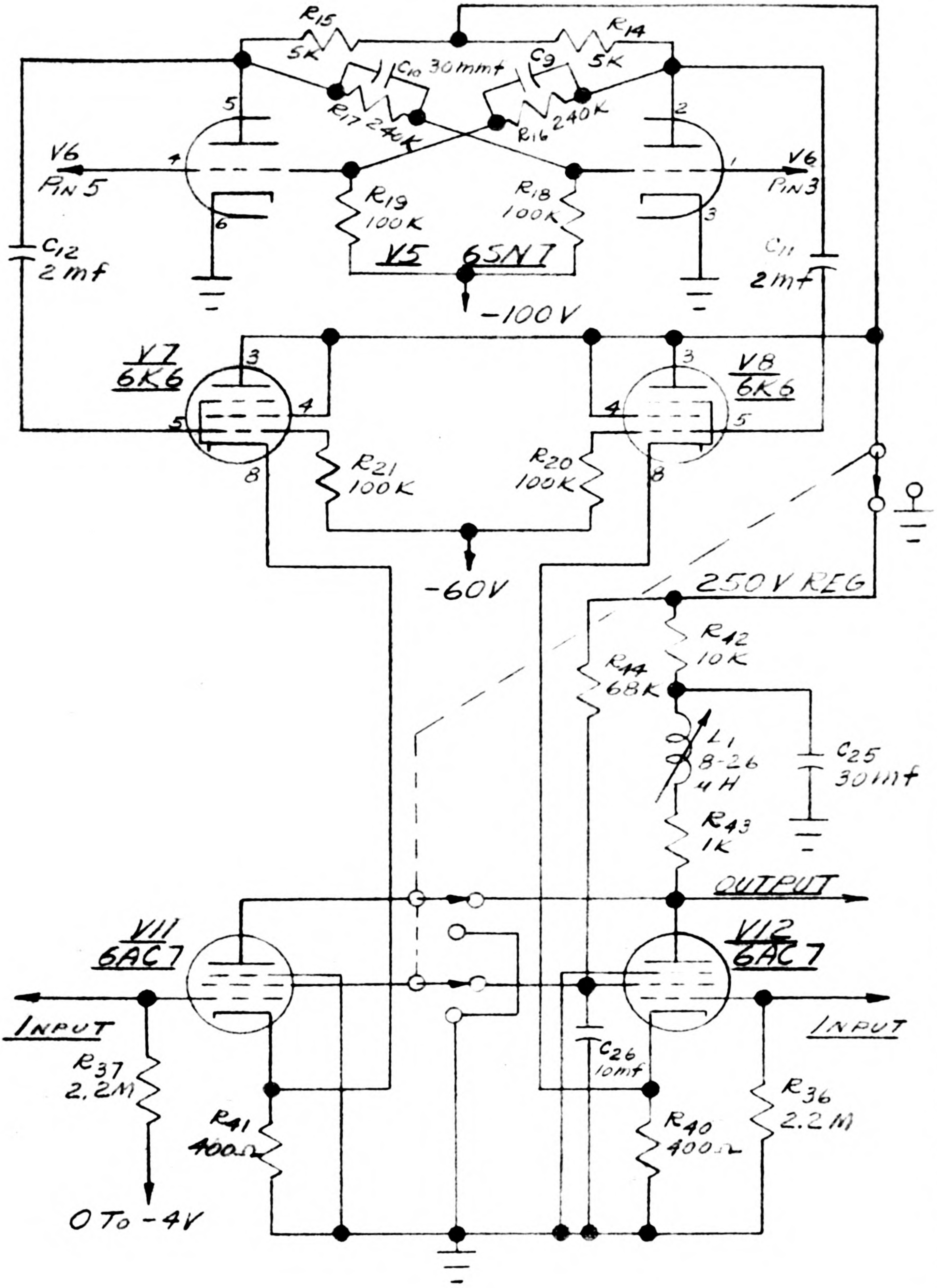
The grid of V11 is returned to a voltage which is variable from 0 to -4 volts by varying R78, the position control, located on the panel. The difference in grid bias of the two keying tubes which are plate coupled causes a change in the point of operation in the plate circuit when V11 is conducting as compared to the point of operation when V12 is conducting. This change, passed through the amplifier, causes the separation of the signals on the screen.

The instrument may be converted to an ordinary amplifier by means of the switch marked "AMP SW" on the panel.

EXPLANATION OF PLATE III

Schematic diagram of the flip-flop circuit, the cathode followers and the keying tubes

PLATE III

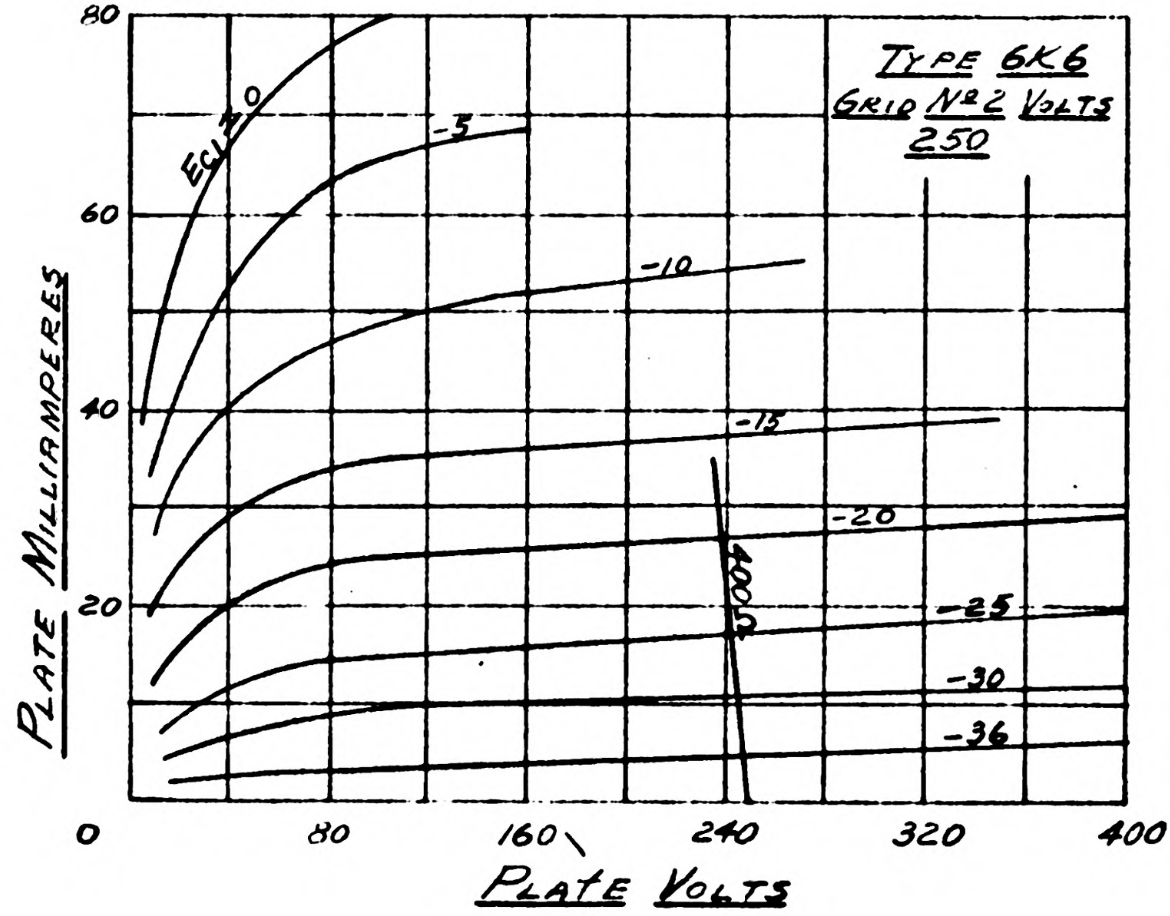


R15
5K
R14
5K
C10 30mmf
C9
R17 240K
R16 240K
5
2
V6
Pin 5
4
1
V6
Pin 3
R19
100K
R18
100K
6
3
V5 6SN7
C12
2mf
C11
2mf
-100V
V7
6K6
3
4
5
8
V8
6K6
3
4
5
8
R21
100K
R20
100K
-60V
250V REG
R42
10K
R44
68K
L1
8-26
4H
C25
30mf
R43
1K
OUTPUT
V11
6AC7
V12
6AC7
Input
Input
R37
2.2M
C26
10mf
R41
400Ω
R40
400Ω
R36
2.2M
0 To -4V

EXPLANATION OF PLATE IV

Plate characteristics of 6K6 with
a 400 ohm load line

PLATE IV


TYPE 6K6
GRID No 2 VOLTS
250
80
60
40
20
0
80
160
240
320
400
PLATE MILLIAMPERES
PLATE VOLTS
Ec1 = 0
-5
-10
-15
-20
-25
-30
-36
4000Ω

THE AMPLIFIER

The input stage to the amplifier is preceded by an isolating capacitor and a three position RC compensated attenuator having ratios of 1:1, 10:1, and 100:1. This attenuator is frequency compensated and introduces negligible distortion within the frequency range of the amplifier. The next circuit is the cathode follower with the gain control potentiometer located in the cathode circuit.

Immediately following the cathode follower stage are the amplifying stages, the first employing a 6AC7 pentode, the second a 6AG7 pentode. Both plate circuits include compensating filters for low frequencies which make it possible for the amplifier to pass a 30 cycle square wave with only slight distortion. High frequency compensation is also provided, shunt peaking is used with the 1000 ohm load resistor of the 6AC7 stage and series peaking with the 1300 ohm load resistor of the 6AG7 stage. A type of compensation allowing a larger plate load for the desired frequency range is used in the latter stage in order that the maximum possible output may be obtained from the output stage which it drives. Transient response is equal to that of the shunt peaked stage. The gain of the 6AC7 stage, including feedback, is 3.5 and the gain of the 6AG7 stage is 14.

The output stage consists of two 807's in push-pull, cathode coupled to give a balanced output. Because of low output capacitance, a 1500 ohm plate load may be used with shunt peaking without reducing frequency response below that of the previous stages. A number of attractive features are offered by cathode coupled push-pull amplifiers. Among them are low distortion and relatively small value of grid current when overloaded, freedom from any tendency to self-oscillation, and absence of "jitter" or hum derived from fluctuations of the power supply.

Table 1. Voltage readings.

Tube	Type	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8
1	6X5	NC	500 VAC	-450 VDC	NC	-450 VDC	NC	500 VAC	500 VAC
2	6SN7	0 V 90 VDC	235 VDC 160 VDC	12 VDC 90 VDC	0 V	250 VDC	8 VDC	3 VAC	3 VAC
3	6AC7	NC	3 VAC	0 V	0 V	0 V	140 VDC	3 VAC	125 VDC
4	6SN7	-20 VDC	250 VDC	0 V	- 30 VDC	250 VDC	0 V	3 VAC	3 VAC
5	6SN7	-15 VDC	195 VDC	0 V	- 15 VDC	195 VDC	0 V	3 VAC	3 VAC
6	6H6	NC	3 VAC	- 15 VDC	0 V	- 15 VDC	NC	3 VAC	0 V
7	6K6	NC	3 VAC	250 VDC	250 VDC	- 60 VDC	NC	3 VAC	6 VDC
8	6K6	NC	3 VAC	250 VDC	250 VDC	- 60 VDC	NC	3 VAC	6 VDC
9	6AG7	0 V	3 VAC	NC	0 V	5 VDC	250 VDC	3 VAC	250 VDC
10	6AG7	0 V	3 VAC	NC	0 V	6 VDC	250 VDC	3 VAC	250 VDC
11	6AC7	NC	3 VAC	0 V	0 V	6 VDC	140 VDC	3 VAC	180 VDC
12	6AC7	NC	3 VAC	0 V	0 V	6 VDC	140 VDC	3 VAC	180 VDC
13	6AG7	0 V	3 VAC	NC	0 V	3.5 VDC	100 VDC	3 VAC	110 VDC
14	807	3 VAC	250 VDC	15 VDC	30 VDC	3 VAC	280 VDC plate	-	-
15	807	3 VAC	250 VDC	15 VDC	30 VDC	3 VAC	280 VDC plate	-	-
16	5R4	NC	540 VDC	NC	500 VAC	NC	500 VAC	NC	480 VDC

Table 1. (Concl.).

Tube	Type	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8
17	5R4	NC	540 VDC	NC	500 VAC	NC	500 VAC	NC	480 VDC
18	6B4	NC	250 VDC	360 VDC	NC	230 VDC	NC	250 VDC	NC
19	6B4	NC	250 VDC	360 VDC	NC	230 VDC	NC	250 VDC	NC
20	6SJ7	NC	3 VAC	150 VDC	100 VDC	105 VDC	140 VDC	3 VAC	230 VDC
21	VR105	NC	0 V	NC	NC	105 VDC	NC	NC	NC
22	VR105	NC	-105 VDC	NC	NC	0 V	NC	NC	NC

All readings with respect to ground, ±10 percent.

Table 2. Resistance readings.

Tube:	Type :	Pin 1 :	Pin 2 :	Pin 3 :	Pin 4 :	Pin 5 :	Pin 6 :	Pin 7 :	Pin 8
1	6X5	NC	85	20 K	NC	20 K	NC	85	80
2	6SN7	.5 M	80 K	12 K	5 K	70 K	1 K	.1	.1
3	6AC7	NC	.1	0	100 K	0	130 K	.1	75 K
4	6SN7	120 K	70 K	0	120 K	70 K	0	.1	.1
5	6SN7	100 K	70 K	0	100 K	70 K	0	.1	.1
6	6H6	NC	.1	100 K	1 M	100 K	NC	.1	1 M
7	6K6	NC	.1	70 K	70 K	130 K	NC	.1	400
8	6K6	NC	.1	70 K	70 K	130 K	NC	.1	400
9	6AG7	0	.1	NC	1 M	500	70 K	.1	70 K
10	6AG7	0	.1	NC	1 M	1 K	70 K	.1	70 K
11	6AC7	NC	.1	0	2.2 M	400	135 K	.1	80 K
12	6AC7	NC	.1	0	2.2 M	400	135 K	.1	80 K
13	6AG7	0	.1	NC	120 K	150	90 K	.1	75 K
14	807	.1	400 K	130 K	200	.1	390 K plate	-	-

Table 2. (Concl.).

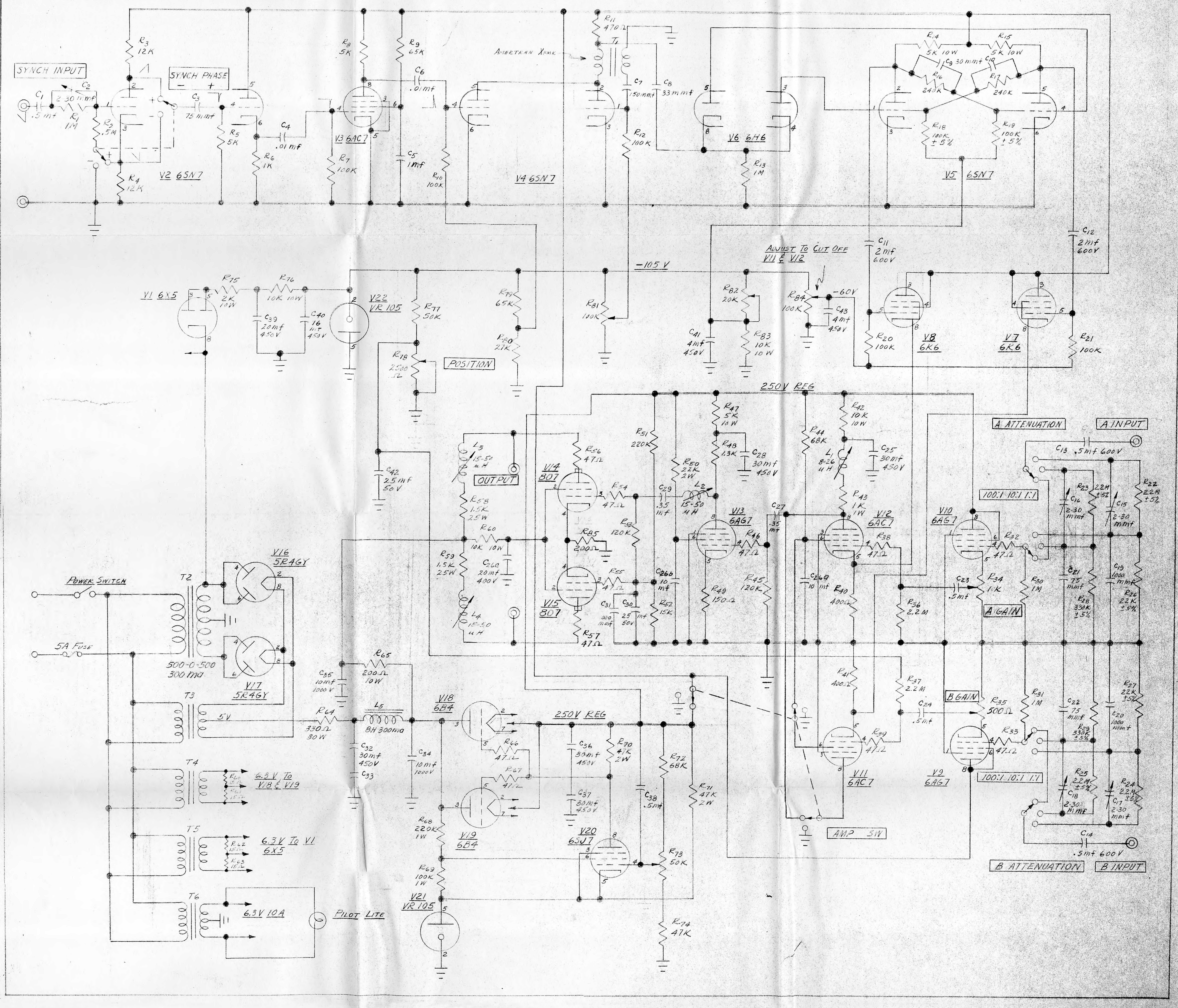
Tube	Type	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8
15	807	.1	400 K	15 K	200	.1	390 K plate	-	-
16	5R4	NC	390 K	NC	80	NC	80	NC	390 K
17	5R4	NC	390 K	NC	80	NC	80	NC	390 K
18	6B4	NC	70 K	390 K	NC	110 K	NC	70 K	NC
19	6B4	NC	70 K	390 K	NC	110 K	NC	70 K	NC
20	6SJ7	NC	.1	110 K	60 K	110 K	200 K	.1	110 K
21	VR105	NC	0	NC	NC	110 K	NC	NC	NC
22	VR105	NC	8 K	NC	NC	0	NC	NC	NC

Resistance readings in the B+ circuit may vary widely depending on the condition of the filter capacitors.
All readings with respect to ground, ±10 percent.

EXPLANATION OF PLATE V

Complete wiring diagram of the instrument

PLATE V


SYNCH INPUT
SYNCH PHASE
V2 6SN7
V3 6AC7
V4 6SN7
AMERTRAN XFMR
V6 6H6
V5 6SN7
V1 6X5
V22 VR 105
POSITION
-105 V
ADJUST TO CUT OFF V11 & V12
-60V
V8 6K6
V7 6K6
250V REG
OUTPUT
V14 807
V15 807
V13 6AG7
V12 6AC7
V10 6AG7
A ATTENUATION
A INPUT
100:1 10:1 1:1
A GAIN
B GAIN
V9 6AG7
V11 6AC7
AMP SW
B ATTENUATION
B INPUT
POWER SWITCH
5A FUSE
V16 5R4GY
V17 5R4GY
T2
T3
T4
T5
T6
500-0-500 300 ma
5V
6.3 V To V18 & V19
6.3V To V1 6X5
6.3V 10A
PILOT LITE
V18 6B4
V19 6B4
V20 6SJ7
V21 VR 105
L5 8H 300ma

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BIBLIOGRAPHY

(1) Cruft Electronics Staff, Harvard University.
Electronic Circuits and Tubes. New York: McGraw-Hill. 948 p. 1947.

(2) Millman, Jacob and Samuel Seely.
Electronics. New York: McGraw-Hill. 721 p. 1941.

(3) Reich, Herbert J.
Theory and Applications of Electron Tubes. New York: McGraw-Hill. 716 p. 1944.

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In the actual working out of a circuit to give the desired result, it was found necessary to introduce two stages and accomplish the switching in the cathode circuit of the second stage for more complete isolation of the switching and signal circuits. Cathode follower input stages are provided with separate gain controls in the cathode circuit. The input stage is preceded by an attenuating network designed to accommodate signals from 0.1 to 600 volts. Positive synchronization was obtained by the use of a blocking oscillator to trigger a flip-flop circuit. Circuits may be switched at frequencies from 30 to 50,000 cycles with the switching interval a negligible part of the sweep cycle.

The amplifier design for electronic switches is conventional except perhaps for the use of peaking coils to pass the higher frequency components of the switching signal. Low frequency compensation was also provided.

The performance of the electronic switch proved to be quite satisfactory.

The application of the cathode ray oscilloscope has been greatly restricted because of its inability to portray more than a single phenomenon at a time. Since it is often desirable or even essential to show two or more waves in their correct relative phase, this limitation has proved to be a serious handicap in the general usefulness of the oscilloscope. For the simultaneous observation of two waves the electronic switch has been developed. One of the most obvious examples of its usefulness would be the viewing of the input and output signal of an amplifier to check for phase shift. A further adaptation might be the determination of vacuum tube characteristics by the switching of some control voltage through a series of fixed values; a set of curves of a tube under test can be viewed on a cathode ray tube screen.

There are a number of disadvantages possessed by commercially available electronic switches. Among them are interaction of the two signals under observation as well as interaction of the switching signal caused by insufficient isolation; usually not enough amplification is provided or the amplifier has poor frequency response causing distortion, erratic synchronization especially at high sweep frequencies, and the effective switching interval is an appreciable part of the sweep cycle at high frequencies.