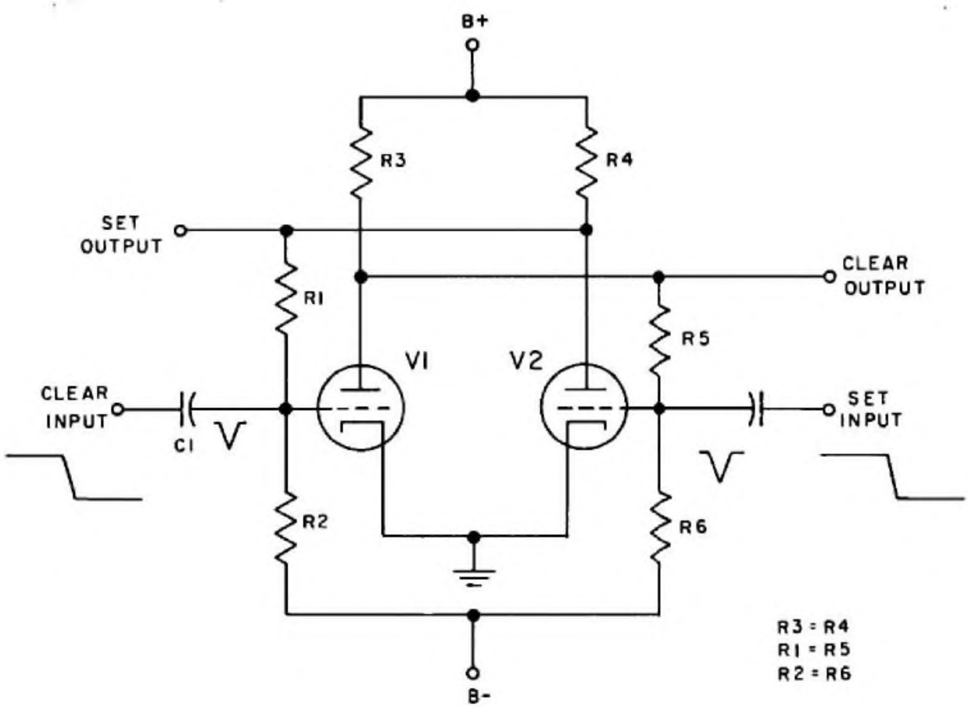
Basic Principles of Vacuum Tube Logic Circuits



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IBM® Customer Engineering Manual of Instruction

604 Electronic Calculating Punch

Principles of Electronic Operation

THIS CHAPTER will cover the principles and operation of the basic 604 "electronic building blocks" and will show how "freed" electronics is able to do already familiar jobs.

Both G suffix and H suffix circuits are covered in this and following chapters. F suffix circuits are similar to the G, though unit locations may differ. Where the F suffix circuit operation is much different, separate descriptions are included.

All circuits are first covered in general form, and then followed by a detailed description as it applies to specific suffix machines. Each circuit description, while dependent upon the objective introduction, is complete in itself. Thus, in studying the H suffix machine, no reading need be done in the sections labeled "G." It is suggested that only one machine type be studied at one time.

Electrons have long helped IBM machines perform, largely through electro-mechanical effects. Relays, mechanical counters, clutches, and ratchet control mechanisms are all examples of mechanical devices controlled by electron flow. In the 604 unit, IBM released a machine which freed electron actions from mechanical inertia. Electronic building blocks were developed to do the jobs previously done by electro-mechanical means.

Instead of relays, electronic switches and triggers are used; instead of counters, trigger combinations were developed, etc. Only the work involved in reading and punching IBM cards has remained mechanical. The increase in calculating speed made possible by freeing electronics from mechanics can be seen by a typical comparison: a normal wire relay can pick in three milliseconds (three thousandths of a second), and for good design, five milliseconds minimum time must be allowed. Its electronic counterpart, an elementary trigger, will flip (or "pick") in two microseconds (two millionths of a second), and five microseconds allows a good margin of safety. Even with the conservative design of the 604, which allows a ten microsecond flip time, this gives a five-hundred-fold speed gain.

BASIC CONCEPTS

THE BASIC CONCEPTS of practical electronics are quite simple. Present theory is that all matter consists of atoms having a central nucleus around which one or more small particles called electrons spin rapidly. An electron which has been pulled away from its nucleus is called a *free electron.* Electrons each have a negative charge and repel one another. A group of free electrons in an area makes this area negative. Given a chance, this accumulation of electrons will try to flow to any other area that is less "crowded" (that is, less negative). An area which has a shortage of electrons is called positive and has a considerable attraction for free electrons. Because of this, electrons always flow from negative to positive. Any material capable of easily carrying a flow of electrons is called a conductor. Any material through which free electrons have difficulty passing is called an insulator. Those materials in between these extremes may resist the flow of electrons to one degree or another and are called resistors. Some combinations of materials will let electrons flow in one direction, but not in the reverse. These are called semi-conductors (half-way conductors). One other important fact is that it is quite possible for an electron to make its force (or presence) felt through an insulator without itself actually passing through the insulator.

The amount of force with which electrons are trying to move from one place to another is measured in an arbitrarily assigned value called a volt. Free electron unbalance being a relative matter, voltage must always be specified as between two areas. Throughout our circuit descriptions, the voltages given will be with respect to the metal frame of the machine (which is called ground). Any exceptions to this convention will be clearly pointed out. Any point having an excess of free electrons will have a negative potential and be noted as a minus voltage, such as —100 volts. Such voltages can be spoken of as "so many volts below ground." As the converse, any point having a shortage of electrons has a positive potential, and would be noted as a plus voltage (such as +150) and spoken of as "volts above ground." Two points, one at −100 volts (with respect to ground) and the other at +150 volts (again with respect to ground) are actually 250 volts apart with respect to each other.

The amount of opposition a circuit presents to the flow of electrons is expressed in an established unit called the ohm. The more resistance a circuit has, the greater its ohmic value. Most of the resistances involved in electronic circuits are in thousands of ohms. As a shorthand notation, the symbol "k" is used to indicate thousands. A 68,000 ohm resistor can thus be written as 68k on diagrams, within text, etc. A convention which has been adopted for the 604 is to leave off the "k" on machine diagrams; all values being understood as in thousands of ohms. 68 on a 604 machine print means 68,000 ohms. A 470 ohm resistor is written as .47. This IBM convention is applied generally to components physically located within pluggable units; external components or components located within the punch or references within the text will be found using the "k" or with the full value written out.

Along the same lines, capacitor values in the 604 are understood to be in micromicrofarads unless a symbol is added to indicate otherwise.

The motion or flow of electrons past a given point in a circuit is measured in an arbitrary unit called the ampere (which represents an actual number of electrons passing a given point in one second). This unit of measurement is somewhat too large for most of our calculating circuits, and as a result the term milliampere (abbreviated, ma) will be used frequently. This is simply one thousandth of an ampere.

With these few facts properly applied, any calculating circuit in the 604 can be explained on a practical level. No attempt will be made to go into electronics in depth, but enough explanation will be given to help explain most conditions encountered in the troubleshooting or learning process.

The circuits in the 604 are designed to work from a ten microsecond pulse of fifty or one hundred volts amplitude. This means that the steady state voltage (electron pressure) at a particular point is shifted either upward or downward by fifty or one hundred volts for a ten millionths of a second time period. This change in voltage level can be passed on to other circuits to cause certain actions. Some circuits will produce or use shifts of longer duration. Where these shift durations exceed twenty microseconds in time they are referred to as gates (since they are generally used to "open" a circuit so a ten microsecond pulse or series of pulses can pass through). It is the control and generation of these pulses and gates that constitutes the whole of 604 circuitry.

A pulse or gate that is more positive (or less negative) during its active time than otherwise, is called a "plus pulse or gate" even if the "up level" is still negative with respect to ground. Similarly, a pulse or gate that is negative (or less positive) during its active time, is spoken of as a negative pulse or gate. For example, a point which rests at plus 150 volts and which drops to plus 50 volts for ten microseconds during active time, is said to have a minus 100 volt pulse available even though the signal did not go negative with respect to ground at any time.

BASIC ELECTRONIC CIRCUITS

NOT ALL of the basic circuits to be described in this section are used in both the G suffix and H suffix machines. Following the headings for the various circuits, the machine type or types using such circuits will be indicated in parentheses.

Power Supply Notation (G and H)

There are five DC supply voltage levels used in the 604 (plus two in the 521 Punch). These five 604 power supplies are numbered in accordance with the Electronic Industries Association coding as follows:

Plus 150 volts is supply number 2.

Plus 75 volts is supply number 3.

Minus 100 volts is supply number 5.

Minus 175 volts is supply number 6.

Minus 250 volts is supply number 7.

Whenever a point in a circuit requires one of these potentials, that point on machine wiring diagrams will be shown connected to a small square box identified inside with the proper code number. The diagrams in this manual will also make frequent use of this coding though in addition the DC voltage equivalent will often be written near the box to help develop familiarity with the coding.

The Inverter (IN) Unit (G and H)

This is the basic electronic circuit from which most others are derived. In its simplest form the circuit con-

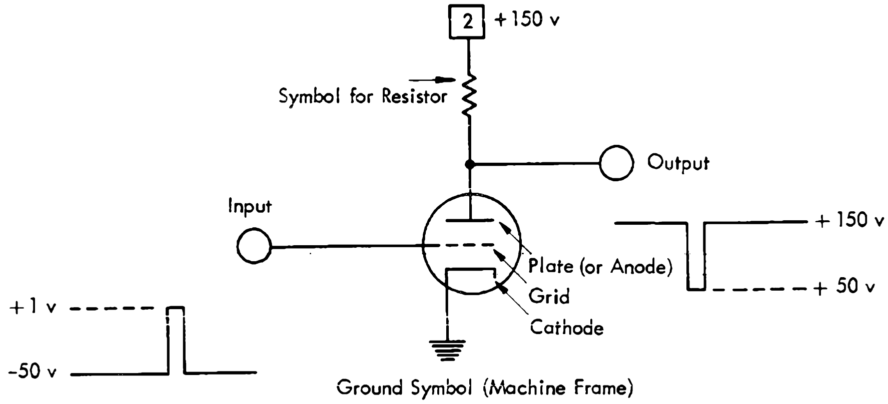


Figure 19. The Inverter

sists of a triode vacuum tube and one resistor arranged as shown in Figure 19. A signal which is applied to the input point goes through the circuit and comes out inverted exactly as indicated by the illustration. Thus the name "Inverter." This inversion is a characteristic of *any* vacuum tube circuit *where the signal goes into a grid and comes off the plate*. However, in the 604 the term "Inverter" is applied only to a particular class of pluggable units using triode tubes. These units are all identified on the handle as "IN" (to designate the general class) followed by a number (to identify the variations within the class). IN-1, IN-2, IN-15, etc., are typical types.

An understanding of this circuit is most important. The heart of it, of course, is the tube itself. This consists of a length of heating wire folded or twisted inside a cylinder called the cathode. Electrons are boiled off the cathode surface when this assembly is heated by

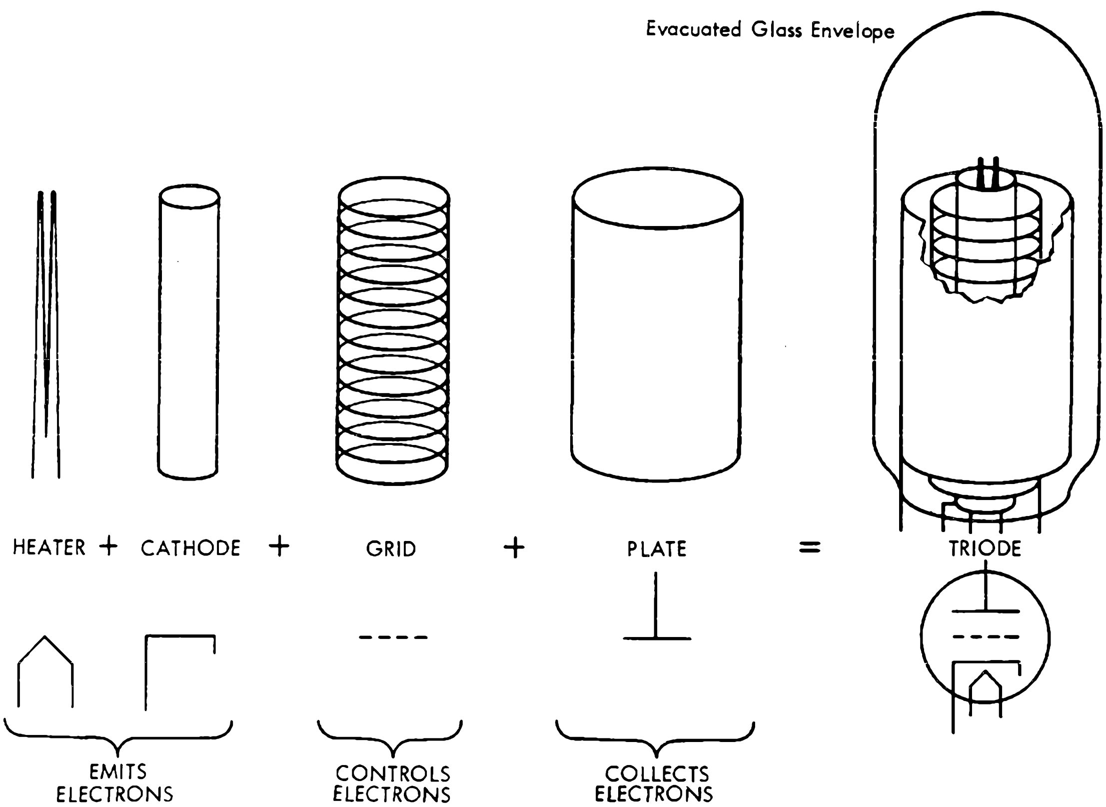


Figure 20. Development of the Triode Tube

passing a current through the heater wire. If a metallic cylinder (called the plate or anode) is placed around the cathode (but separated from it) and this entire assembly sealed in an evacuated envelope, it will be possible to make electrons travel from the cathode to the plate. This is done by making the plate positive with respect to the cathode. As the electrons are boiled off the hot cathode, they tend to move toward a less "crowded" area and thus find the plate very attractive. Such a tube is called a diode (consisting as it does of two basic elements, the heater-cathode combination and the plate). This diode has one very important characteristic that makes it of practical value in circuits actually used in the 604H calculator: electrons are able to travel from the cathode to the plate if the cathode is hot and the plate has a positive potential with respect to the cathode; but electrons cannot travel from the plate to the cathode no matter what the relative voltages are. This is because the plate is not heated and thus does not "boil off" electrons. The diode thus becomes a semi-conductor (a half-way conductor). Its practical use and application will be described later.

The triode tube used in the inverter circuit is a three element tube consisting of a cathode and plate with a *grid* inserted in the space between them. This grid consists of a coil of fine wire with spacing between each turn. Electrons can still pass between the grid turns and flow to the plate under proper conditions. See Figure 20.

With the cathode heated and a positive voltage applied to the plate, electrons boiled off the cathode will be attracted to the plate, as with the simple diode, except that they will now have to pass between the turns of the grid wires. If a negative, repelling voltage is applied to the grid with respect to the cathode, the electrons emitted by the cathode will not feel the attraction of the plate as much as they did before. As a result, the flow of electrons from cathode to plate will be greatly reduced. If the grid voltage is made sufficiently negative with respect to the cathode, it will be so repellent to the electrons that none will reach the plate. The negative grid voltage which will completely stop current flow to the plate for any particular tube and plate supply voltage is called the "cutoff" potential. For the triode tubes and voltages used in the 604 this value is ten volts negative or less. Once a tube has been cut off by driving the grid sufficiently negative, driving the grid still more negative has no further effect. From these facts, the action of the basic inverter circuit can be explained.

In Figure 21 a resting voltage of minus twenty with respect to the cathode is applied to the grid. Because of this, there is no electron flow through the tube (the tube is cut off). As a result, there is no electron flow through the 20,000 ohm resistor between the plate of the tube and the plus 150 volt supply. The output point is therefore at the same level as the supply voltage, 150 volts positive with respect to ground.

By throwing the switch in Figure 21 from A to B, the potential on the grid of the triode tube with respect to the cathode will be changed from minus twenty volts to zero. Electrons boiling off the cathode will now no longer feel a repelling grid and will instead be strongly attracted to the positive plate. As a result of this, electrons will flow through the tube and through the resistor in its plate circuit, causing a voltage change from one end of the resistor to the other. With the tube type used in the 604, at the supply voltage used (plus

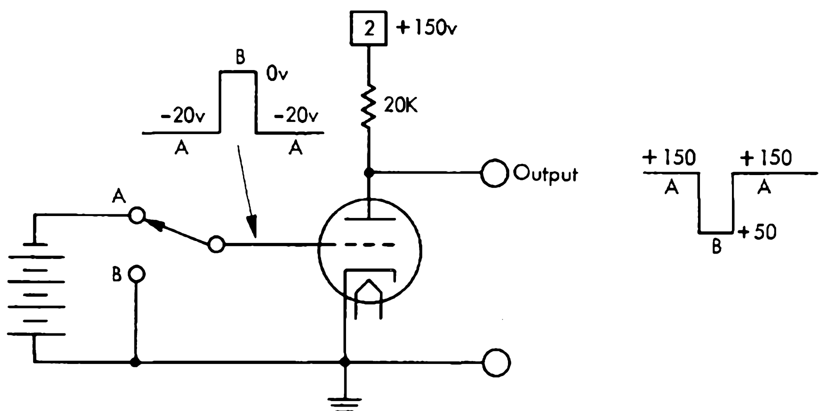


Figure 21. Basic Inverter Circuit

150), and with a 20k plate load resistor, 5 milliamperes of current will flow through the tube and resistor. By Ohm's law ($E = I \times R$) this indicates that a one hundred volt drop occurs across the plate load resistor. Since the +150 volt supply end of the resistor is rigidly held at +150, this 100 volt change must occur at the plate end of the resistor. This leaves +50 volts at the tube plate and at the output point. Returning the switch to the minus twenty grid volt position, A, will again cut off the tube and restore the plate and output point to plus 150 volts.

Two items about this action should be noted. First, during the active portion of this cycle, while the switch was thrown to B, the grid signal was less negative and thus more nearly positive than during its normal state. In other words, a positive (going) signal was applied to the grid. This, however, resulted in a lowering of the positive level on the plate of the tube where the output is taken. A negative (going) signal thus came from the output point when a positive (going) signal was applied to the grid. This is the inversion effect mentioned earlier.

A second point to note is that though only a twenty volt change was applied to the grid circuit of the tube, a one hundred volt change resulted in the output. This action of a triode, its ability to amplify an input signal, is used only indirectly in the 604 calculating circuits. The amplifying ability of a tube changes considerably with the aging of the tube, and any computer making much use of this factor would (unless constantly compensated) be rather unstable with the passage of time. The 604 generally uses tubes either in their full conduction state or cut off completely. While the total amount of full conduction current may vary through the life of the tube, the circuits are designed to work well with any normal variation.

PRACTICAL INVERTER CIRCUITS (G AND H)

There are twenty-seven types of INverter units used in the various 604 types. They all follow the theory discussed above, but practical considerations have introduced a number of variations. An IN type pluggable unit contains two separate inverter units. The tubes used for 604 inverter service are all dual triode types with characteristics (though not construction) somewhat similar to the commercial 6J6. These tubes contain two separate triode units sealed within the same evacuated glass envelope. The two cathodes of the separate sections are internally tied together electrically and the heaters connected in series. This allows a seven pin tube base to be used where ten pins would otherwise be required. Such tubes are called the 6J type class by IBM to identify directly interchangeable tubes of various designs and manufacturers.

The 5965 is a heavier duty type of dual triode used by IBM for occasional inverter service and for extensive service in other types of circuits. This tube has a nine pin base which allows separate connections to be made

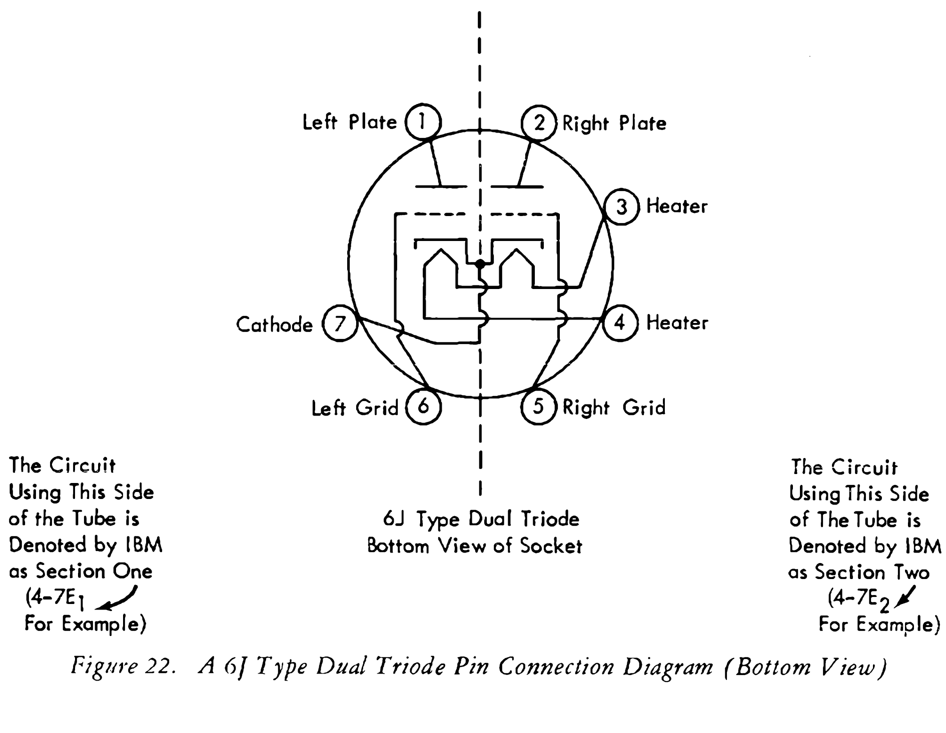


Figure 22. A 6J Type Dual Triode Pin Connection Diagram (Bottom View)

to each cathode. A tap is also made to the heater wire where it runs between the two tube units; this permits a 12 volt series connection or a 6 volt parallel connection of the two unit heaters. The parallel arrangement used by IBM for circuits using this tube type makes it possible for one section of a 5965 to have an open heater while the second section is heating correctly. This is not true of the 6J type with their internal *series* connection. The basing connections for these and other tubes used in the 604 can be found in the Appendix of this book.

Since two functionally separate triodes are available in one glass bulb, a great saving is made in the number of pluggable units required by the machine through including the components for two separate circuits in one unit basket. This does, however, require an addition to the pluggable unit location code described in Chapter One, Figure 12, in order to positively identify the particular circuit section of such a dual unit. A subscript 1 is added to the right of the location code (such as 4-7E_1) to identify the circuits used with the left half of the tube as drawn in the manufacturers' tube basing diagrams (Figure 22 and in the Appendix). A subscript 2 is used to indicate the circuits for the right half of the tube (such as 4-7E_2).

Because almost all vacuum tubes have heaters and their presence is so widely understood, it is common practice to omit the symbol for the heater wire itself when drawing a circuit diagram. This convention will be used throughout this manual. In certain tubes (used in the 604 only in the power supply) the heater itself is used as the electron emitter (cathode). No hollow sleeve cathode is used. In such instances the heater is called a filament and is always drawn on the diagram.

A typical and practical inverter circuit is shown in Figure 23. Three resistors have been added to the grid circuit of the theoretical stage discussed earlier. Inverter units are always driven from some other electronic source such as another inverter unit, power unit, trigger unit, etc. These units generally have a plate output which varies from about +140 volts with the tube cut off, down to +50 volts with the tube conducting. As was discussed earlier, the grid of an inverter must receive about 20 volts negative to reliably cut it off and a zero or positive condition to cause heavy electron flow. In Figure 23, the 390k and 470k resistors connected between the plate of the driving stage and a source of −100 volts acts to convert the driver plate voltage levels into a form usable at the grid of the inverter stage under discussion. Because of the electron flow from the −100 volts up through the 470k and 390k resistors and up through the 20k plate load of the driving stage, the voltage at the plate of the driving stage rests at about +140 volts with the tube cut off rather than the +150 volt level considered earlier. Point C, the connecting point of the three grid circuit resistors, will be found to be at about +30 volts if Ohm's law is applied to the voltage divider network. It would seem that the grid of the inverter

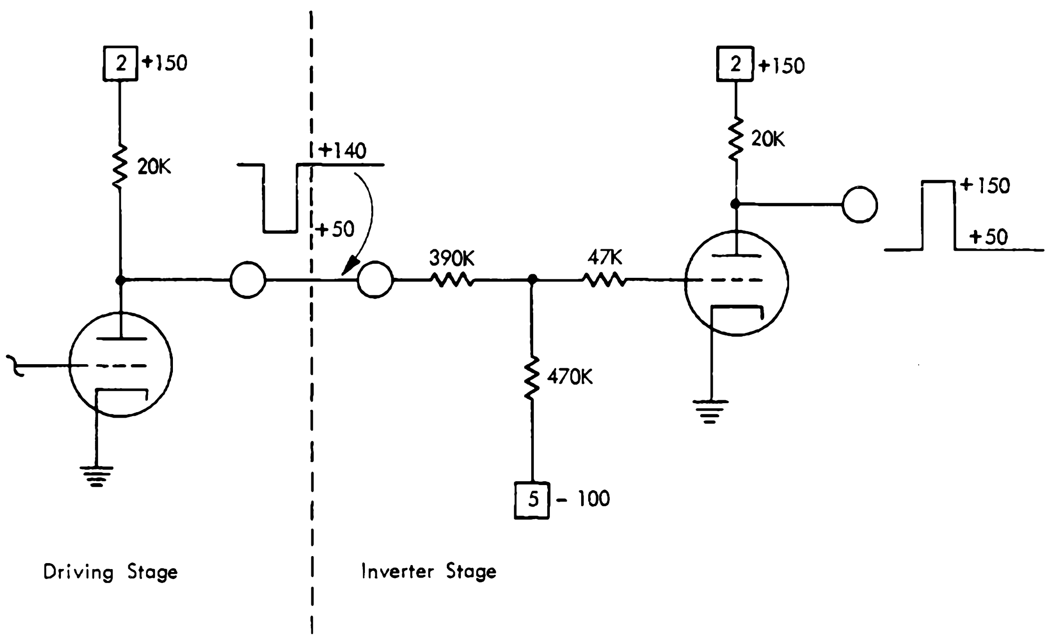


Figure 23. A Practical Inverter Circuit

would also be at plus 30 volts, but such is not the case *so long as the cathode of the inverter tube is hot.* The inverter tube grid is very close physically to the cathode. Whenever this grid goes positive with respect to the cathode, it draws from the cathode electrons which act to neutralize the expected plus potential. The grid current drawn reflects itself at point C and keeps that point also from reaching the expected +30 volts. The 47k resistor in series with the grid, as well as the high resistances of the other two grid circuit resistors, helps limit the amount of grid current actually drawn. This is important since too much grid current could melt the fine grid wires and destroy the tube. The circuits used within the 604 are so designed that no grid will ever be driven more than about one volt positive at the tube, regardless of the input signal applied to the pluggable unit pins. This potential is enough to make the tube pass the desired electrons from cathode to plate and bring the plate output down to about plus 50 volts. This is the condition of the inverter in Figure 23 when the plate of the driving stage is at its high, plus 140 volt point.

If the input to the driving stage is altered so that tube draws heavy current, the plate of the driving stage will drop to a voltage level near 40 or 50 volts. The resistance coupling network will now cause point C and the grid of the inverter stage to be at about −20 volts, cutting off current flow within the tube, and permitting the inverter plate and output point to rise to +140 to 150 volts (depending on the circuit connected to the plate). It can be seen that by circuits such as this, one tube can be used to control another. This method of coupling between tubes is called straight resistance or DC coupling and permits a direct current condition to be passed and held between tubes. In the example given, as long as the driving tube is conducting, the inverter tube is cut off, and vice versa, regardless of the time involved.

INVERTER CIRCUIT VARIATIONS (G AND H)

Certain variations of the basic inverter circuit will be found in a number of the pluggable unit types. These variations will be discussed separately, but they may be used in any combinations within any pluggable unit type. Each half of an IN unit may use different variations and units other than the IN type will use these same principles. A study of the unit diagrams in the Appendix will show the actual circuits used in any 604 pluggable.

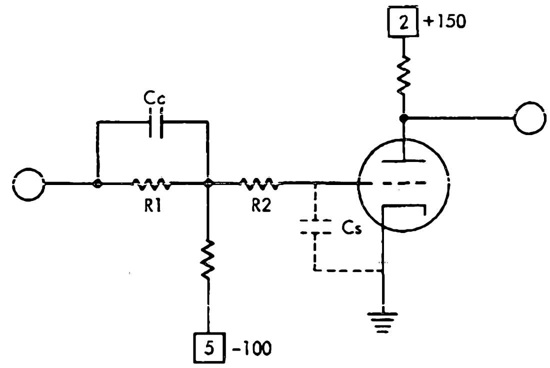


Figure 24. The Compensating Capacitor

The Compensating Capacitor. An understanding of the need for the compensating capacitor, Cc in Figure 24, will require some discussion of the characteristics of a capacitor. Any two conductors that are insulated from one another form a capacitor, the symbol for which is quite representative of its construction. The closer these two conductors are to one another, and the larger their surface area, the greater their capacitive effect. A large number of free electrons can be trapped on one or the other of these conductors or a large number of electrons can be removed from one of the conductors and not permitted to return. In both of these cases, the capacitor is called "charged" meaning the electron distribution is unbalanced. Putting these electrons on a capacitor or taking them off, takes an amount of time which is directly proportional to the resistance through which the electrons have to pass to get on or off the capacitor. The actual electrical size of the capacitance directly affects the voltage (electron pressure) to which a capacitor will charge through a given resistor in a given amount of time. The practical effect of this is that a capacitor will not instantaneously change the voltage across its conductors (which are generally called plates). While acting as an open circuit for long term steady voltage conditions, the capacitor acts as a temporary short circuit for any *changes* in the applied voltage.

The grid and cathode of a vacuum tube and the wiring to it, being conductors insulated from one another, constitute "invisible," stray capacitance drawn in as Cs in Figure 24. Before any change in voltage can be produced between the grid and the cathode of the tube, and thus affect the cathode to plate electron flow, this capacitance must have its voltage balance altered. Any signal voltage change applied to this capacitor must come through the resistors R1 and R2. R2 is so

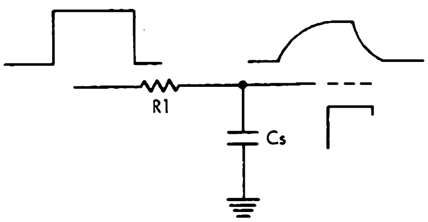


Figure 25. Stray Capacitance

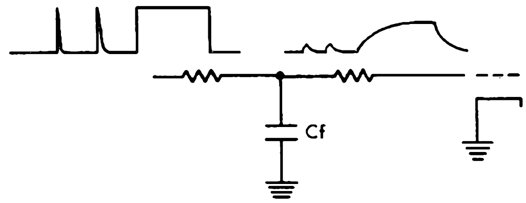


Figure 27. An External Capacitor Used to Desensitize a Circuit

small in comparison with R1 that it may be neglected in this phase of the circuit operation. The relevant parts of the circuit, without the compensating capacitor, are drawn in Figure 25.

A crisp input signal is rounded over and distorted on the grid of the tube because the stray capacitance, Cs, shorts out and delays the voltage changes. The capacitor cannot rapidly change its charge through the series resistor R1. Reducing the resistance in R1 would reduce this rounding but would also disturb the steady state conditions of the circuit.

desensitizing capacitor shorts to ground any short, rapid changes, and delays the circuit response to longer duration impulses. Both of these actions can be useful in certain areas.

The Coupling Capacitor. Another use for a capacitor is to eliminate the direct voltage coupling between two stages while permitting any voltage changes or signals to pass through. A side result of this is that some signals can be passed through a capacitor coupling network substantially unaltered, while other signals of longer duration are converted into pulses. Both of these effects are applied in 604 circuitry.

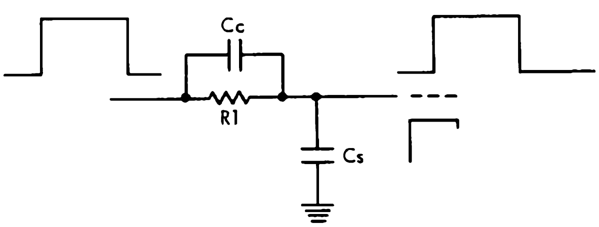


Figure 26. RC Circuit with Compensating Capacitor

Placing the compensating capacitor, Cc, in parallel with resistor R1 changes this action considerably. A capacitor of the proper size, acting like a short circuit to rapid voltage changes, can short these changes around R1 and force the stray capacitance to respond instantly so the voltage on the grid of the tube looks exactly like the applied signal. For steady state conditions no change is noticed by the circuit, the resistors alone providing the needed actions. Any 604 circuit that must have a fast response will be found to use a compensating capacitor.

The Desensitizing Filter Capacitor. The sensitivity of a circuit to short duration spikes, called noise, can be greatly reduced by effectively *increasing* the stray capacitance and eliminating the compensating capacitor. Figure 27 shows an external capacitor, Cf, connected between the grid circuit and ground. This filter or

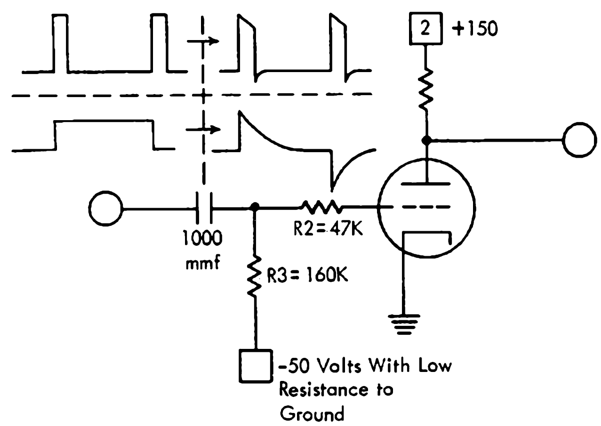


Figure 28. The Coupling Capacitor

Figure 28 shows the basic capacitor coupling circuit and its effect on typical input signals. The coupling resistor has been removed and its place taken by a capacitor. The effect of this change is always to separate the DC levels of the two circuits. What it does to the signals applied depends on the type of the signal and the value of the capacitor and any resistance in series with its charge path. With the values given in the figure a voltage pulse of ten microseconds will pass through the network with very little change, while a gate of two hundred microseconds is considerably altered. The important relationships are between the time length of the signal and the time constant of the resistance-capacitance network. The time constant can be determined from a simple formula:

$$T = RC$$

Time Constant (in microseconds) = Resistance (in millions of ohms) times Capacitance (in micromicro-farads).

If the duration of the applied pulse in microseconds is one tenth or less of this RC product, that pulse will be passed substantially unaltered. If the applied pulse is five or more times as long as the RC product, the signal will be peaked into a curved sawtooth-like pulse with a practical width in time of about twice the RC product. In-between relationships will produce intermediate effects.

The circuit being investigated must at times be carefully studied to determine the value to use for the R in the formula. In Figure 28, the value normally used would be the 160k (.16 megohms) of R3. If the signal drives the grid into the positive area *where grid current is drawn,* however, the 47k resistor can be considered as being in parallel with the 160k resistor. This is because a tube, while drawing grid current, has a low resistance effectively between the grid and the cathode (on the order of one thousand ohms). It is thus possible for a circuit to have one time constant for a positive going signal and a second for a negative going signal.

The Tapped Output. In some instances the full one hundred volt change normally produced at the plate of a 604 circuit tube is more than required. Any desired degree of signal output (generally about 2/5, or 40 volts change) can be obtained by taking the output not from the plate, but instead from a tap on the plate resistor or from a connection between two series plate resistors. This is shown in Figure 29. The closer the tap is (resistance-wise) to the plate, the greater will be the output voltage change.

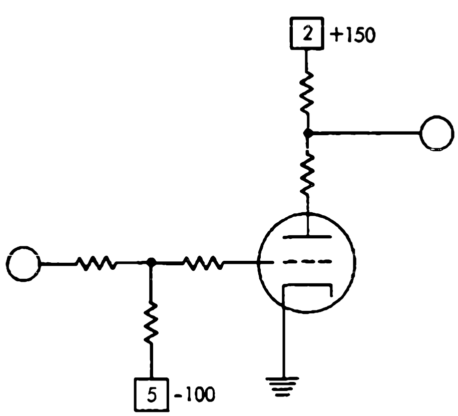


Figure 29. The Tapped Output

The Slave Unit. Some pluggable units have been designed to work only in parallel with other units, sharing their components, and depending on the presence of these other pluggable units for voltages, etc. These dependent units have very few of their own components and are called slave units. Figure 30 is typical.

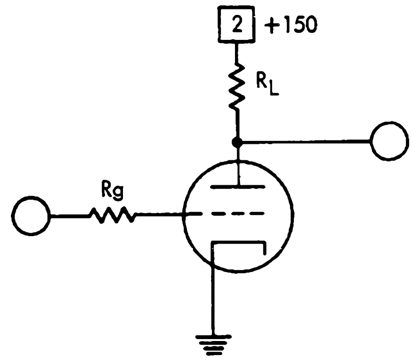


Figure 30. The Slave Unit

The plate load resistor, R_L, and the grid current limiting resistor, Rg, may either or both be missing within the slave unit itself, but when the complete circuit is traced through the units to which a slave is connected, the expected components can be found.

To repeat an earlier statement about all the foregoing circuit arrangements, these principles and variations will be found singly and in combination in all types of units in many circuits throughout the 604.

USES OF THE INVERTER

There are seven general uses for inverters within the 604:

1. inversion
2. level setting
3. clipping and shaping
4. delay
5. isolation
6. OR circuit (mixing)
7. AND circuit (switching)

As was true with the circuit variations, these uses may be applied singly or in combinations. No other

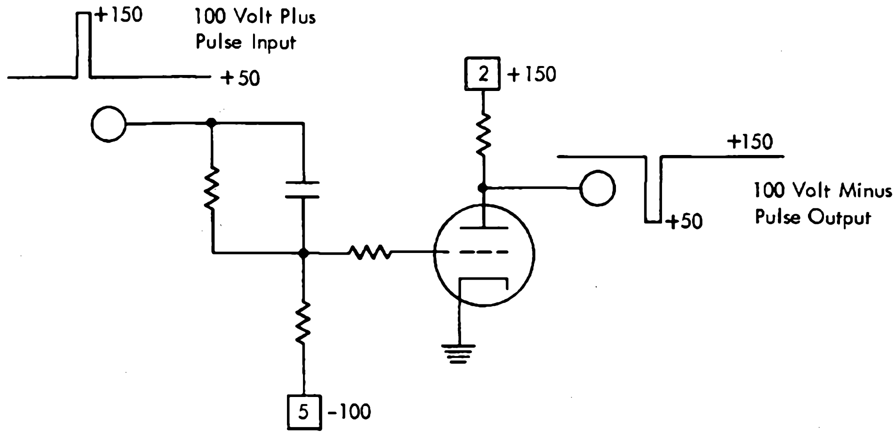


Figure 31. Signal Inversion

type of unit is applied to so great a variety of different jobs.

1. Signal Inversion (Figure 31). Particular types of circuits require a particular direction of signal shift to produce the desired action. A trigger may require a negative pulse to cause it to flip at a time when only a positive pulse is available. Running this pulse through an inverter converts it to the desired polarity. Inversion of a negative pulse or gate to a positive signal is also easily accomplished.

2. Level Setting (Figure 32). A minus 25 volt to plus 25 volt signal, for instance, can be converted to a +150 volt to +50 volt plate output level. In this example not only was the level changed, but the signal was also inverted and amplified in the process. The inversion can be overcome by running the new signal through a second inverter. The amplification can be neutralized by a tapped output. (If a second inverter was used to restore the original signal polarity, the tap would be on the output resistor of the second inverter.)

Figure 32 shows a single, inverting level setter with the optional tapped output shown in dotted lines. Also in Figure 32 is introduced the signal level code used in the 604. Signal levels are held to a small number of possible variations which can be identified where necessary by small, parenthetical letters. A "(c)" near a wire indicates a signal level from minus 25 to plus 25, such as is obtained from the output of a Cathode Follower (to be described later). A "(t)" indicates the tapped plate output signal with a normal 50 volt shift from about +150 to +100 volts. An unlabeled line is the standard, full plate level shift of 100 volts. There is also a level used to drive a triode switch and called the triode switch level, identified as "(s)", which runs from 0 to —40 volts. The triode switch uses IN units but will be described in later pages.

3. Clipping and Shaping (Figures 33 and 34). It takes sharp, flat, noise free signals to insure proper operation of the 604. As pulses are run throughout the machine, they may become distorted and "sloppy." This

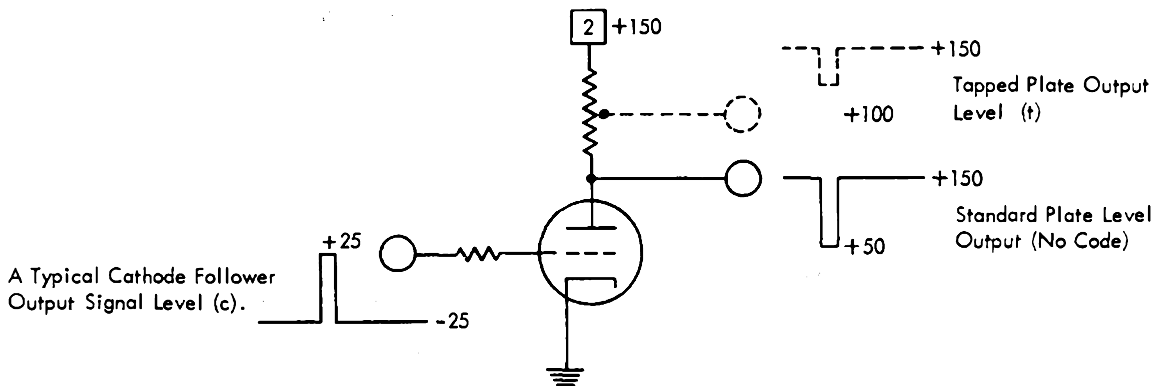


Figure 32. Level Setting

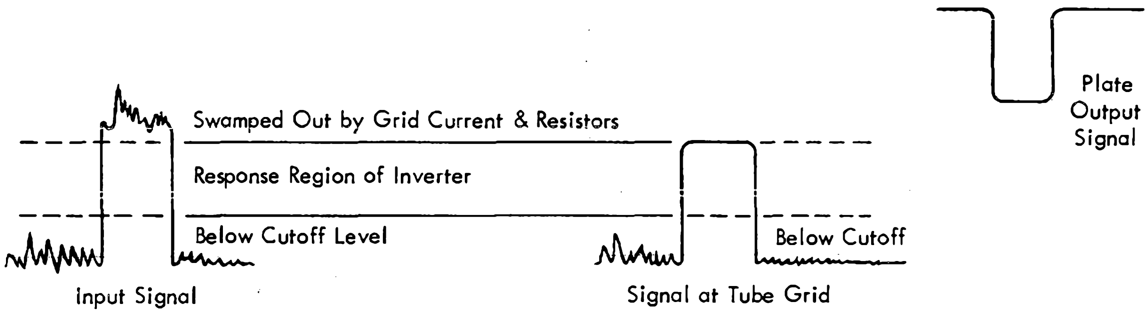


Figure 33. Clipping and Shaping

condition can be corrected by an inverter. Signals more negative than the amount needed to cut off electron flow within the tube are not reflected in the output of an inverter. At the other end, signals which try to drive the grid positive with respect to the cathode are effectively swamped by the grid current which results; the plate current levels off at a fixed point. This over-driving of the units is engineered into the 604 and clips off any roughness at the extremes of a signal. This happens almost every time a normal signal is run through a tube unit as shown in Figure 33. A similar effect results when a signal with a sloping leading or trailing edge overdrives an inverter, Figure 34. A high

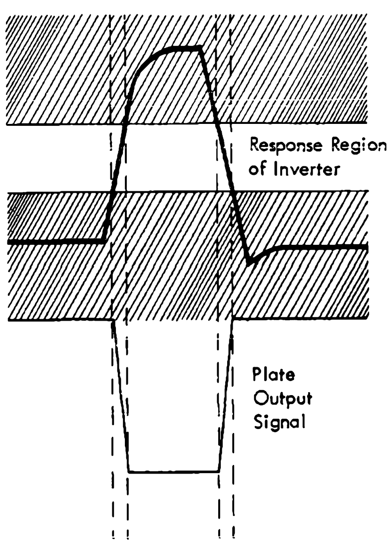


Figure 34. Signal Reshaping

degree of improvement results in the rise time and fall time since only a portion of the rise and fall time produces any actively changing plate signal level. This is a very important function of inverters since sloping wave fronts will not properly operate triggers (which are the sole memory devices used in the 604).

4. Delay (Figure 35). An inverter unit can be used to introduce a slight amount of delay in the transmission of a pulse from one circuit to another. This delay is generally quite short, less than a microsecond, but can help stabilize an occasional circuit. This delay is a function of the coupling to the inverter unit. The compensating capacitor is left out of the circuit, which puts a slope on the leading edge of the signal. The time it takes for the tube grid to rise from a point below cut off to the point where cathode to plate electron flow begins gives the desired delay. The amount of delay can be increased somewhat by adding a small shunt capacitor, Cd in Figure 35.

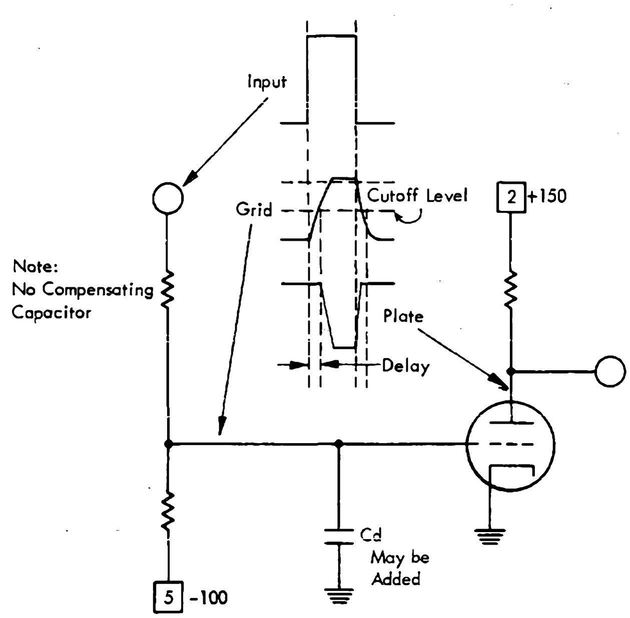


Figure 35. Signal Delay

5. Isolation. Isolation is a very important use of a tube unit. As previously mentioned, variations on the grid of a tube are reflected in the plate circuit because electrons flowing from the cathode to the plate must

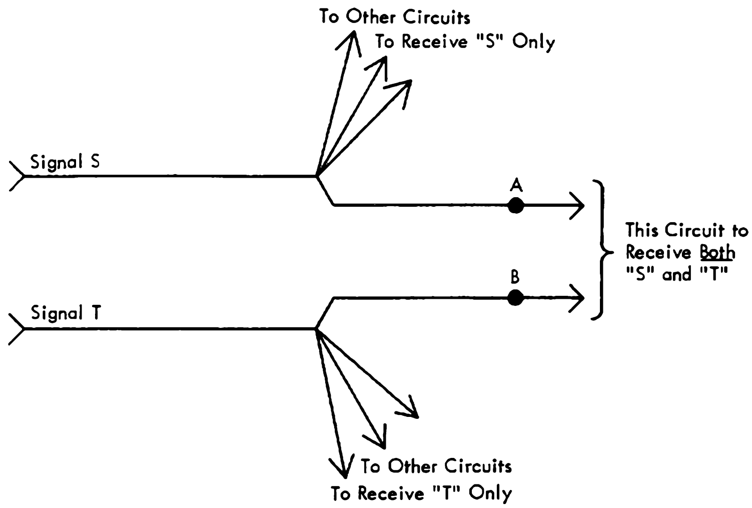


Figure 36. The OR Circuit Mixing Problem

pass through the grid. There is no electron flow from plate to grid, however. Therefore, except for a small capacitative effect between the plate and grid, the grid is electrically independent of the plate. Variations on the plate have practically no effect on the grid or circuits connected to it. Some 604 circuits, such as triggers, can be flipped by stray pulse pick-up (called cross talk or noise) even when applied to their output points. To prevent this effect, the output of a trigger, for instance, will be run through a physically close inverter before a lead of any great length (and therefore liable to stray pick-up) is run throughout the machine. A similar "back circuit" elimination is used in the "OR circuit mixing" to be described next.

6. *The Inverter OR Circuit (Mixing) (Figures 36 and 37).* The problem to be solved is represented by Figure 36. Two separate signals, "S" and "T", which do not necessarily occur coincidentally in time, are used to separately control different circuits within the machine. One circuit, however, is to receive and be controlled by BOTH these signals. Merely shorting together points A and B will provide the desired S and

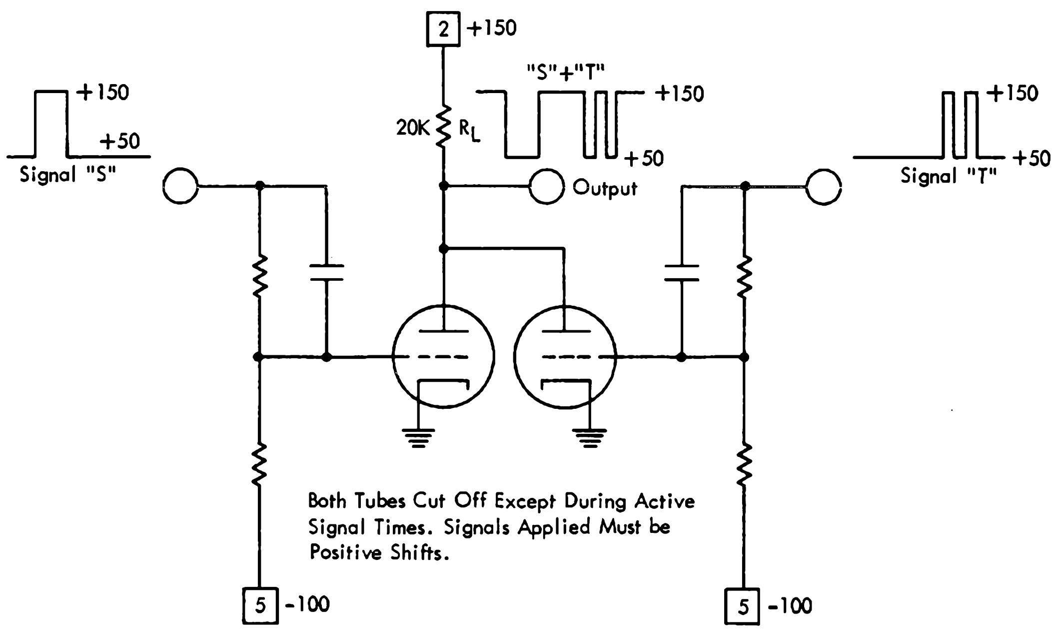


Figure 37. The Inverter OR Circuit (Mixer)

T signals to the desired circuit, *but all the separate S circuits will now also receive the T signal and vice versa.* A circuit is desired which will create an output whenever one signal OR another signal is applied to it without interaction between the input signals. Figure 37 shows one solution through the use of two inverter circuits with separate inputs *but sharing a common plate load resistor.* The values of the components and the circuits which feed this mixer (OR circuit) are chosen so both triodes are normally resting below cutoff. When signal S comes in to the left inverter, this inverter conducts and the inverted signal is developed across the plate load resistor, R_L. When signal T comes in to the right inverter, the right inverter conducts and develops the inverted signal across the same plate load resistor, R_L. Both input signals thus affect the output, but there is no effect upon signal S by signal T or vice versa, because signals on the plate of a tube are not reflected back to the grid.

Almost any number of tubes can be connected to share the same load resistor (so long as each of the tubes is normally cut off) thus making multiple mixing OR circuits possible. Such combinations are used in the 604.

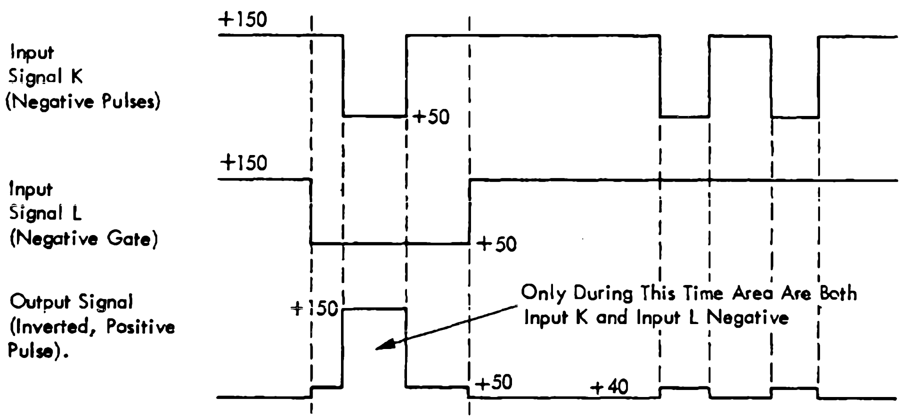
An understanding of the problem solved by an OR circuit mixer is quite important. The solution of the problem is an important application of inverter (IN) units, but other units such as diode types (DS), cathode followers (CF), and pentagrid switches (PS) can solve this same problem. These units will be described later.

By definition, an OR circuit is a mixer which allows two (or more) separate inputs, not necessarily coincident in time, to be combined on a separate output without interaction between the inputs. "This" OR "that" will produce an effect.

7. *The Inverter AND Circuit (Switch) (Figures 38 and 39).* The control of electronic pulses (allowing a pulse to reach a circuit at one time but not at another) is one of the primary design elements in the 604. In electrical IBM machines, series strings of relay points perform this control function; all relay points in the string must be closed before the circuit is completed. In the 604, electronic switches allow similar control. The definition of a switch is *an electronic circuit which requires two coincident inputs to obtain an output.* The logical name "AND circuit" has been applied to such a device because "this" condition AND "that" condition must be true at the same time to secure an effect.

Figure 38 shows the basic electronic problem. It is desired to let only a particular negative pulse from signal "K" get to a circuit and produce an effect. The somewhat wider negative signal (a gate) shown as "L" has a time coincidence with the desired "K" pulse, but not with the undesirable pulses, and can thus be used to make this particular pulse selection possible. Figure 39 shows the Inverter Switch (AND circuit). As with the OR circuit mixer, other types of units which will be described later can also be used to accomplish the same objective.

The circuit of the Inverter Switch is identical to the Inverter Mixer. The only difference is that both sections of the Inverter Switch are driven by a normal no-signal +150 volt level and thus both triodes are conducting during no-signal time (with the Inverter Mixer, both triodes were normally cut off). We have discussed the



Control or Selection of a Pulse is a Problem for the "AND Circuit" Switch.
Waveshapes Drawn are Representative of an Inverter Switch.

Figure 38. Control or Selection of a Pulse

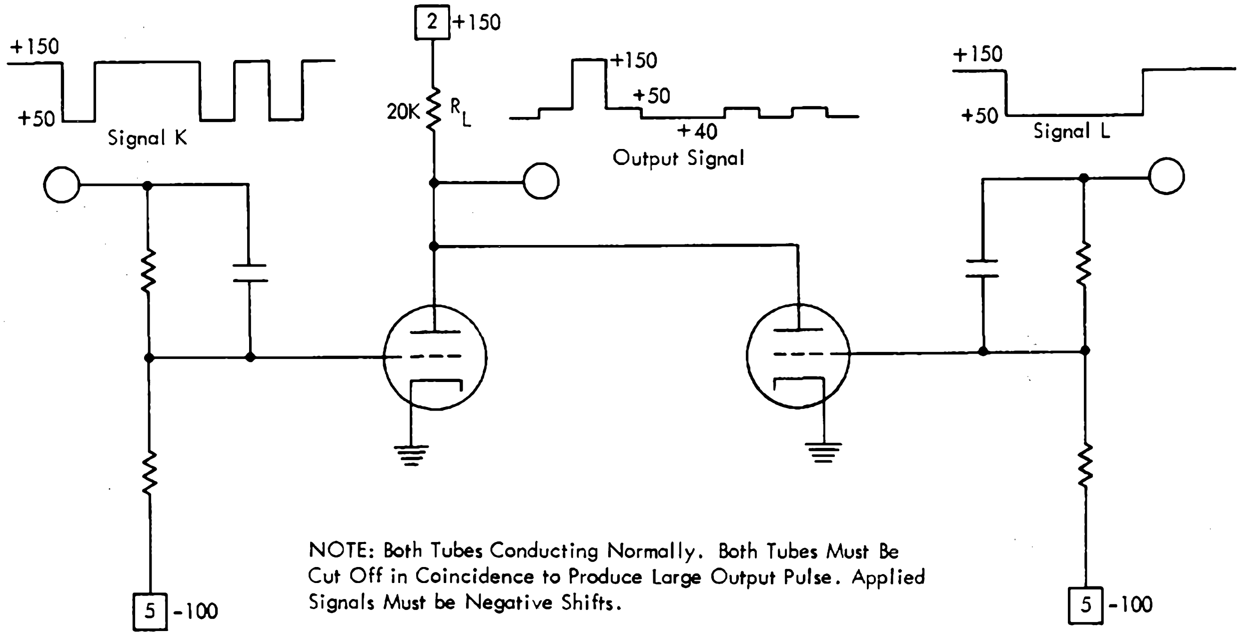


Figure 39. The Inverter AND Circuit (Switch)

fact that one inverter triode conducting through a normal 20k plate load will reduce the potential on the plate down to about +50 volts. When a second inverter triode is connected to share the same plate load and is conditioned to conduct, a current sharing action takes place. When the second triode is told to conduct while the first triode is also conducting, only a plus 50 volt potential is available on the second plate to attract electrons. Electrons leaving the second triode cathode are thus only mildly attracted to the plate, but a few do make the trip and further lower the potential on the tied together plates of both the tubes. This reduces somewhat the electron flow in the first tube. The net effect is that the combined plates fall to about 40 volts (a drop of only 10 additional volts), and the total electron flow through the tubes divides about equally. This is the heart of the Inverter Switch action: either tube conducting alone will drop the combined plates to +50 volts, while both tubes conducting together cause only an additional ten volts of drop. This is shown in Figure 38. Such a small (10 volt) change will have no effect on following 604 circuits. When both triodes in coincidence are cut off, the plate output potential rises to +150 volts. It thus takes two coincident negative going input signals to produce any appreciable voltage level change at the output.

Since the circuits of the Inverter Switch and the Inverter Mixer are identical, examination of the preceding circuits must be made to determine the true action. This will be found true of any circuits in which a load resistor is shared by two or more units. It should be noted that the Inverter Switch is more frequently used than the Inverter Mixer.

Power (PW) Units (G and H)

The inverter units previously discussed are designed to work with tubes capable of passing safely a current of about five milliamperes. The basic pulse amplitude of the 604 is 100 volts; and if 5 ma of current is to produce this much voltage drop, a 20k plate load resistor is required. In some instances twenty thousand ohms is more resistance than can be used for successful circuit operation. For instance, in Chapter One, Figure 5, a general layout of the machine was given. A number of entry channels were indicated as running throughout the machine. These channels feed many units in parallel, each loading the circuit to some degree. Further, the long leads of these channels have considerable capacitance between themselves and ground, and other circuits. To prevent severe distortion and delay of the voltage pulses, these conditions demand a low resistance plate load to drain the capacitive charge quickly at the end of the pulse, and a high current tube to charge the capacitance and drive the receiving unit grids sharply at the start of a pulse. A three thousand ohm plate load is indicated, but a 6J type tube could only produce a twenty to thirty volt shift across such a resistor. It is possible to connect 6J type tubes in parallel

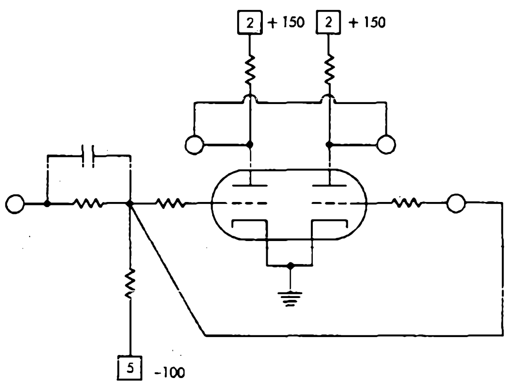


Figure 40. A Semi-Power Arrangement Using Two Triodes in Parallel

to increase the current capacity, but this would require an excessive number of units in some cases. It is done occasionally with the two sides of one IN unit where only a moderate power increase is needed. Figure 40 shows such an arrangement. This hook-up is called a semi-power unit usage of an IN unit. Notice that *both* grids and *both* plates are connected together. Other circuits, such as switches or mixers, connect EITHER the grids OR the plates together, but these configurations are *not* for semi-power reasons.

To achieve the power capabilities desired, using only one pluggable unit, a larger and different tube is used in Power Units (coded PW). One type of power unit, the PW-12, uses a 5965, which is a heavy duty dual triode. The two units are effectively in parallel as discussed above under the semi-power unit connection.

The use of the larger tube type in this circuit permits a 60 volt signal (from +150 to +90 volts) to be developed across a plate load of less than one thousand ohms.

All other PW units in the 604 use a type 6AQ5 beam power tube. The five electronic elements which make up the construction of this tube form the cathode to plate electron flow into a heavy stream or beam. A typical diagram for this power unit, showing the symbol for the tube used, is given in Figure 41.

The larger physical size of the elements within the 6AQ5 tube and the addition of the screen grid between the control grid and the plate both make this tube capable of easily passing the 15 to 30 milliamperes required by certain 604 circuits.

The screen grid in the 6AQ5 overcomes one of the limitations of the triode. As a triode passes electrons to the plate, the plus potential of the plate is somewhat neutralized. The plate potential drops, and it is this drop which constitutes the signal output. However, the lower plate potential does not attract electrons from the cathode with as much force nor in as great a number as would have been true had the plate volage not dropped. In short, the plate potential *must* drop to produce a signal but it should *not* drop if maximum electron flow is to be obtained. These mutually incompatible requirements are resolved by the addition of the screen grid between the grid and the plate.

The screen grid is connected through a 470 ohm limiting resistor to +150 volts. With such a low value of series resistance, very little voltage variation is

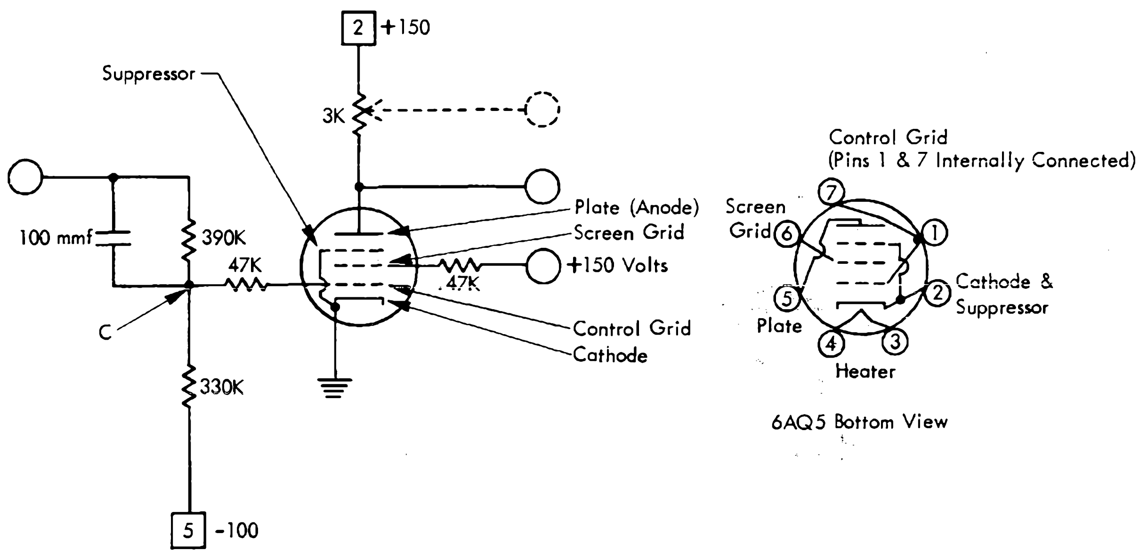


Figure 41. A Power Unit Using a 6AQ5

noticed at the screen regardless of the current drawn by it. Even 10 ma of screen current (which is excessive for a 6AQ5) would lower the screen voltage only 4.7 volts to about +145. The screen potential thus remains quite stable despite the amount of current flow through the tube. Since the screen is located physically nearer to the cathode than is the plate, the screen exercises a greater attractive force for electrons boiled off the cathode than does the plate. In fact, the potential on the plate is practically unfelt at the cathode, due to the screening action of the screen grid. When the control grid permits them to do so, the electrons from the cathode stream toward the attractiveness of the screen grid. The screen grid is made of turns of fine wire with wide spaces between the turns. By the time the electrons get near the screen grid wires, they are traveling so fast that they are unable to turn and actually land on the wires. Instead, most of them pass right by the screen and continue going until they strike the plate. These electrons trying to flow through the 3,000 ohm plate load resistor cause the plate potential to drop and thus develop the output signal, but the lowered plate potential does not reduce the number of electrons striking the plate. The net result is that an output signal level change from +150 to +40 volts is produced across a 3000 ohm plate resistor. This signal is too large for some applications, and as a result some power units use a plate resistor with an adjustable tap to permit any desired signal amplitude to be obtained. This tap *must* be adjusted any time a tube is replaced in such a unit to insure specified output (generally a fifty volt signal). Figure 41 shows this tapped output in dotted lines.

The suppressor grid shown between the screen grid and the plate of Figure 41 prevents electrons from returning to the screen grid from the plate under certain conditions of operation. With the power tube passing a heavy electron flow, the positive potential on the plate may only be thirty to forty volts due to the voltage drop through the plate load resistor. As the electrons are thrown at the plate by the action of the screen, a chipping effect takes place. Secondary electrons are knocked off the plate and could readily be attracted to the screen grid, since under these conditions the screen still has a plus potential of nearly 150 volts on it while the plate is only at 30 volts or so. Any electron flow from plate to screen would decrease the effective plate current and increase the screen current; both effects are undesirable. This is prevented by the suppressor which is electrically connected to the cathode within the tube and thus presents a repelling, negative barrier to any slow moving electrons released by the plate. The higher velocity electrons traveling from the cathode to the plate are only sightly affected. Having five active elements within its glass envelope, such a tube is called a pentode (*penta* indicating five). With some types of tube construction the suppressor grid is not physically included, the effect being obtained from a repelling

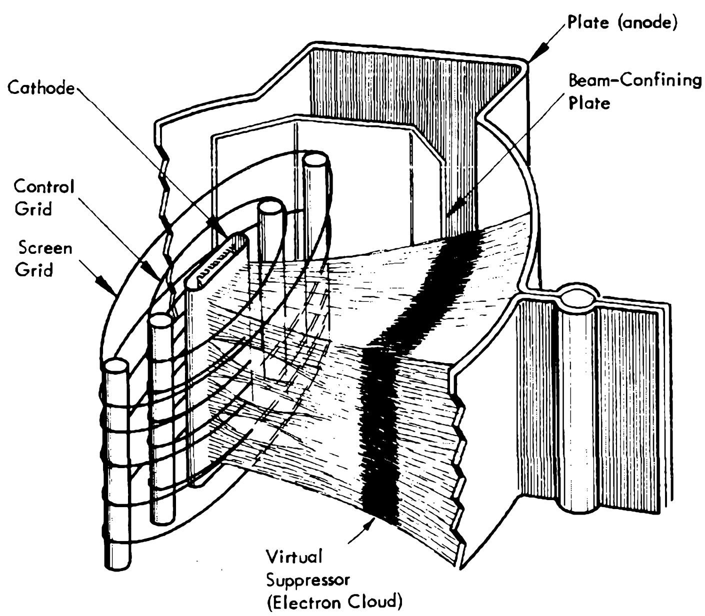


Figure 42. A Beam Power Pentode

cloud of electrons produced by the beaming of the electrons toward the plate. Figure 42. In this case the beam confining plates are the fifth tube element. They are generally represented by the tube symbol in the same way an actual suppressor grid would be drawn and as indicated by Figure 41.

The pentode tubes used by the 604 require a potential of nearly —20 volts on the control grid to cut off most of the electron flow. This is twice or more than required by the dual triode 6J type. The values of the resistors in the power unit grid circuit are different from those generally found in inverter units in order to produce a voltage swing from —32 to +14 at point C, Figure 41. As with the inverter unit, if the tube cathode is hot, the drawing of grid current will keep the plus level at something less than +1 volt.

In summary, type PW units are high power inverter units using pentode tubes or, in the PW 12, a heavy duty dual triode. The PW units are used when a number of tubes are to be driven in parallel or when a circuit wire must physically run for a considerable distance.

Cathode Follower (CF) Units (H suffix only)

The Cathode Follower is a type of circuit which is in certain ways even better than a Power Unit for driving many parallel circuits or long lead length circuits. It is extensively used in the H suffix machine but not at all in the G and earlier.

Throughout this discussion of the 604 electronic circuits, the term "voltage on the grid with respect to the cathode" has been frequently used. It is this difference of potential which controls the electron flow within a tube. The voltage on the plate with respect to the cathode also has an effect on the cathode to plate electron flow, but a relatively weaker on. In circuits discussed up to now the tubes had their cathodes connected directly to ground and any change in voltage on the grid was totally reflected as a change in grid to cathode potential. In the cathode follower this is not the case. Figure 43 shows that a resistor has been connected between the cathode and a point with a potential 100 volts below ground (that is, 100 volts minus). The plate of the tube is now connected directly to +150 volts. In effect, the plate load resistor of the inverter type unit has been shifted down through the tube to the cathode circuit. With this arrangement, any change in electron flow through the tube directly affects the potential on the cathode with respect to ground. It is this change in cathode potential which constitutes the output signal, just as the plate level change in inverters, power units, etc., makes up *their* output. An important result of this shifting cathode potential is that the grid to cathode potential is changed every time the cathode level shifts, and the cathode potential shifts every time the grid potential is changed. This interacting effect is the heart of cathode follower operations.

Unlike other unit types of the 604, cathode followers are designed so they never cut off, nor are they driven into the grid current region. Electron flow through the tube is always present. As the grid moves toward a more positive potential, the electron flow through the tube increases, more electrons are removed from the cathode, and the cathode becomes less negative (more positive). If the grid is shifted in a negative direction, the electron flow through the tube is reduced; this reduces the electron flow through the load resistor, R_L, and as a result the cathode moves nearer to —100 volts. That is, the cathode also shifts in a negative direction. This means there is no inversion of the signal through

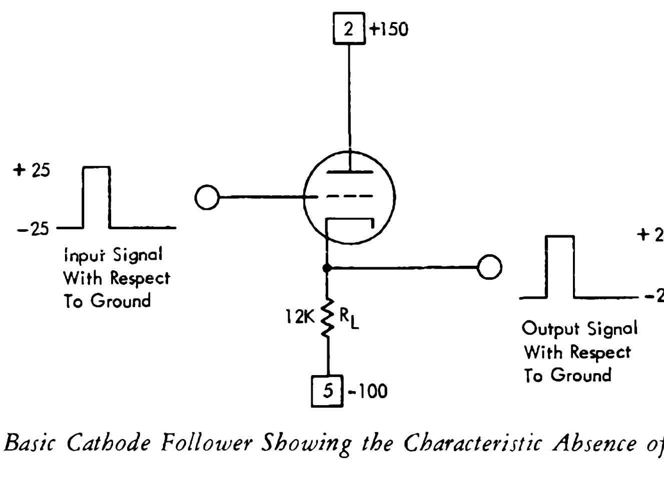


Figure 43. A Basic Cathode Follower Showing the Characteristic Absence of Signal Inversion

a cathode follower. At times this is an advantage, at other times not, but it is an invariable fact in any event.

A type 5965 tube is generally used in 604 cathode follower units. This tube will cut off when the voltage on the grid *with respect to the cathode* is more than five volts negative, and it will draw grid current whenever the grid goes positive *with respect to the cathode*. The normal signal applied to the grid itself of a 604 cathode follower is from −25 volts to +25 volts with respect to ground, and yet the statement was made, and is true, that the cathode follower tube is never driven either to cut off nor into the region of grid current flow. The answer to this seeming contradiction lies in the fact that the cathode *follows* the grid, always staying slightly more positive than the grid, and always staying within zero to five volts of the grid potential. This of course means the signal output voltage from the cathode can never be greater than the signal applied to the grid. There is actually a slight signal voltage loss through a cathode follower, but there is a power (current) gain which makes the circuit useful.

The reason for the cathode's staying within a few volts of the grid can be seen by considering the circuit of Figure 43. If the −25 volt signal on the grid of the tube did manage to cut off cathode to plate electron flow, there would be no electron flow through the load resistor, R_L, and the potential on the cathode would then drop to −100 volts (75 volts more negative than the grid). Put another way, the *grid* would be 75 volts more *positive* than the cathode. This would demand a heavy electron flow through the tube and would cause the cathode to move in a plus direction. But if the cathode goes more than five volts positive *with respect to the grid*. the tube electron flow will be cut off (since this is the same to the tube as having its grid five volts negative with respect to its cathode). If the electron flow is stopped, we are back to the starting point of our discussion. Neither of these extremes happens, of course. Instead, for any given input signal the cathode instantly shifts to a balance point that will make the grid to cathode voltage remain within the operating range of the tube.

In the cathode follower circuit a change in the cathode potential has as much effect on the electron flow through the tube as a change in grid potential. This introduces the second important point about a cathode follower, the "stiffness" of its output signal. A cathode follower has a low output impedance, which simply means that any stray signal which may happen to be picked up by a circuit connected to the cathode output is effectively swamped or balanced out. This fact made it possible in the 604H suffix to eliminate the shielded cables found in earlier machine to prevent trouble from stray pick-up (cross talk) on the long entry and exit channels that run throughout the machine. Plain wires and cathode followers are used in the H suffix where power units, inverters, and braid shielded cables were formerly needed.

The reason for the output circuit "stiffness" of a cathode follower can be seen by imagining a stray picked up signal that tries to drive the cathode negative. This has the same effect within the tube as making the grid more positive. This increases electron flow through the tube and tries to make the cathode go in a positive direction, instantaneously neutralizing to a very large degree the effect of the initial stray, negative signal applied to the cathode. A stray positive signal produces a similar effect in reverse. We have, in a manner of speaking, provided electronic shielding to the output circuits.

In summary, a cathode follower:

1. Does not invert the input signal.

2. Gives out slightly less signal voltage than is applied to the grid.

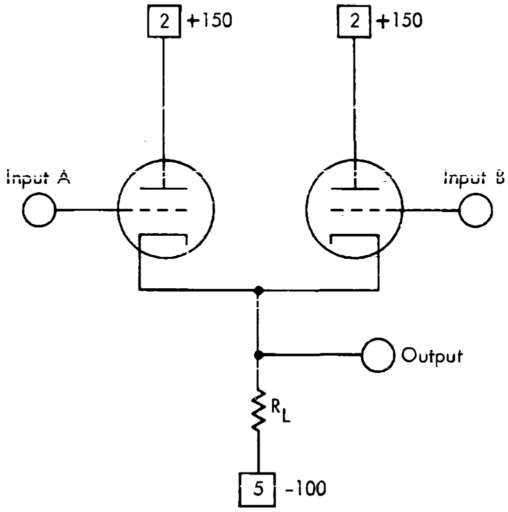
3. Gives a gain in signal power through heavier electron flow.

4. Has a stiff (low impedance) output.

CATHODE FOLLOWER SWITCHES AND MIXERS (FIGURE 44)

As was true with two inverters sharing a common load resistor, two cathode followers sharing a common load resistor can be used either to combine signals (the OR circuit mixer) or to control pulses (the AND circuit switch). Figure 44 shows the basic circuit for both these logical functions. As was true with the inverter circuits, the polarity of the input signals makes the difference. It is as a switch (AND circuit) that the 604 generally uses this arrangement.

Whichever tube has the more positive signal input to its grid controls the output at the cathodes. If the no signal point of both grids is −25 volts, with respect to ground, the combined cathode output will be near −22 volts. If input A is shifted to +25 volts, the left cathode will rise to about +26 volts and draw the right cathode up with it. With the right cathode at this +26 volt level and the right grid still at −25 volts with respect to ground, the right tube is completely cut off

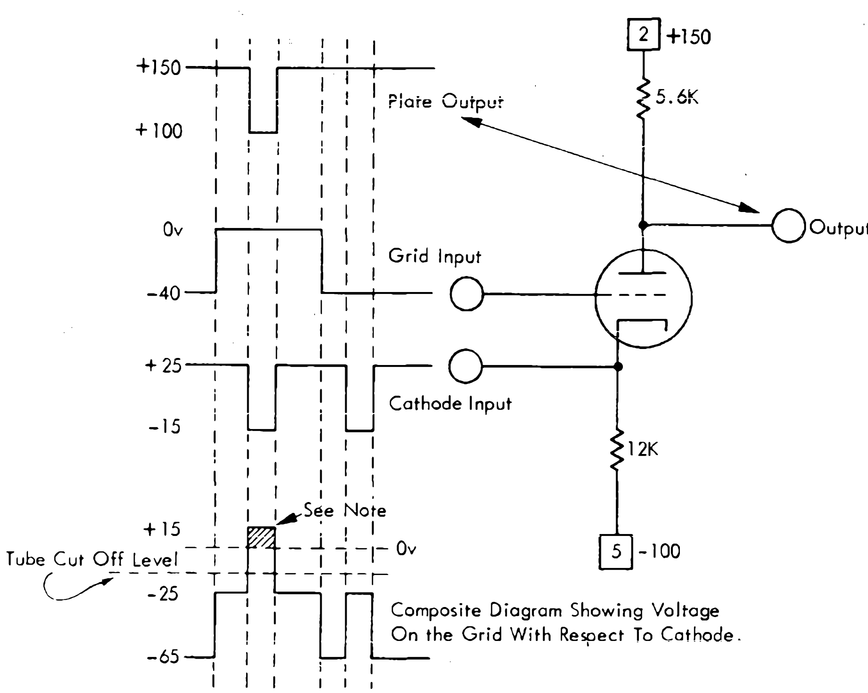


Input A	Input B	Output	
−25	−25	−22	(Mixer No Signal Condition)
+25	−25	+26	
−25	+25	+26	
+25	+25	+26	(Switch No Signal Condition)

Figure 44. The Cathode Follower Switch Circuit

and no longer acting as a cathode follower. The left tube is thus controlling the output since it has the more positive grid. Returning input A to −25 volts and raising input B to +25 volts produces the same type of action. A plus input on either grid will thus produce an output. There is no interaction between input circuits, and thus the conditions required for an OR circuit mixer have been met.

When used as an AND circuit switch, a resting no-signal condition of +25 volts is on both grids. As long as either grid is positive, there will be no output variation. Only when both grids go minus at the same time



Note: Portion shown shaded (where grid goes plus with respect to cathode) will, if cathode is hot, be swamped due to grid current flow.

Figure 45. The Basic Triode Switch Unit

will the cathode level drop and produce an output signal. This meets the requirements of a switch, a device which requires two coincident inputs to secure an output signal. In this case both the input signals and the resultant output are negative shifts. These actions are summarized in the chart of Figure 44.

The Triode Switch (H suffix only)

The Triode Switch uses an inverter, IN type unit, but involves some of the principles discussed under the cathode follower. A triode switch has a resistor in both the cathode lead and the plate lead. Input signals are applied to the grid and across the cathode resistor, with the output taken from the plate of the tube, as shown in Figure 45.

Once again it must be emphasized that it is the voltage on the grid *with respect to the cathode* that controls the electron flow through a tube. The grid of a triode switch is driven over a range of —40 to 0 volts with respect to ground. The cathode is driven from +25 to —15 volts, again with respect to ground. Translating these values into the important grid to cathode relationship shows that the grid varies from —65 to +15 volts *with respect to the cathode.* This is shown by the bottom graph on Figure 45. Any time the grid is more than five to ten volts negative with respect to the cathode, the tube current is cut off. As a result, only when the grid is at the zero volt level with respect to ground AND the cathode is at the —15 volt level with respect to ground, can cathode to plate electron flow take place. Only at this time is the tube not cut off. We thus have the requirement of a switch: it takes two coincident inputs to secure an output shift. With the triode switch, one plus shifting signal is used on the grid and one negative shifting signal on the cathode to secure a 50 volt negative shift in plate output during coincident time.

Both inputs to a triode switch generally come from cathode followers. The grid signal level (from —40 to 0) is voltage-wise obtained most easily from a cathode follower, and the cathode signal input (+25 to —15) must be from a stiff, low impedance source ideally supplied by a cathode follower. The particular voltage levels needed are secured from the proper selection of resistor values in the cathode follower driver circuits. A typical diagram is shown in Figure 46.

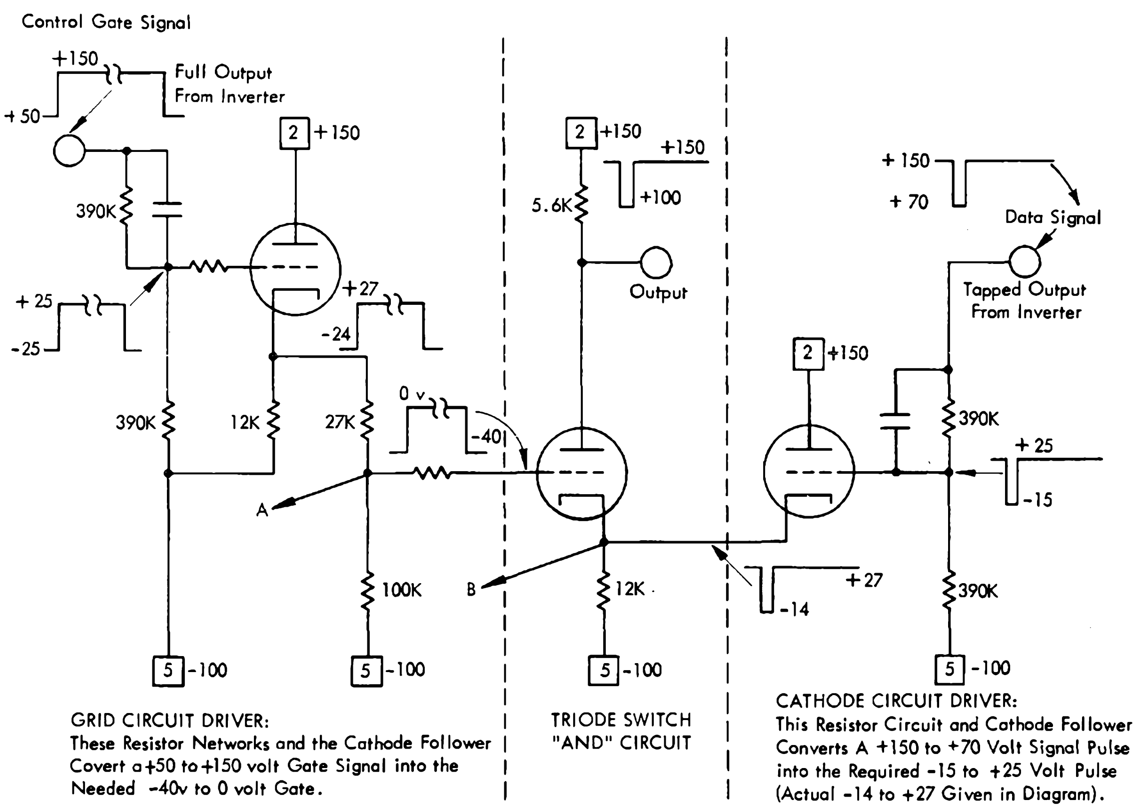


Figure 46. The Practical Triode Switch and Driver Circuits as Used in the 604H Column Shift Unit

The illustration shows the actual components used in the 604H Column Shift unit which makes the major use of Triode Switches. The Control Gate Input at the upper left of the diagram has its level changed by the resistor net feeding the grid of the cathode follower driver. A resistance network in the cathode circuit converts the Control Gate into the necessary voltage levels for application to the grid of the triode switch.

The Data or Information Signal entering at the upper right of the diagram also has its voltage level changed by a resistance circuit before being applied to the grid of the cathode follower driver. This tube drives the cathode circuit of the triode switch and provides the needed second input at the proper amplitude and level.

The Column Shift Unit of the 604H uses sixty-three triode switches, but this does not mean that individual driver tubes are needed for each switch tube. Figure 46 shows two leads, A and B, which each control five or more separate triode switch tubes. The total number of tubes is thus less than might at first glance be expected, and since two triode switches are available in one pluggable unit, the space required by the 604H Column Shift circuits is comparatively small.

The Pentagrid Switch (PS) Unit (G and H)

The Pentagrid Switch unit uses a special, multi-element tube in a circuit specifically designed for switching applications. In machines prior to the H suffix, 63 of them were used in the column shift unit alone, as well as for numerous applications in other areas. H suffix machines use fewer of these units, but their application is still extensive.

Figure 47 shows the basic elements of a Pentagrid Switch unit. An electron leaving the cathode must pass through two grids, one after the other, before reaching the plate. Either one of these grids, if sufficiently negative, can repel the electrons and cut off the cathode to plate electron flow. Both grids must be at their high, or plus level at the same time to permit electrons to reach the plate and produce a negative output signal shift. It thus takes two coincident conditions to produce an output shift, meeting the requirements of a switch unit. As is true of tube circuits using grid input and plate output, the signal is inverted in passing through the unit.

Pentagrid switch units use the IBM type class 6B tube; the commercial 6BE6 was the basis for its design. Special industrial tubes, such as the 1680 or 5915A, are actually used in the 604. Different type numbers are used from time to time as engineering designs or finds improved performance possibilities. A —6 volt potential on either control grid with respect to the cathode will cut off electron flow to the plate.

Figure 48 shows an actual PS unit circuit and represents the 6B tube as it really is. There are not just two, but five grids within the tube (thus the name, *pentagrid*), numbered from one to five as they are located in the electron stream from cathode to plate. Grids 1 and 3 are the control grids. Grids 2 and 4, called screen grids, are internally tied together and connected through an external 470 ohm resistor to +75 volts. These two grids accelerate the electrons on their trip from cathode to plate (which of necessity is somewhat longer than that found in triode tubes). They also act as shield screens to reduce interaction and cross talk between the control grids and to make the cathode to plate electron flow relatively independent of plate potential. Grid number five is called the suppressor and is internally connected to the cathode. Its function is to repel back to the plate any slow-moving secondary electrons which are chipped off the plate by the high velocity cathode to plate elec-

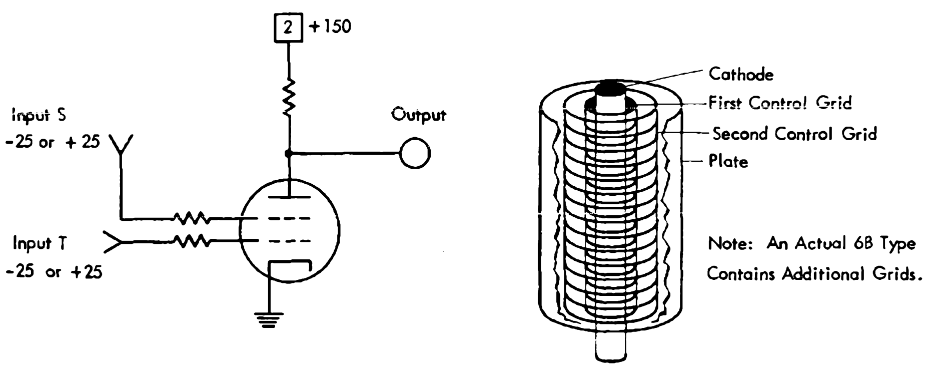


Figure 47. The Basic Circuit of the Pentagrid Switch Unit and a Cutaway View of a Simplified Tube for Use in the Circuit

trons, as was discussed under "Power Units." The large number of grids and the resultant close spacing between the elements makes this tube more liable than other types to develop internal shorts. For instance, the spacing between the cathode and the number one control grid is about .015 inch. A small flake of oxide material from the cathode can cause intermittent or permanent shorts between the cathode and this grid. Where a number of these tubes are connected in parallel (as in the G suffix column shift) such shorts can appear to be trouble in units other than the one actually at fault; knowing this can help trouble analysis.

In practice, the signals applied to the input points of the unit shown in Figure 48 vary from a down level of +40 volts to an up level of +140 volts. The resistors in the grid circuits will convert these levels to about −25 to +25 volts at the grids themselves. The drawing of grid current will generally prevent the up level from going much above +1 volt *at the grids.* However, if grid number 1 has cut off electron flow through the tube, there will be no electrons around for grid number three to draw. Under these conditions grid three *can* go to +25 volts if its input signal is at the high level. If the cut off voltage on the number one grid should now be shifted and permit electrons to flow, the number three grid would have electrons to draw and would drop to the one volt point. The effect of this 24 volt change in grid number three potential can be noticed on some scope pictures, especially where slave units are involved. While this effect is considered in machine design, the high values of the resistors used in the grid circuit prevent most of this shift from being reflected back to the input point and driving tube.

VARIATIONS IN PENTAGRID SWITCH UNIT CIRCUITS

There are thirty different types of PS units used in the 604 series of machines. The basic variations to be found in the plate circuit or in the grid circuits of PS units are the same as those discussed under Inverter Units:

1. The compensating capacitor to prevent signal distortion.

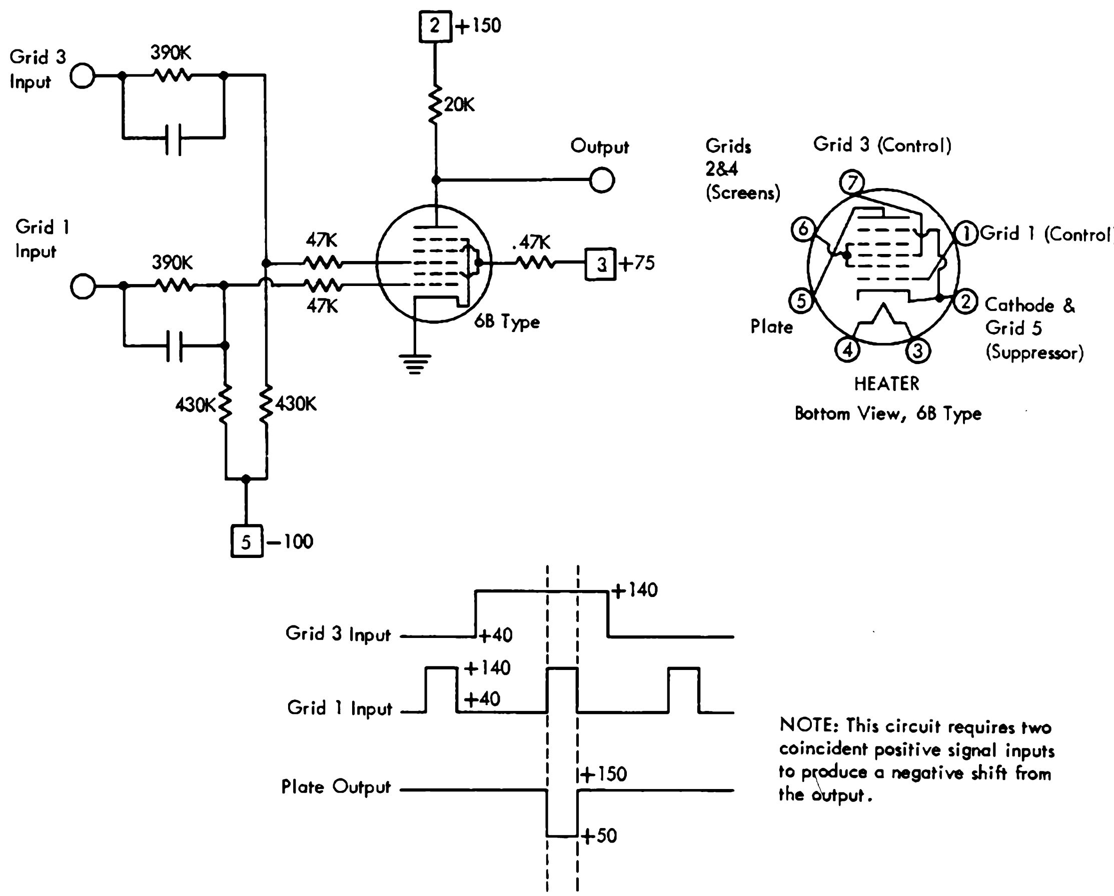


Figure 48. A Practical Pentagrid Switch Circuit Showing All Five Grids and the Base Connections for IBM 6B Class of Tubes

2. The grid to ground shunt capacitor to desensitize that input and swamp out noise.

3. The coupling capacitor to separate the AC component from the DC and to convert long duration gates into short peaked pulses.

4. The tapped output to reduce the amount of output signal shift taken from the plate circuit.

5. The slave unit to work in conjunction with other units to save components.

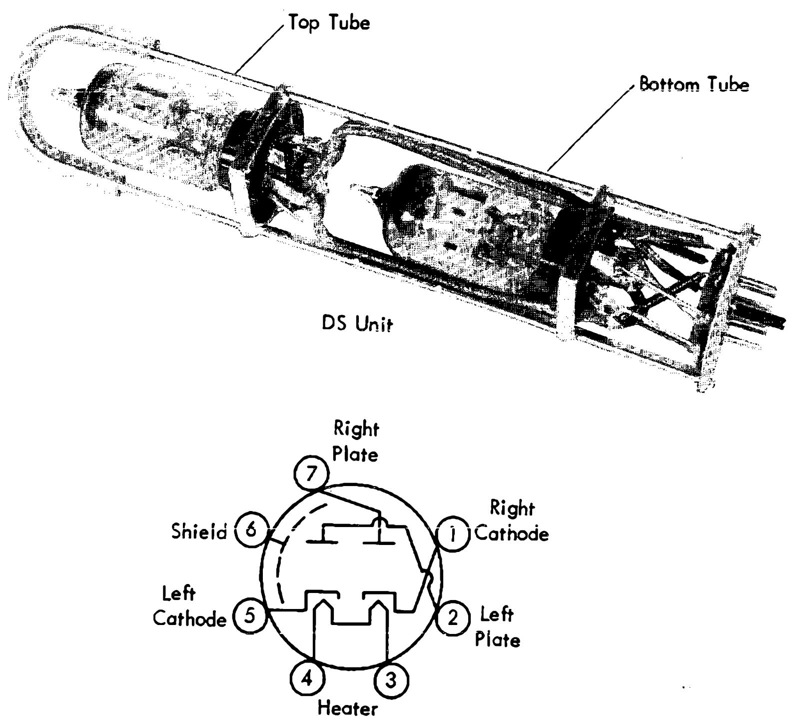
There is one unique variation for the PS unit; connecting the two control grids together produces a unit having the ability to amplify rather greatly any variations in input level. Very small changes on the grid (s) produce large changes in the output level. This principle will be found used in the regulating portion of the reset circuits to be described later.

In several instances in the 604, the PS unit will be found used as an OR circuit mixer. In these cases the normal resting point of the input signals will be at the up level (+150 volts). The tube will normally be in conduction. Dropping the signal level to one grid OR the other will shut off cathode to plate electron flow and produce a positive output shift from the plate. Such usage is rare, but will be found (in the Column Shift Control circuits, for instance).

The Diode Switch (DS) Unit (H suffix only)

The simplest and smallest per circuit AND/OR device used in the 604 is the DS unit using two 6AL5 dual diode tubes mounted in one pluggable unit. Figure 49 shows the small physical size of these tubes and the small number of components needed. There are four tube sections within such a pluggable unit. To permit specific identification, this makes necessary the addition to the panel location code of the letter "T" for top tube and "B" for bottom tube. When used with the already discussed subscript 1 for the left tube section and 2 for the right, this will provide the needed exactness. 3-8EB$_1$ would indicate a diode section in panel 3, row 8, column E, bottom tube, left half.

A diode will permit electrons to flow only from its cathode to its plate. This electron flow will only take place within the diode if the plate is more positive than the cathode. The Diode Switch (which can also be used as a mixer) makes use of this fact. When the diode is



Bottom View, Type 6AL5

Figure 49. A Diode Switch Pluggable Unit and the Base Diagram for Type 6AL5 Tubes

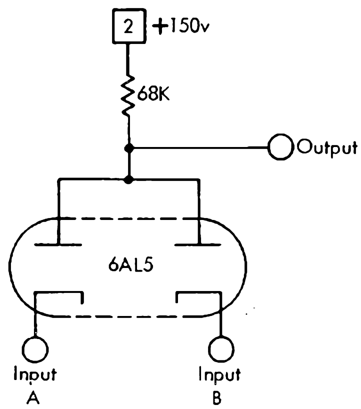
passing electrons to the more positive plate, the tube acts much like a short circuit (the actual conducting resistance of a 6AL5 is in the range of 200 to 1,000 ohms, depending on voltage conditions). The tube acts like and is an open circuit when the plate is more negative than the cathode.

A cathode follower signal shift from −25 to +25 volts is generally used to drive a DS unit, though inverters, pentagrid switches, or power units can also provide the needed drive. There is no amplification of any kind in a diode, and as a result it will load (draw electrons) from any circuit feeding it. Because of the sensitivity of trigger units to loading, they are not generally connected directly to Diode Switches. The operation of triggers will be covered later.

The input signals to a DS unit can be applied either to the cathodes or the plates; these options will be discussed separately.

CATHODE INPUT

With the circuit of Figure 50, the two plates share a common 68k load resistor which runs to the +150 volt supply. Input signals are applied to the separate cathodes. Whenever a cathode is more negative than its plate, that diode will act as a very low resistance and draw the plate down to within a volt or so of the cathode level. The plate of the second diode (sharing the same load resistor) will also be pulled to the same lowered level. If this makes the second plate more negative than its associated cathode, electron flow through the second diode will be stopped. Whichever cathode is most negative will therefore control the output level and stop electron flow in the other diode (or diodes if more than two are sharing the same load resistor). If the cathodes of the diodes have the exact same potential, there will be a sharing of electron flow and the plates will approach closely the cathode level. The chart in Figure 50 shows all the conditions possible when cathode level signals are used to feed such a circuit. While OR circuit usage is possible, within the 604 this circuit is used exclusively as an AND switch. The resting point for both cathodes is at −25 volts; both input signals must shift to the +25 volt level to permit the output point to rise (two coincident inputs to get an output signal).



If Input A is:	And Input B is:	The Output Level Will Be About:
+ 25 v	+ 25 v	+ 25.5v (Both Tubes Share)
− 25 v	+ 25 v	− 24v (Left Tube Conducts)
+ 25v	− 25v	− 24v (Right Tube Conducts)
− 25 v	− 25 v	− 24.5v (Both Tubes Share) ← AND Circuit Starting Conditions

NOTE: The output level will be about equal to the voltage at the most negative (or least positive) cathode. This circuit is used in the 604H as an AND circuit switch.

Figure 50. A Diode Switch with Cathode Input

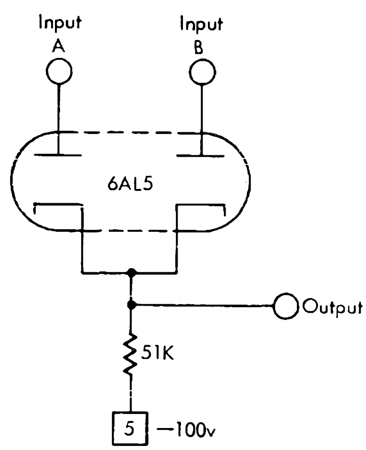
PLATE INPUT

With the plate input arrangement, the cathodes are connected to share a common, 51k load resistor which returns to the —100 volt supply. This introduces a form of cathode follower action. The cathodes will try to rise to the most positive plate. If one of the plates is more positive than the other, this plate will draw both cathodes up to within about a volt of itself. The second cathode will thus be more positive than its associated plate and the electron flow through this second section will cease. If both plates are at the same potential, each tube will pass a share of the total electrons. This arrangement is used in the 604 as an OR circuit mixer by placing the diode plates at a no-signal level of —25 volts. The cathode output will rest at a slightly more negative potential (near —25.5 volts). If one of the plates should be raised to +25 volts, the cathode line will be pulled up also. One input OR another input will thus produce an output. Since electron flow through the non-active diode(s) ceases, there is no interaction be tween inputs. One application in the 604 H True-Compliment Trigger Control circuit has five plate input diodes sharing a common load resistor, making it a five channel mixer. The chart of Figure 51 shows the possible voltage output conditions when cathode level inputs are applied to the plates.

Germanium Crystal Diodes and Selenium Rectifiers (G and H)

Germanium crystal diodes and selenium rectifiers act much like the tube diodes in that they permit electrons to flow readily in one direction but not in the other. These semi-conductors have a very low forward resistance, but unlike vacuum tube diodes they do leak electrons in the back direction. This limits their use in certain applications. Crystal diodes are very small, have very little stray shunt capacitance, and require no cathode heating. They can readily be used in switching circuits, but the greater cost and the ease with which they can be destroyed by even momentary overload has limited their use in the 604 to a few applications where space is a factor.

The construction of a typical germanium diode and the diagram symbol for it is shown in Figure 52. Electrons flow readily from the germanium block to the metal "cat's whisker", but with great difficulty in



If Input A is:	If Input B is:	The Output Level Will Be About:
—25 v	—25 v	—25.5 v (Both Tubes Share)
—25 v	+25 v	+24 v (Right Tube Conducts)
+25 v	—25 v	+24 v (Left Tube Conducts)
+25 v	+25 v	+24.5 v (Both Tubes Share)

← OR Circuit Starting Conditions

NOTE: The most positive plate will set the output level.
This circuit is used in the 604H as an OR circuit mixer.

Figure 51. A Diode Unit with Plate Input

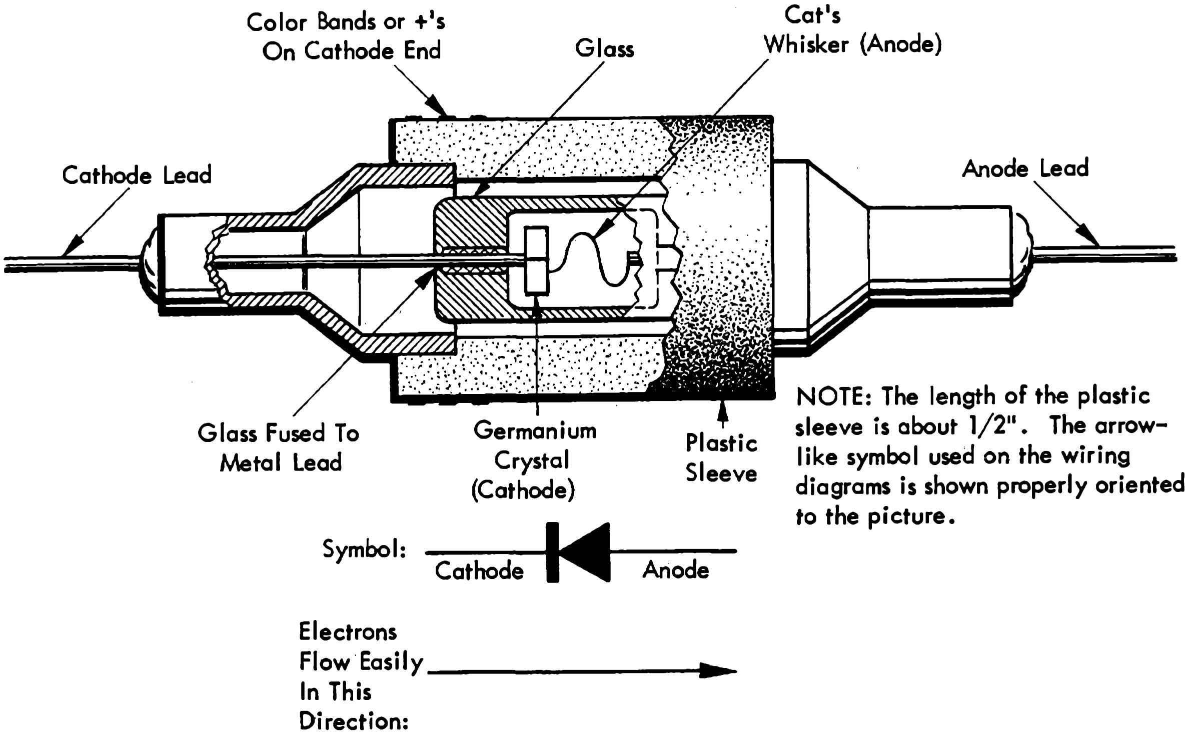


Figure 52. An Enlarged Diagram of a Germanium Diode Showing Construction

the reverse direction. The germanium thus acts like the cathode and the "cat's whisker" like the plate or anode. Since the internal construction of a germanium diode is most often not visible, an identifying band of color (or a plus symbol) will be printed on the *cathode end* of the case. Some diodes will instead have the diode symbol imprinted on the case. Note particularly that (except for leakage) electron flow through the diode is *opposite* to the direction of the arrow symbol. This can possibly be remembered more easily by visualizing the arrow symbol to be as drawn in Figure 53.

Typical germanium diodes will have forward resistances of from 50 to 500 ohms and back resistances of from 100,000 to 1,000,000 ohms. These values vary with the diode, the current, the temperature and the applied voltage. Forward current ratings of small diodes range near 25 to 50 milliamperes, and the maximum

Figure 53. Derivation of the Symbol for Solid State Diodes

voltage across the diode in the reverse direction must be limited to 50 volts or less (100 volts with some types). Diodes are easily ruined by excessive heat. For this reason field replacement within units (where soldering is required) is not advised. Replace the complete unit.

Selenium rectifiers have the same symbol and general action as crystal diodes. They are physically larger (being made up of stacks of steel plates coated with alloys and selenium), have higher internal shunt capacitance, and have a higher resistance to the passage of electrons in the forward direction. They are used in the 604-521 as power rectifiers, arc suppressors, and polarity traps, due to their availability in higher current and reverse voltage breakdown ratings. They are less susceptible to burnout from momentary current overload, which makes them useful in circuits with high transient conditions. Some of the smaller selenium rectifier diodes, such as are used in the wiring of the 604 electronic tube gate panels, are encased in small cardboard tubes. The cathode end is identified the same as germanium diodes.

Thyratron (TH) Units (G and H)

Filling the glass envelope of an electron tube with a gas such as argon increases the current carrying capabilities of the tube from two to ten times. Such a tube is called a thyratron and is an excellent high current, low voltage control device. It also has certain other characteristics which make it very useful whenever a relay or a punch magnet coil must be energized under electronic control, as when punching out calculated answers. The industrial type 2D21 tube is used in all thyratron units of the 604. This tube, about the physical size of the 6AQ5, is capable of passing the 80 milliamperes required by the usual relay coil and up to the 400 milliamperes required for brief periods when energizing a punch magnet coil. Figure 54 shows a typical circuit and the basing diagram for the 2D21. Notice the dot within the tube diagram which indicates a gas filled envelope.

As with a vacuum tube, electron flow through a thyratron tube can be held cut off by a negative potential on the grid. Minus 5 volts is enough to hold a 2D21 non-conducting with 65 volts applied to the plate. If the grid is driven to zero volts for several microseconds, the electrons streaming toward the plate will strike and break down into ions the gas molecules inside the tube. This ionized gas blooms throughout the cathode to plate area and conducts heavy current. Some of these ions (which have a positive charge) are attracted to the grid and neutralize any further electrons which may flow to it from the external circuits. Because of this, it is impossible to cut off a once fired thyratron by reapplying a negative potential to the grid; the ionized gas in the tube simply will not allow the grid to become negative. A resistor in series with a thyratron grid is mandatory to limit grid current and prevent tube damage under these conditions. The only way to stop current flow in a thyratron, once it is started, is to disconnect the plate potential long enough (fifty microseconds or more) to allow all the gas molecules to recombine and deionize. The grid can then go negative and assume control again. This action provides an excellent way to convert a short electronic pulse into a time duration long enough to cause a mechanical action.

Because of the gas in the tube, the voltage drop from cathode to plate within a conducting thyratron will not exceed 10 to 15 volts regardless of how much current is passed through the tube. The circuits using thyratrons must be designed to limit the current to a safe value for the conducting time involved. This small voltage drop through the tube permits the use of lower voltage power supplies within the punch. These are safer and less expensive.

The circuit shown in Figure 54 is typical of the different TH unit types used in the 604. The magnet coil to be energized is placed in the *cathode* circuit simply to permit a common connection among the negative sides of all coils in the 521, as has been common practice in IBM high speed punches. The circuit breaker in the plate supply lead allows mechanical control of the tube shut-off after sufficient energization time for the coil has been allowed. The 25 micromicrofarad capacitor between the tube grid and cathode is to bypass undesired transients that might be picked up and which

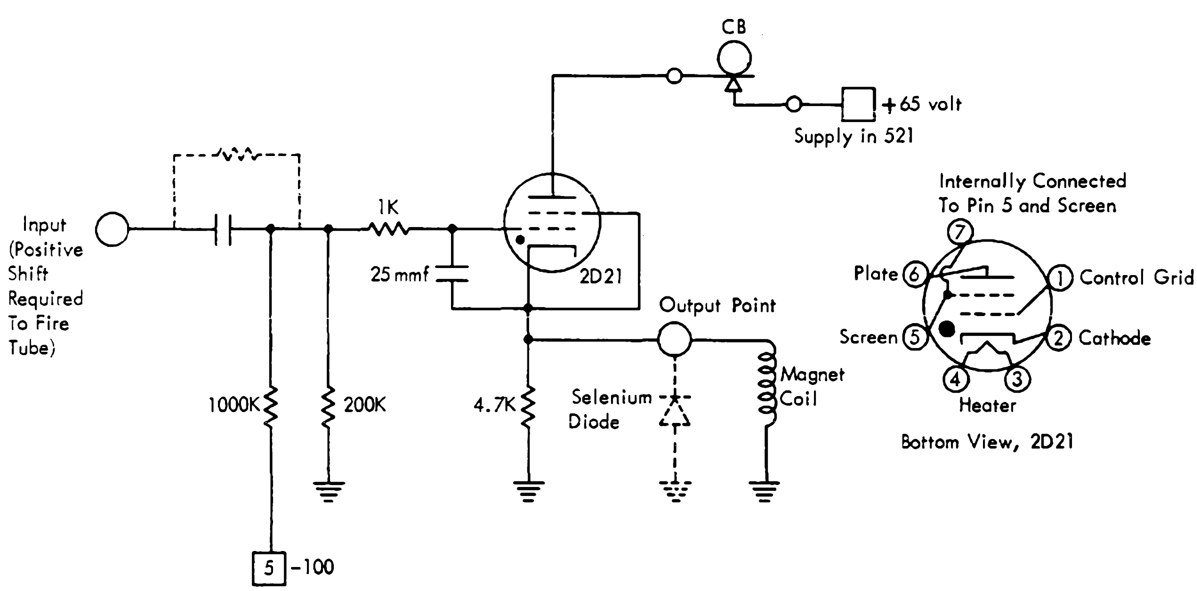


Figure 54. A Typical Thyratron Unit Circuit and the Base Diagram for the Type 2D21 Tube

could cause unwanted firing of the tube. The 4.7k resistor in the cathode acts as a load resistor to keep the cathode near ground potential should a magnet coil not be wired to the tube (which is possible with control panel wiring involving storage and counter read outs to punch magnets, all of which do not have to be wired). The 1k resistor in the grid lead limits grid current to a safe value. The 1000k and 200k resistors in the grid circuit provide a minus 17 volt bias potential to keep the 2D21 from firing until a plus shift signal is applied to the input.

Some TH units use a straight capacitive input while others use a resistance connected input with compensating capacitor. This is indicated in Figure 54 by the dotted resistor around the input capacitor. There is a basic and important difference in the circuit action with these two input variations. Imagine a positive potential applied to the input point of a unit with CAPACITOR input. At the instant this positive potential is applied, a positive pulse will be applied to the grid of the tube. A capacitor will couple only a *change* in potential, not a steady state condition. If the circuit breaker in the plate circuit of the thyratron is closed *before the time the voltage shift is applied to the input,* the thyratron will fire and then keep the coil energized until the circuit breaker opens. Further closings of the plate circuit breaker will NOT refire the thyratron unless another positive *shift* is applied to the grid input while the circuit breaker is closed.

With the RESISTANCE COUPLING input, a positive level applied to the input will hold the grid at the firing point for as long as the signal is present. When the plate circuit breaker is closed, the thyratron will fire and energize the coil for as long as the circuit breaker remains closed. When the circuit breaker opens, conduction will stop; but, unlike the capacitor input type unit, the tube will refire each time the circuit breaker closes as long as the positive input level remains. It takes both the closed plate circuit breaker and the positive grid input at the same time to start conduction (though with the resistance coupled unit either condition may occur first). Conduction is terminated only by opening the plate circuit breaker.

It is possible to fire a thyratron (when the plate circuit breaker is closed) by applying a sharp negative potential to the cathode. Such negative spikes may result from transformer-like coupling between punch magnet coils or relay coils. Even with the plate circuit breaker open, these spikes can be passed through the 25 micromicrofarad grid to cathode capacitor and be fed back to circuits feeding the thyratron unit. For this reason thyratrons do not provide particularly good isolation between the input and output circuits. To prevent these effects, the selenium rectifier diode shown dotted from the tube cathode line to ground in Figure 54 is used in a number of applications. Due to their size these selenium rectifiers are mounted behind the tube panels, external to the pluggable units. Since a diode acts like a short circuit to electrons flowing in a direction opposite to the arrow symbol, the stray negative signals will be shunted to ground. This diode will also shunt to ground and eliminate the negative spike from the collapsing field of the coil being driven by the particular thyratron unit and in this way help eliminate a source of stray pulses.

The selenium rectifiers provide still another advantage in the circuit. Some thyratron tubes have a tendency to flutter the current flowing through them (regardless of whether the load is inductive or resistive). It is possible for this flutter to be severe enough

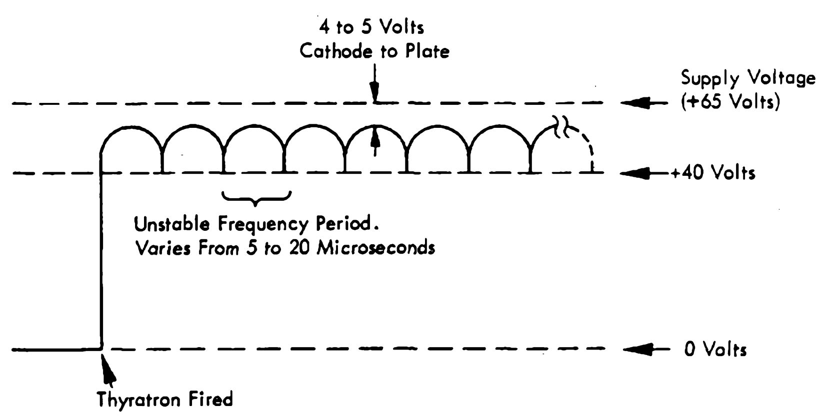


Figure 55. Thyratron Flutter or Oscillation

to cause the gas to deionize during the brief periods when the cathode to plate voltage is at its lowest. Figure 55 shows a waveshape that might be seen across the load of some thyratron units (particularly if the selenium diode is omitted). The peaks of the oscillations reach to within four or five volts of the supply potential, leaving only this small difference across the tube to continue the gas ionization. If the gas deionizes in a capacitor input TH unit, the tube will then cease to conduct until the next input pulse is applied. This could result in dropped punches or relays. The external selenium rectifiers reduce this effect and insure more stable operation.

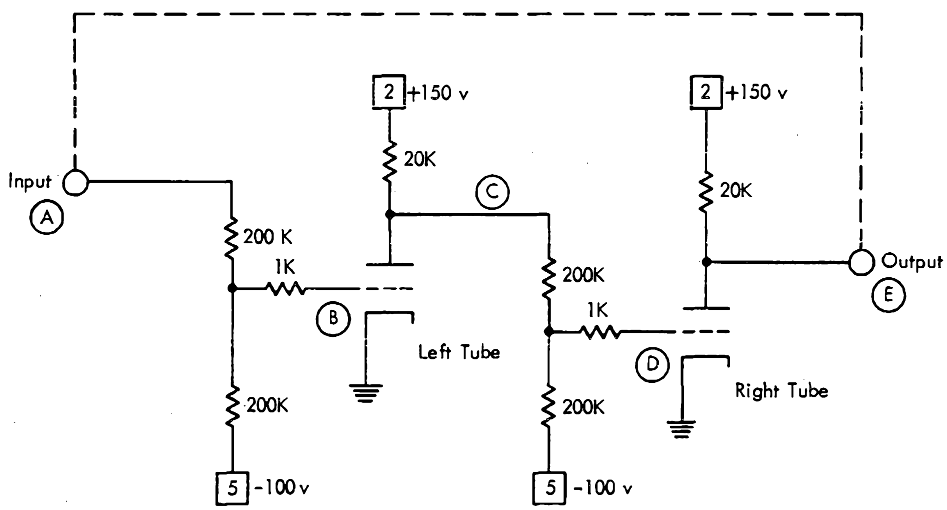
Trigger (TR) Units (G and H)

Triggers are the memory units of the 604. They are important and versatile building blocks which can generate timing pulses, create electronic control gates, convert electrical impulses from the 521 into electronic conditions, remember that a pulse has been applied, count and store a number of pulses, and so on. Triggers are functionally similar to a holding or latch type relay. Just as a relay can be up or down, a trigger can be ON or OFF, and it will stay that way until controlled otherwise (or until power is turned off). All of the circuit types discussed earlier will be found controlled by triggers, and they will in turn control other triggers.

For all its importance, the trigger is a simple unit consisting of one 6J type dual triode tube arranged in what is fundamentally just two inverter circuits. The circuit in Figure 56 shows one inverter feeding another inverter, an arrangement similar to that found in a trigger.

If the input "A" is connected to a plus 150 volt point, the input resistance network will try to drive the left tube grid to plus 25 volts (though the drawing of grid current will limit this to about plus one volt). The left tube will conduct and drop the left plate to a level near plus 50 volts. The resistance network from this plate to the grid of the right tube will convert this plus 50 volt level to minus 25 volts at the right grid. The right tube is thus cut off and its plate will be plus 150 volts. Because of the double inversion of this cir-

NOTE: The chart shows the voltage levels through the circuit for input signal levels of plus 150 volts and plus 50 volts. The output level in both cases is the same as the input.



If Input (A) At:	Then (B) At:	(C) At:	(D) At:	& Output (E) At:
+150	+25* (+1v)	+50	-25	+150
+50	-25	+138	+25* (+1 v)	+50

*These Points At These Times Try to Go to +25 Volts But Grid Current Stops Them at About +1 volt.

Figure 56. The Development of a Trigger. One Inverter Feeding Another

cuit the output, "E", is the same as the input signal applied to point "A".

Placing input "A" at a level of only plus 50 volts will cause the left grid to go to minus 25 volts and cut off the tube. This will let the left plate rise toward plus 150 volts (actually stopping at plus 138 volts due to electron flow from the minus 100 volt supply up through the resistance network). With the left plate at this up level, the right grid is made positive and causes the right tube to conduct. The right plate will thus drop to about plus 50 volts. Again the double inversion produced the same level at the output as at the input.

Notice that in both the cases given one tube or the other is cut off and the remaining tube is conducting. In both cases the input and output points are equal. If these two points, "A" and "E", are connected together, as shown by the dotted line, we will have a basic, self-holding trigger unit. Notice the loop arrangement of the circuit: as long as the right tube is cut off, points "E" and "A" are at the high level. As long as they are at the high level, the left tube is conducting. As long as the left tube is conducting, the right tube is cut off. The circuit will stay in this condition until some external control makes the right tube conduct for a brief period. The drop in the voltage level at the right plate will then be coupled to the left tube and keep it cut off. This will in turn force the right tube to *stay* conducting. The loop action will now retain the new status. Note that a tube which is driven beyond cutoff is in a rather stable, non-conducting state; a tube driven into the grid current region is also in a stable, but conducting, state. A condition where both tubes are conducting is so highly unstable that it will be found to exist only during a brief fraction of a microsecond while the trigger is flipping from one conducting status to the other.

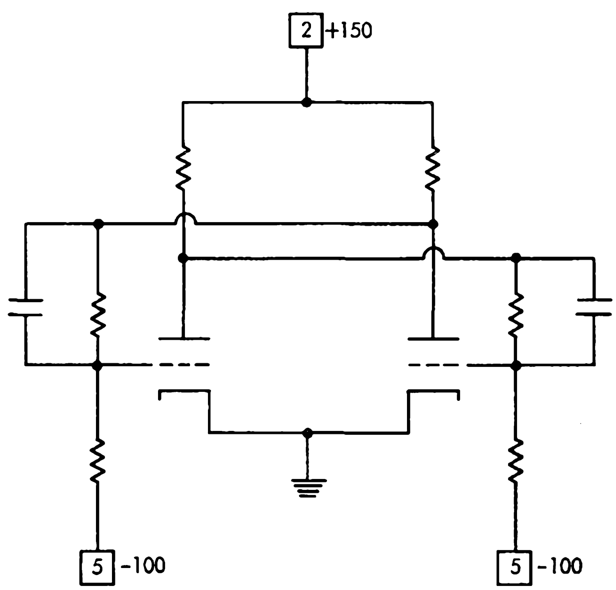


Figure 57. A Trigger with Compensating Capacitors

COMPENSATING CAPACITORS

Figure 57 shows a typical basic trigger circuit as normally drawn. Just as with inverter circuits, compensating capacitors are used from each plate to the grid being fed. These overcome the effects of stray capacitance and more rapidly couple to each grid any shift at the opposite plate. This speeds up considerably the completion of the flipping action once it is started. All trigger types except the TR-41 and TR-42 use them. In these two cases a variation is used to deliberately desensitize and slow down the triggering action. In the circuit descriptions to follow the compensating capacitors will be drawn in only where there is some unusual feature to their overall action. Normally they just speed up flipping and do not have to be considered in a basic discussion. The valve is 100 micromicrofarads.

TRIGGER ON-OFF CONVENTION

A very important convention about triggers must be understood. A trigger is said to be ON *or* OFF depending on which one of the sections in the dual triode used is conducting. If the left triode (as drawn in circuit and tube base diagrams) is conducting, the trigger is ON. If the right half is conducting, the trigger is OFF. Left ON, right OFF. This convention is true regardless of the type of the trigger, its use in the machine, or the logic name given to it. This convention makes discussing circuits much easier. It is shown in Figure 58.

TRIGGER RESET

Triggers are balanced circuits. The two plate resistors within a trigger unit are matched to within 2½%, as are the two plate to grid resistors and the two grid to minus 100 volt resistors. This is done to insure that a trigger will flip as readily in one direction as in the other. A result of this balance, however, is that it is not possible to predict which status a trigger will assume when power is first applied. Whichever triode section heats up first, or has the greatest emission, or first receives a random noise pulse will become the conducting side. The setting of the trigger at the start of a calculation cannot be left to chance if consistent

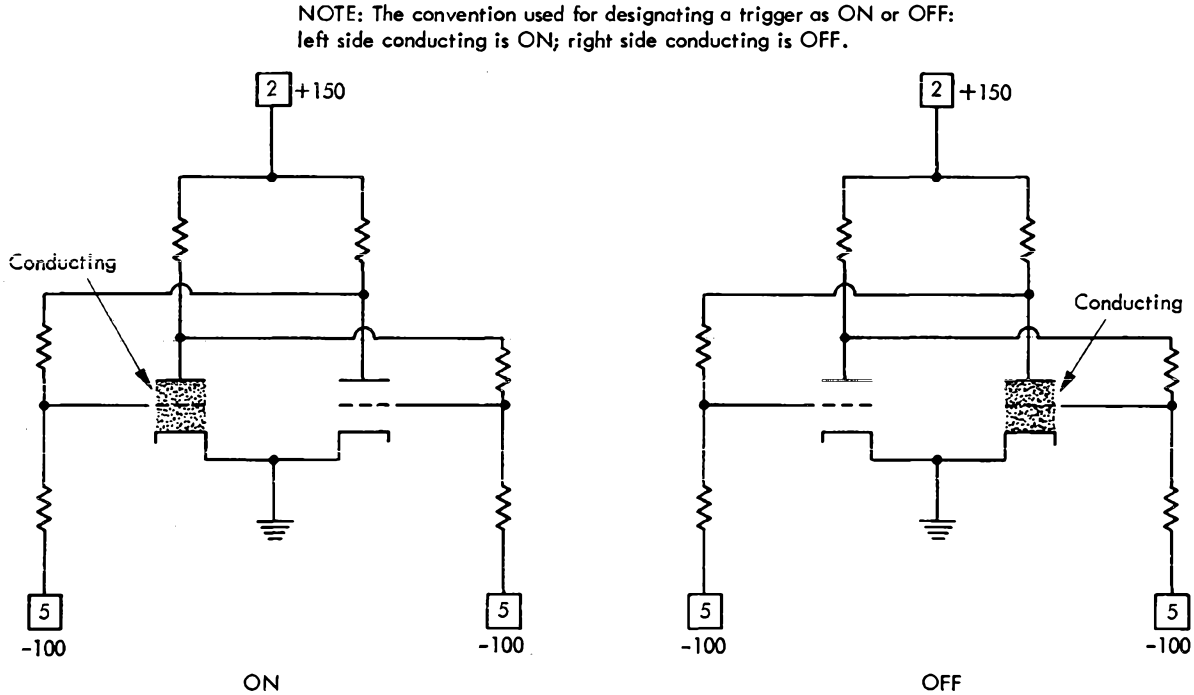


Figure 58. "Left ON, Right OFF"

answers are to result. For this reason special resetting circuits have been developed to insure that a trigger or group of triggers is correctly set to start an operation.

Removing the minus 100 volts from the lower end of one of the grid resistors (the right side in Figure 59) will remove from that grid any negative going tendency. The released grid will thus go positive, force conduction to take place in that side of the tube, and make the plate drop to about 50 volts. This will be reflected at the other grid (which still has the minus 100 volt supply attached to its grid resistor) as a minus 25 volt, cutoff level. The trigger status is then set and will not change when the removed minus 100 volt basis is reapplied.

While Figure 59 shows the circuit to leave a trigger in the OFF state after reset, triggers are just as easily

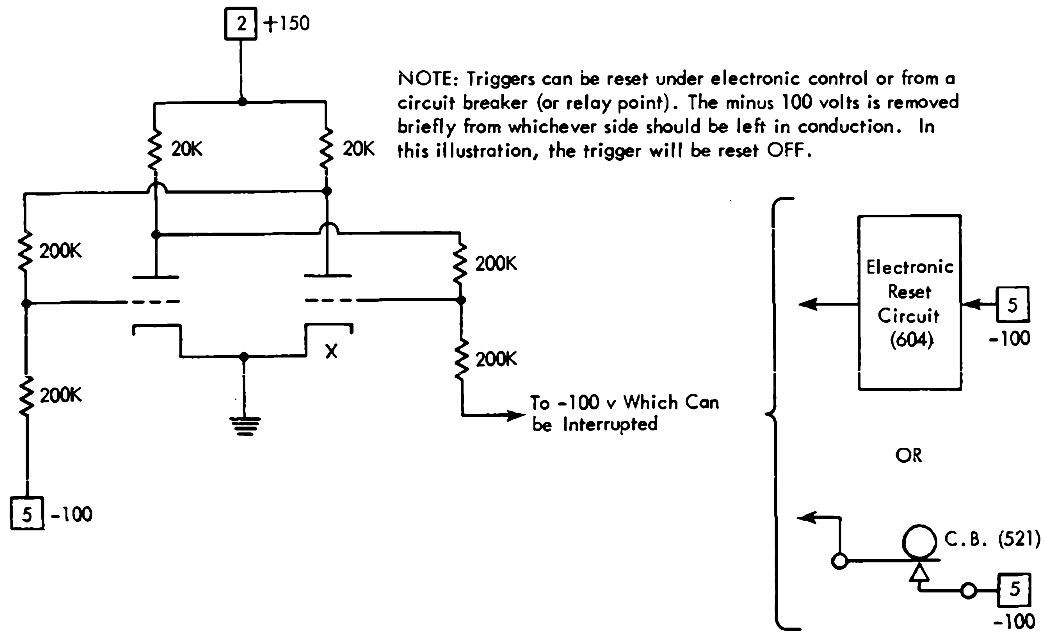


Figure 59. Trigger Unit Reset

reset ON by interrupting the minus 100 volts from the left side grid resistor. The "X" under the right cathode in Figure 59 is a symbol frequently used on wiring diagrams (G suffix and earlier) to indicate the side of the tube which will be conducting just after reset. On the *System* (block) *Diagrams* (used for H suffix 604's and to be described later) the reset status is indicated by the location of the "type of reset" box within the larger box representing the trigger.

The method used to remove the minus 100 volts varies with the particular application. Units can be reset during a program step of a calculation by using an Electronic Reset circuit which removes the minus 100 volts for 110 microseconds. This "ER" circuit will be described separately later. A circuit breaker in the 521 can be used to remove the minus 100 volts from desired triggers during punching time (Punch time Reset, PR) or during calculating time (Calculate time Reset, CR). Those triggers needed for calculating purposes are properly reset during reading or punching time by the "PR" circuit breaker. Those circuits needed for punching and reading are reset during calculate time by the "CR" circuit breaker. A few triggers in the 604H are reset at the end of punching time by a third circuit breaker feeding the Unfinished program Reset, UR, line.

The 604 Counter unit is usually reset electronically, but in addition to this the minus 100 volts supplying one side of each trigger in this unit goes through a relay point. This relay is itself picked up by the minus 100 volt supply. When DC power is applied to the machine, the time taken to pick the relay will give a delay of ten milliseconds or so before the minus 100 volts is applied to the relay controlled side of the triggers. This causes them to reset to the desired status.

TRIGGER FLIPPING

Five circuit arrangements for flipping triggers are used in the 604. One of these, removing the minus 100 volts from one side, has been described above and is used exclusively for resetting. For high speed flipping of triggers during reading, calculating, or punching, one of the other four control methods will be used as fits the application. The one point to remember about triggers used in the 604 is that if external controls make them assume a status for several microseconds or more, the trigger will stay in that status when conditions return to normal. There are three points in the trigger circuit loop where this external control can practically be applied: 1) The high level plate can be pulled down, 2) the positive grid can be driven to cutoff, or, 3) the cutoff side grid can be driven positive. All of these are used in the 604.

Plate Pullover. Figure 60 shows the basic circuit for what is called the plate pullover type of trigger control. The control tube is one triode of an INverter unit biased so it rests cut off, acting like an open circuit. A positive pulse applied to the control tube grid will make the tube conduct and pull the plate down to about plus fifty volts. The control tube plate is directly tied to the plate of the right side of the trigger and will pull that plate down with it. This negative going shift is coupled to the left trigger tube, cutting it off and letting its plate go positive. This positive shift is coupled

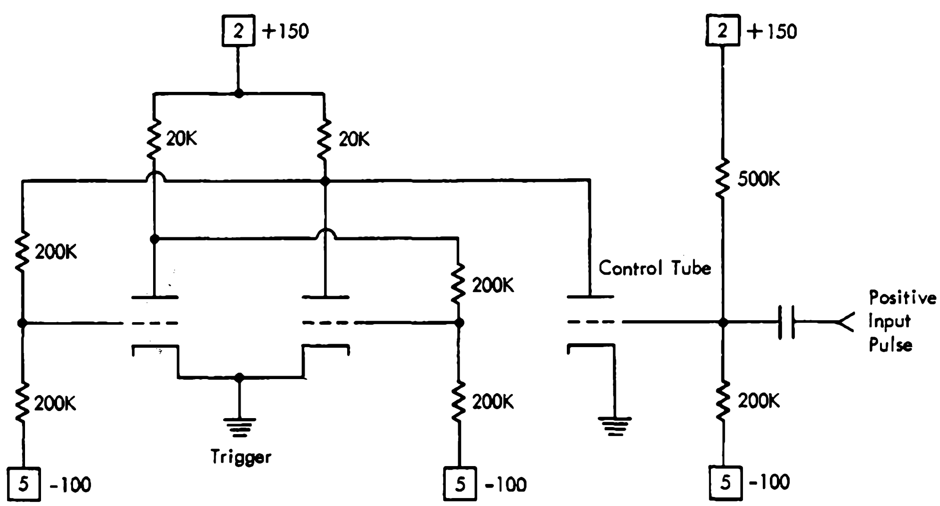


Figure 60. The Basic Plate Pullover Circuit

to the right trigger grid and will make the right tube conduct. When the input pulse is removed and the control tube again cuts off, the conducting right trigger tube will hold its own plate at the low level. The trigger is now OFF. Further impulsing of the control tube will have no further flipping effect on the circuit because the right trigger plate is already at its low level. This sharing of a common plate load resistor by two tubes is similar to that of the Inverter Switch discussed earlier in this chapter.

With the circuit as drawn in Figure 60, the trigger can only be flipped to the off position. To turn the trigger on (make the left side conduct) a second control tube can be attached to the left plate; or the trigger can be reset on; or one of the grid input arrangements described below can be used. Like the resetting circuit, plate pullover can be used with any general class of triggers. The wiring within the pluggable unit must provide a pin connection directly to the desired trigger tube plate or plates, however. Since base pins are at a premium in some trigger units, not all types have these direct plate connections and therefore cannot use this type of flipping control. Unlike other flipping methods, an extra control triode must be used. This circuit is used primarily to provide an extra, isolated input to a trigger already being fed with another control method.

Direct Grid Input. This method of flipping a trigger is applicable only to that class of triggers having direct resistance connections to the tube grids. In the 604 this Direct Coupled class of triggers contains four types only, the TR-31, TR-32, TR-41, and TR-42. Figure 61 shows the basic circuit for this class. An 82k isolating, current limiting resistor is run from each grid to the input point connector. This is the only change in the basic trigger circuit as discussed up to now.

If the trigger in Figure 61 is assumed to be ON (left side conducting) there are two ways it can be flipped OFF from a *direct coupled* grid input signal:

1. A negative potential of fifty volts or so can be applied to the left input point, "A", which will cut off electron flow through the left tube. This will permit the plate to shift toward plus 150 volts, force the right tube to conduct, and flip the trigger.

2. The second way is to apply a plus fifty volt potential to the right input point, "B". This will force the right tube to conduct and pull its plate down, cutting off the left tube and completing the flipping of the trigger. It is this second method that is used in the 604. A plus fifty volt potential is applied to the right input point to turn such a trigger OFF or to the left input point to turn such a trigger ON.

This Direct Coupled class of triggers is used in the 604 primarily to convert electrical conditions from the 521 into electronic levels usable by the 604. The reading brushes and circuit breakers which feed such triggers supply the needed plus fifty volts. Brushes and circuit breakers have been known to bounce while making, even when in perfect condition. In relay circuits used in non-electronic machines this bounce, unless too severe, does little more than delay the pick of the relay or magnet being controlled. Triggers, on the

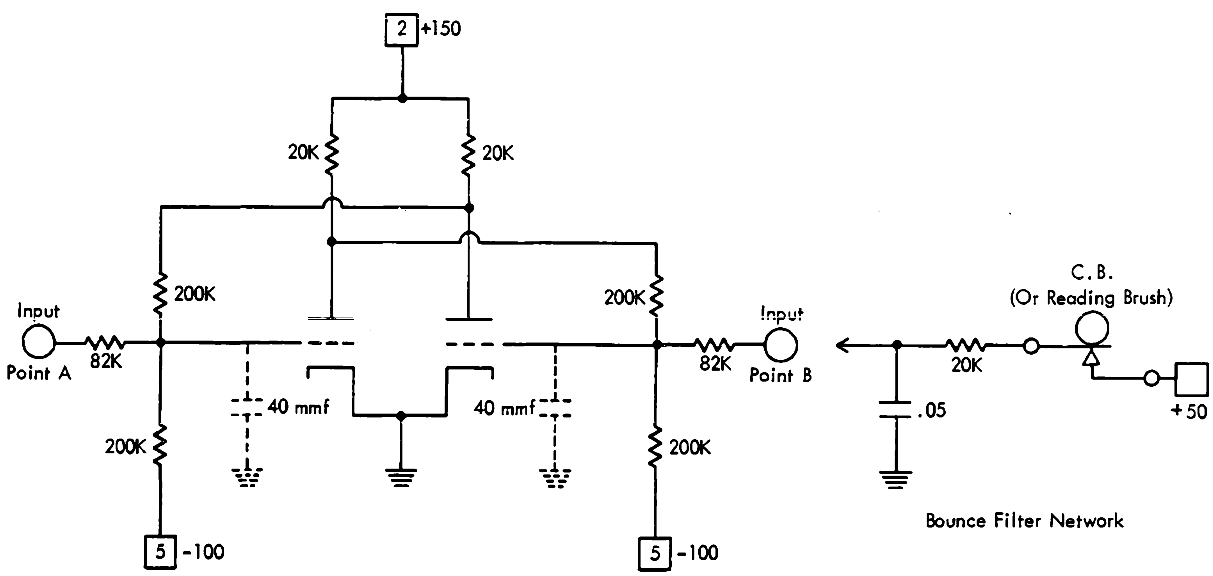


Figure 61. The Direct Coupled Trigger Input

other hand, can change their status in two millionths of a second. Such contact bouncing could produce noise and spikes that would make the trigger flip several times instead of once and make its final status a matter of chance. To eliminate the effect of this bounce, resistance-capacitance filters are used right at the input to the trigger with types TR31 and 32. This is shown in Figure 61. A .05 microfarad capacitor shunts to ground any noise pulses. Until this capacitor has been charged to the proper level through the 20k resistor, the trigger will not flip. This will delay, by a millisecond or so, the time at which the trigger will begin to flip, but once the flipping begins it is completed very rapidly (about two microseconds). The .05 capacitor is physically too large to mount within the pluggable unit. For this reason these resistance-capacitance filters will be found wired in on the unit panels. Within the units themselves additional 40 micromicrofarad capacitors connected from each grid to ground work in conjunction with the 82k input resistors to provide additional filtering. These capacitors are shown dotted in Figure 60.

Trigger types TR-41 and TR-42 make use of a different type of filter to desensitize them to short noise spikes and contact bounce. A 1000 micromicrofarad capacitor (which is small enough to mount directly within the pluggable unit) is connected between each grid and the same side plate. Figure 62 shows the circuit.

These triggers are designed to work from plus fifty volt impulses from the 521. Assume the trigger of Figure 62 is OFF. The left tube will then be cut off and its grid at minus 25 volts. If a short duration positive spike is applied to the input point "A", the grid will try to rise. At some point electrons will begin to flow through the tube and start to make the left plate go in a negative direction. This negative plate shift will be coupled back to the same side grid through the 1000 micromicrofarad capacitor. This will in large measure neutralize the input pulse and prevent further lowering of the plate potential, thus suspending the flipping of the trigger. If the input pulse lasts long enough (two milliseconds or longer), the plate to grid capacitor will charge fully and become an open circuit incapable of further oppositional feedback. At this point, the trigger will start to flip. This type of trigger is rather slow to complete its flipping operation: seven or eight microseconds are required, whereas other trigger types flip in two.

Notice that the cathodes of this type of unit are not grounded but are instead returned to minus 100 volts through a common 20k resistor. This cathode coupling circuit reduces the sensitivity of such a unit to variations in supply voltages (plus 150 and minus 100 volts).

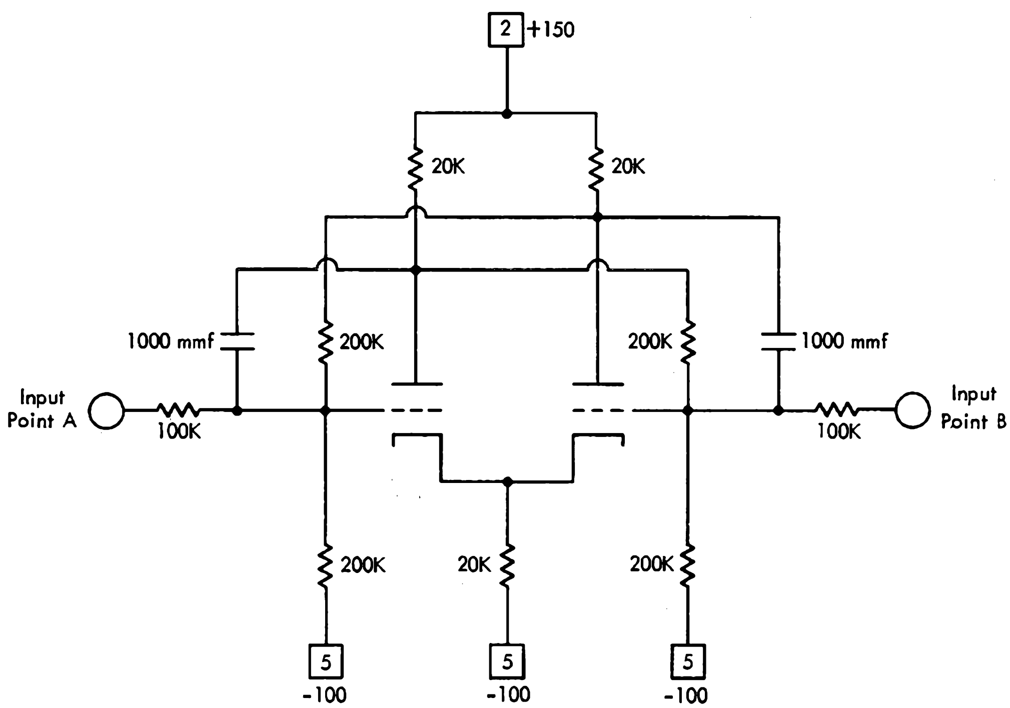
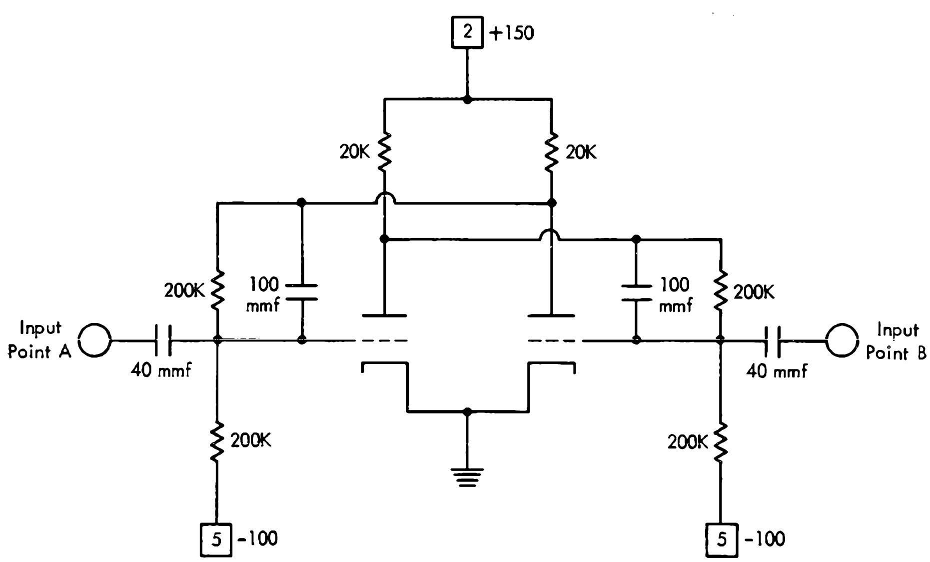


Figure 62. Desensitized Triggers, Types TR41 and TR42

Capacitive Grid Input. Capacitive Input triggers are a second class type used in the 604. Inputs to the grids of the tubes in these units must pass through 40 micromicrofarad capacitors. This is an important change since now only sharp, fast-changing voltage shifts applied to the inputs can cause the trigger to flip; capacitors only couple to the grids changes in voltage, not steady states or direct current. While triggers of this type can be designed to have various characteristics, those used in the 604 will only respond to **negative shifts of more than four microseconds duration and more than twenty volts amplitude.** Circuits which are to flip these triggers normally provide a minimum of ten microseconds and forty volts. **Positive shifts will not affect this class of 604 triggers** regardless of the duration of the shift, unless the amplitude is quite large (80 to 100 volts, or more). These characteristics are deliberately built into these triggers to simplify overall machine design. These triggers are extensively used in the electronic controlling circuits of the machine. A typical, basic Capacitive Input trigger circuit is shown in Figure 63. The compensating capacitors are shown in this illustration because they have a special action in reducing trigger sensitivity to positive input shifts.

As a starting point for discussion, assume the trigger is OFF (right side conducting). This will mean that the left grid is negative (about minus 25 volts) and cutting off electron flow through the left tube. Applying negative shifts to the left side input point "A" will therefore have no effect on the circuit since they will only drive the grid more negative. Since the left tube is cut off already, this can produce no change in the potential at the left plate (a necessary action if the trigger is to flip). A negative shift applied to the *right* grid input point, "B", however, can produce a plate action and cause flipping. The right grid rests at about plus one volt when the trigger is in the OFF state. Heavy electron flow is occurring through the right tube. The right plate is therefore at a low level near plus fifty volts. A negative shift applied to the right input point, "B", will couple through the 40 micromicrofarad capacitor and drive the left grid negative. If the amount of the shift is great enough (twenty volts or more, to allow for losses through the capacitor), the right grid will be driven beyond the tube cutoff point of minus eight volts. The right plate will shift instantly to its up level near plus 138 volts. This shift will couple to the left grid and force the left tube into conduction. The lowered potential resulting at the left plate will couple back to the right grid and keep the right tube cut off even after the original input shift is no longer being coupled through the input capacitor. The input shift will disappear at the grid either because the input signal is removed or because the capacitor became charged and no longer coupled what had become to it a steady state condition. This total action from the start of the input shift until the trigger is self-held in the flipped status takes from two to four microseconds. In summary, a twenty volt negative shift applied to the conducting side input will flip a trigger such as this.



NOTE: Capacitive input triggers in the 604 respond only to negative shifts.

Figure 63. A Capacitive Input Trigger

At first thought it would seem that a positive shift of fifty or sixty volts applied to the non-conducting side input would be able to flip such a trigger, just as was true with the Direct Coupled class described earlier. Such is not the case due to a combination of reasons. For example, the cut off side grid is held by the unit resistors at a point almost twenty volts lower than the cutoff point of the tube. If the full amplitude of the input shift reached the grid, it *would* probably cause triggering, but there is a shift loss through the 40 micromicrofarad input capacitor. This capacitor is in series with the 100 micromicrofarad compensating capacitor. Together these capacitors form a voltage divider for input shifts. As a result, about two thirds of the signal is lost across the input capacitor. Even a fifty or sixty volt positive shift will therefore not drive the grid to the conduction point. A second factor working against the flipping of a trigger from a positive shift involves grid current. If the plus shift does drive the grid positive, the drawing of grid current will quickly charge the input capacitor and convert it into an effective open circuit before the trigger has a chance to complete its flipping cycle.

Positive pulses applied to the conducting side of the unit have no appreciable effect on the already conducting tube, and are furthermore swamped by the drawing of grid current. In summary, 604 capacitive input triggers will not respond to normal amplitude positive shifts.

Binary (commoned input) Triggers. A Binary Connected trigger has both grids fed in parallel from one common input point. It is designed to respond to negative shifts only, and will change its status, whether ON or OFF, each time a negative shift is received. Every second pulse will return the trigger to its original position. Thus the term *binary* (meaning by two's). All binary connected triggers are capacitive input. The capacitive input triggers discussed above can be and frequently are externally wired to convert them into the binary acting circuit to be discussed here. There is, however, a third, Binary Connected class of triggers used in the 604 in which the common input connection is made internally. Whether internally or externally connected, the operation is the same. Their use is very important in the storage and counter units of the 604.

A comparison of the binary trigger circuit of Figure 64 with the capacitive input trigger of Figure 63 will reveal the great similarity. The two 40 micromicrofarad input capacitors have been tied together at the input point. The 100 micromicrofarad compensating capacitors paralleling the resistors from each plate to the

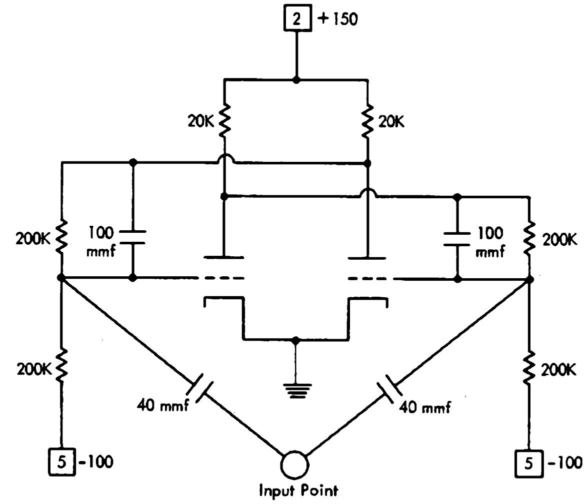


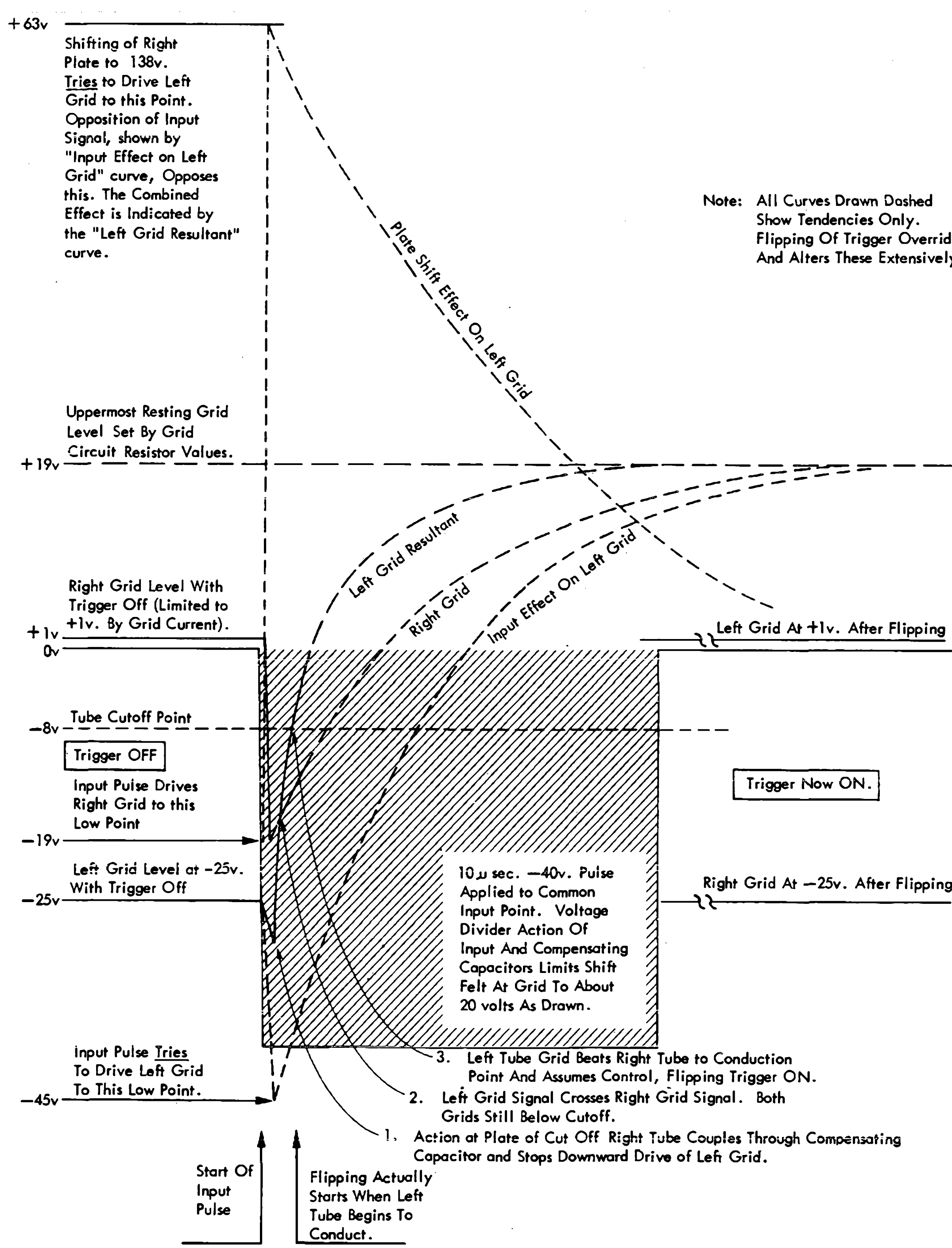
Figure 64. A Binary. Commoned Input Trigger

opposite grid have also been shown in this circuit; in the binary connected trigger their inclusion is most important if a change of trigger status is to be obtained *from a pulse applied to the common input point.*

Assume that the binary connected trigger of Figure 64 is in the OFF status (right side conducting). A negative shift of twenty volts or more applied to the common input point will go to both grids. Since the left grid is already below cutoff, the input pulse merely drives it further negative and has no other effect on the tube. The shift felt at the right grid, however, quickly changes the status of the right tube from conduction to cutoff. For an instant neither tube is conducting. Then the plus shift of the right plate due to that tube's being cut off, couples to the left grid and forces the left tube into conduction. The resulting drop in potential at the left plate couples to the right grid and holds the right tube cut off, completing the flipping action.

The action of the compensating capacitors in making this circuit flip from a pulse applied to the common input point can be seen from a slow motion analysis. Notice that the compensating capacitors have two and one-half times the capacity (100 mmf) of the input capacitors (40 mmf). The length of time a capacitor will continue to couple a pulse or gate signal from one point to another depends on the capacitance and the resistance in the circuit. This is called the Time Constant of the circuit and was discussed earlier in this chapter under "Practical Inverter Circuits, the Coupling Capacitor." The input circuit of these triggers will couple a shift to the grids for about four microseconds. The compensating capacitor circuit, on the other hand, will continue to couple a shift for about ten microseconds.

Assume again that the trigger in Figure 64 is OFF (conducting on the right). When the negative input signal is applied to the common input point, both tubes are cut off. There is no change at the left plate because that tube was already cut off. The right (formerly conducting side) plate is released, however, and goes positive. This positive shift will continue to be fed through the compensating capacitor to the left grid for about ten microseconds. The input signal cutting off both tubes will cease to be felt after only four microseconds.



Circuit Response WITH Compensating Capacitors.

Figure 65a. Waveshapes of Binary Trigger Action With Compensating Capacitors

The longer lasting, compensating capacitor fed shift will thus assume command at some point and force the left tube to conduct and flip the trigger. Because the shift at the right plate is much larger than the input signal (100 volt plate shift as against a normal 40 volt input signal shift), the compensating capacitor fed shift will assume command and flip the trigger even before the input capacitors stop coupling their signal. The usual *binary coupled* trigger used in the 604 will flip in about three microseconds.

Without the compensating capacitors in this example the action is different. The input shift will drive both grids downward by the same amount from their starting points. Without the compensating capacitor to act as capacitive voltage dividers, practically the full amount of the input shift will be felt at the grids. With a 40 volt input signal the left (cut off) grid will be shifted downward (from its minus 25 volt starting point) to a level of about minus 65, a forty volt drop. The right, conducting side grid will also be shifted downward

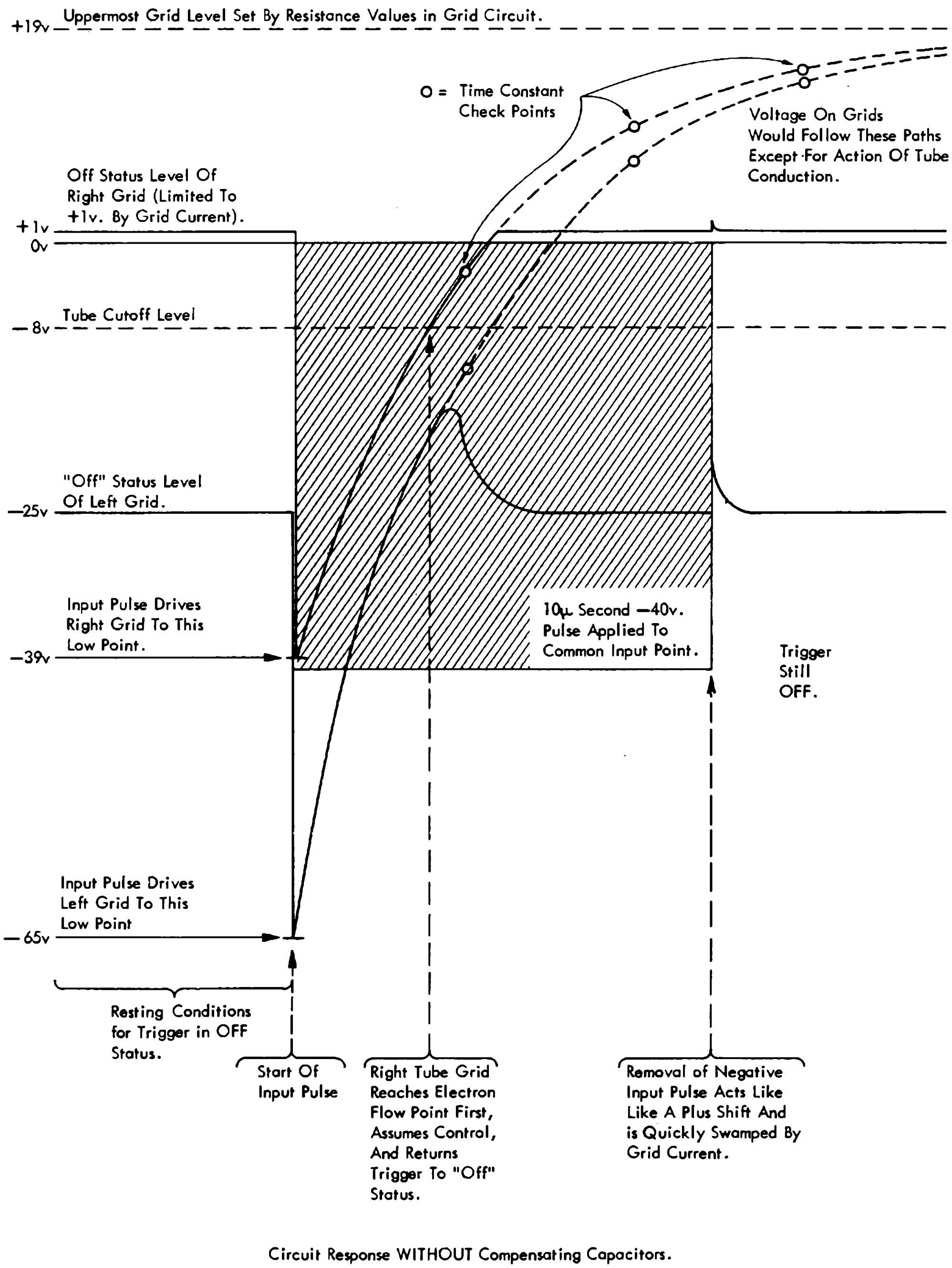


Figure 65b. Waveshapes of Binary Trigger Action Without Compensating Capacitors

forty volts (from its starting point of plus one volt) to about minus 39 volts. This will cut off the right tube; but without the compensating capacitor to quickly bypass it, the plate to grid resistor will itself absorb the resultant plate shift. As the 40 mmf input capacitors gradually become charged, these grid voltages will follow a charging curve aiming toward plus 19 volts (the value the grids would try to assume due to the voltage divider action of the circuit resistors alone). The right grid, being less negative to begin with, will reach the conduction point before the left grid. The right tube will thus go into conduction first, assume control, and return the trigger to its former OFF status without flipping. The binary connection thus makes compensating capacitors of the correct size a necessity if flipping is to occur. The two parts of Figure 65 show in simplified graphic form the timings involved both without and with compensating capacitors.

TRIGGER UNIT CIRCUIT VARIATIONS (G AND H)

As with other types of units, there are certain special items found in trigger unit circuits: 1) A 1000 ohm resistor is directly in series with each tube grid. This would appear to be a grid current limiting resistor but is actually included to suppress parasitics (erratic voltage fluctuations which triggers can produce due to the speed with which they flip). 2) Some trigger units have a small, 10 mmf capacitor connected from grid to grid. This acts to slightly desensitize the trigger to short noise pulses and delays just a bit the start of the flipping action on a normal pulse. 3) Triggers are generally driven by 40 or 50 volt shifts since they are most reliable in this area. When triggers are used to drive other triggers directly, a tapped output must be provided on one or both of the plate load resistors to supply the desired 40v portion of the 100 volt plate shift. 4) A few trigger types (604H only) have a built-in germanium diode to help provide a needed "tens limiting action" when these triggers are used in counter and storage circuits. This will be discussed in the next chapter.

Properly designed triggers such as used in the 604 are reliable storage devices with a high degree of stability and lack of sensitivity to supply voltage variations. Varying either the plus 150 or the minus 100 volt supplies over a range of plus or minus 10 percent will not upset normal operations.

The Multivibrator (G and H)

A trigger was shown to be simply two resistance coupled inverters that would hold themselves in one status or another when once set. A multivibrator is similar to a trigger except for the substitution of plate to grid *capacitors* for the plate to grid *resistors* of a trigger. Since a capacitor is incapable of passing and holding a *steady state* condition, the multivibrator repeatedly and automatically changes from one status to the other, producing a desirable, pulse-like waveshape output. The circuit for a basic multivibrator is shown in Figure 66. Notice that the grid resistors are returned

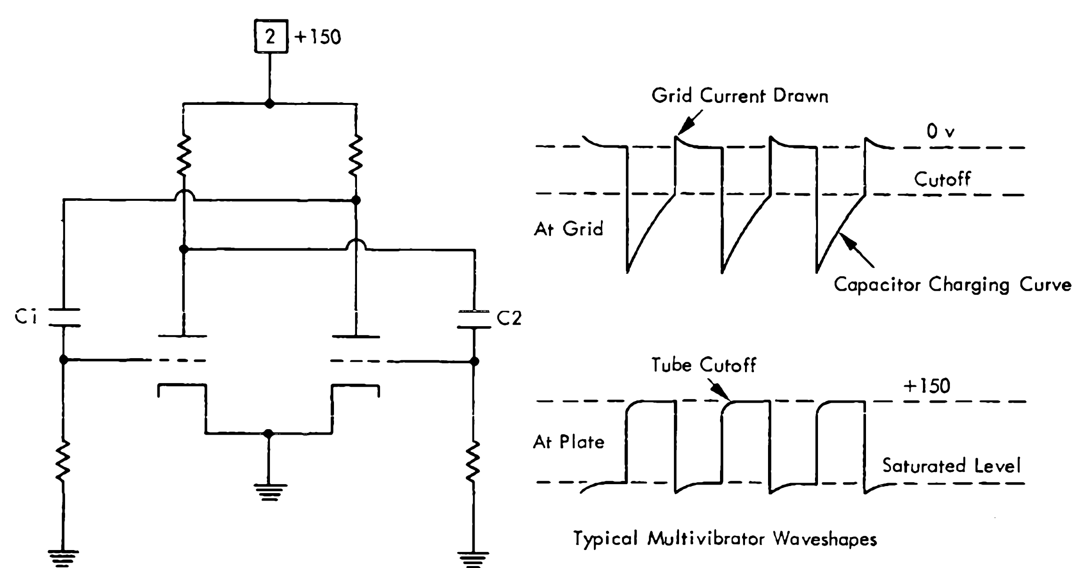


Figure 66. The Basic Multivibrator and Typical Waveshapes

to the same potential as the cathode (ground in the illustration) rather than the minus 100 volts used in the trigger. The one and only multivibrator used in the 604 is the source of the basic timing pulses for the machine. It is externally wired using an IN type unit as its basis.

No two tubes are ever exactly matched. When power is first applied to a multivibrator, one of the tubes will conduct first or more heavily. Let us assume this is the left tube. The left tube plate will drop in potential first or more rapidly. This negative shift will couple through the capacitor C2 to the right grid and hold the right tube cut off. The left plate will continue to drop until the left tube is passing maximum current and can lower its plate potential no further. All this while the right tube is being held cut off through the coupling action of the capacitor C2. When the circuit settles with the left tube conducting and the right tube cut off, the capacitor C2 will gradually become an open circuit and permit the grid of the right tube to move toward zero volts. When the right tube cutoff point is reached, a few electrons will begin to flow through the right tube. This will lower the potential at the right plate. This negative shift at the right plate will couple through capacitor C1 and cause the left grid to move negatively. Electron flow through the left tube will be reduced and the left plate will start to shift positively. This positive shift will couple through the capacitor C2 and cause the right grid to move upward even more quickly. The right plate potential drops even further, which further cuts off the left tube. In a fraction of a microsecond this feedback-loop action is completed and stops when the left tube is cut off and the right tube saturated. The left grid now begins to move toward zero volts. When the left tube cutoff point is reached, the few electrons that trickle through the tube as a result start the entire flipping action in reverse, ending with the left tube conducting and the right cut off. This back and forth action will continue as long as power is applied. How long it takes on either half of the cycle for the cutoff tube to start passing electrons depends upon electrical size of the coupling capacitors and the resistance value in series with them (in this case primarily the grid to ground resistors). The larger the capacitance and the resistance values are, the longer the RC time constant, and the longer each half cycle will take. If each half cycle is to be the same (as is desired in the 604), the coupling capacitors and grid resistors for each side of the circuit must be equal.

Figure 67 shows a typical multivibrator circuit as used in the 604. It is frequently desirable to be able to vary the frequency of the multivibrator (and thus examine the circuits under abnormal conditions as an aid to analysis). The resistors in each grid circuit are made variable and ganged together for this reason. The

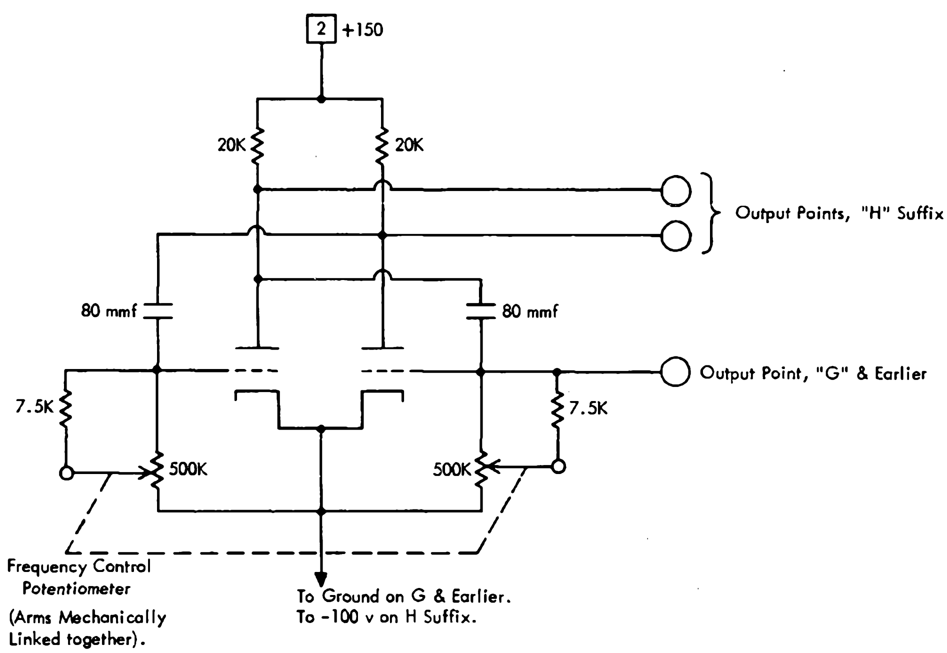


Figure 67. 604 Multivibrator Circuit

frequency range of the circuit is from about 5,000 cycles per second to 100,000. The normal working frequency is 50,000 CPS.

Machines wired to the "G" and earlier suffix prints also have a special control switch setting which places larger (.05 mfd) capacitors in parallel with the 80 mmf coupling capacitors. This "LO" setting is used only for testing and changes the multivibrator frequency range to between 1 cycle per second and 100. At this very low frequency it is possible to watch data flow through the machine.

The signal output from a multivibrator can be taken either from a grid or from a plate. The design of different circuits using the output of the multivibrator may find one or the other more desirable. In the 604H an output is taken from each plate. In the earlier 604's the normal high speed setting output was taken from the right grid and the low speed setting from the right plate.

To produce the square wave signal most desirable for timing control of the 604, the output of the multivibrator is run through one or more shaping tube units. These units are driven into the cutoff and the grid current regions as discussed earlier in this chapter under "Inverter Units, Clipping and Shaping." The peaks of the normal multivibrator output are leveled off in this way. In the 604H, as indicated by Figure 67, the cathode and grids of the multivibrator are returned to minus 100 volts rather than ground. With the plus 150 still used as the plate supply, this connection gives a total of 250 volts across the multivibrator. The resultant output signal shifts from plus 145 to minus 30 volts, a shift of 175 volts. This is almost twice the signal available from 604G and earlier circuits and is much more easily clipped and shaped, allowing the use of fewer shaping tubes by the H suffix machine. Figure 68 shows a good square wave signal such as produced and used by 604's.

Neon Indicators (G and H)

It is frequently desirable to be able to tell the status of a trigger or a control line while checking the operation of the machine. This could be done in some cases with a voltmeter or an oscilloscope, but in many instances the mere act of attaching the instrument to the trigger would be enough to flip it. Customers checking program layouts step by step like to trace information flow and development throughout the machine. Using a voltmeter would be tedious and impractical for such an application. Fortunately the small and inexpensive type NE-2 baseless neon bulb lends itself ideally to 604 indicating purposes. This tube will start to glow whenever 90 volts or more is applied across its terminals and will extinguish when there is less than 60 volts. A one million ohm series resistor limits the current drawn by these bulbs to a very low level and prevents circuit loading and interaction. The bulb and resistor units are generally connected to glow when the particular trigger is ON or when a control line is high. They are wired directly in behind the unit sockets where their indication will aid Customer Engineering analysis. A second set, primarily for customer use but also valuable to a Customer Engineer, is compactly arranged in an indicating panel located directly above the 604 Control Panel. These bulb and resistor units have the resistor directly connected to the desired active point in the circuit. A lead runs from the resistor to the bulb. The other side of the bulb is connected to a voltage source (obtained in some cases from a resistor voltage divider) such that the difference of potential across the bulb and resistor will be above 90 volts to glow or less than 60 volts to be dark.

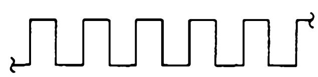


Figure 68. A Square Wave Produced by Clipping and Shaping the Output of a Multivibrator

Figure 69 shows two alternate ways of connecting a neon indicator to a trigger so the bulb will glow when the trigger is ON. Both systems are in use on different 604 triggers depending on convenience of wiring. Bulb "A", in parallel with the left plate load resistor, will glow when the trigger is ON because at this time there is a 100 volt drop across the load resistor. This reduces to about 12 volts when the trigger is OFF. The bulb "B" connection is between the right plate and ground. When the trigger is ON, the right plate rises to plus 138 volts and makes the bulb glow. When the trigger is OFF, the right plate drops to plus 50 volts, which is not enough to cause a glow. Similar circuits can be used with Inverters, Power Units, Pentagrid Switches, etc., to indicate the cutoff or conducting status. Other arrangements (used primarily on the 604H) will be found on *System Diagrams* page 0-0005.

Charts showing the location of the neon bulbs behind the tube panels, and their indication, for both the H and G suffix machines, are in the Appendix. These charts are important because the operation of the machine is revealed by its neons.

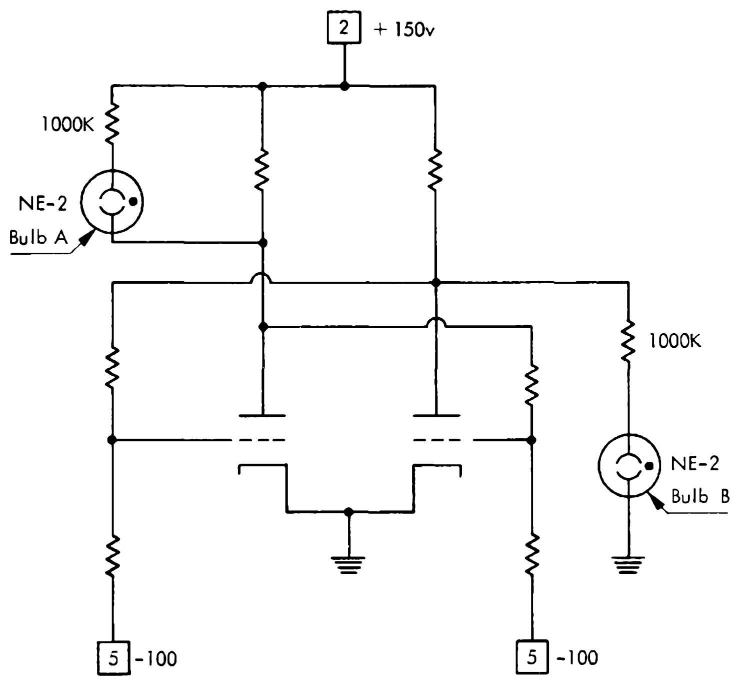


Figure 69. Neon Indicator Bulb Circuits for Triggers

The Electronic Reset Circuit (G and H)

In the discussion of triggers it was shown that a trigger can be reset to a desired status by momentarily removing the minus 100 volt bias supplied to one or the other of the grid resistors. Cams or relay points are practical for slow speed resetting under control of the 521. Resetting during electronic calculating needs a faster, smoother, and electronically controllable device. Through the use of the Electronic Reset circuit a group of triggers can be reliably reset in 110 microseconds or less.

Due to voltage loss through the reset control tubes, the source of power for the minus 100 volt Reset Lines is the minus 175 volt supply. Except while actually resetting, the voltages supplied to each side of a trigger should be closely balanced. A standard testing procedure used with the 604 entails varying the output of the minus 100 volt supply, plus and minus ten percent while calculating. The regulating portion of the reset circuit keeps the Reset Lines within a fraction of a volt of the bias supply output at these altered levels. Aging reset circuit tubes and varying circuit loads are also compensated.

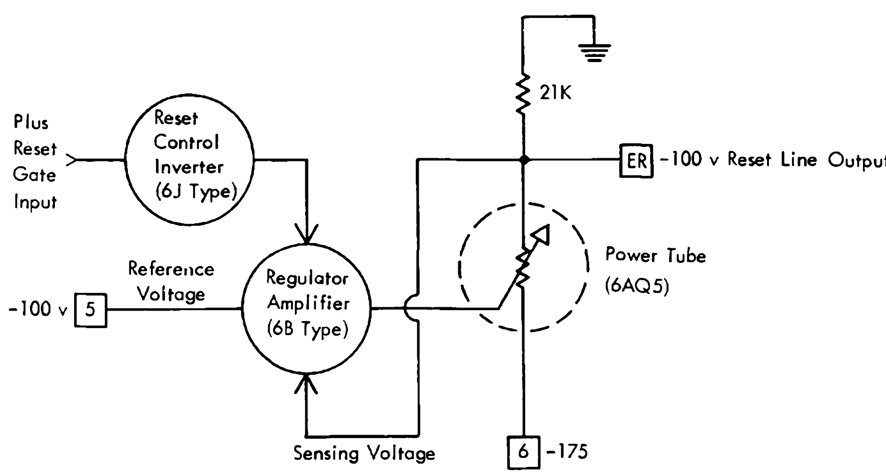


Figure 70. Basic Workings of the Reset Regulator

A logic diagram of the reset regulator is shown in Figure 70. A voltage divider between ground and minus 175 volts provides the desired minus 100 volt electronic reset output. One of the "resistors" in this voltage divider is actually a 6AQ5 power tube. The cathode to plate resistance of this tube is variable over a wide range by changing the potential of the 6AQ5 grid with respect to its cathode. If the grid is made more negative with respect to the cathode, the effective resistance of the tube is increased and the Reset Line will move nearer to the zero volts of ground (and vice versa). The grid to cathode potential of the 6AQ5 tube is controlled by the Regulator Amplifier tube. This uses the minus 100 volt supply as a reference source against which the Reset Line is compared. Any difference between the minus 100v bias supply and the Reset Line is sensed and the proper correction applied to the 6AQ5 grid to restore equality by shifting the Reset Line. When reset of the triggers is desired, a plus shift or gate is fed into the Control Inverter tube. The end result of this is electron cutoff in the 6AQ5 power tube, making it effectively an open circuit that lets the reset line shift upward to ground or zero potential.

Figure 71 shows the reset circuit used in 604 machines. One such circuit is provided for each General Storage Unit, each Factor Storage Unit, the MQ Unit, and the Counter (a total of ten). When studying this circuit it is important to recall that the absolute voltages with respect to ground do not have much effect on vacuum tube actions. It is the voltage on one tube element with respect to another that is important. For instance, the 6AQ5 power tube has no positive potential on its plate. The cathode is at minus 175 volts, however, and to electrons there the plate seems positive and attractive. By putting the proper potential on the grid of the power tube with respect to this minus 175 volt cathode, exactly 75 volts can be dropped through the tube, leaving minus 100 volts for the reset line. The potential on the 6AQ5 grid is determined by the resistors making up the voltage divider in its grid circuit. This voltage divider consists of a 207k, an 820k and a 100k resistor in series running from minus 250 volts up to plus 150 volts. The plates of the 6B Amplifier and the 6J Control Inverter tubes are connected to the lower end of the 100k resistor. Drawing current through either of these tubes can vary the voltage drop across the 100k resistor. Any change there will be reflected at the grid of the 6AQ5, altering the voltage drop through it. The 100 mmf capacitor in parallel with the 820k resistor is a compensating capacitor that speeds up the response of the circuit. The grid circuit of the 6J Reset Control Inverter puts a minus 37 volt potential on the grid of this tube with respect to its cathode and keeps it cut off *except during reset time.* During reset time a positive input gate signal couples through the 1000 mmf capacitor and forces this tube to

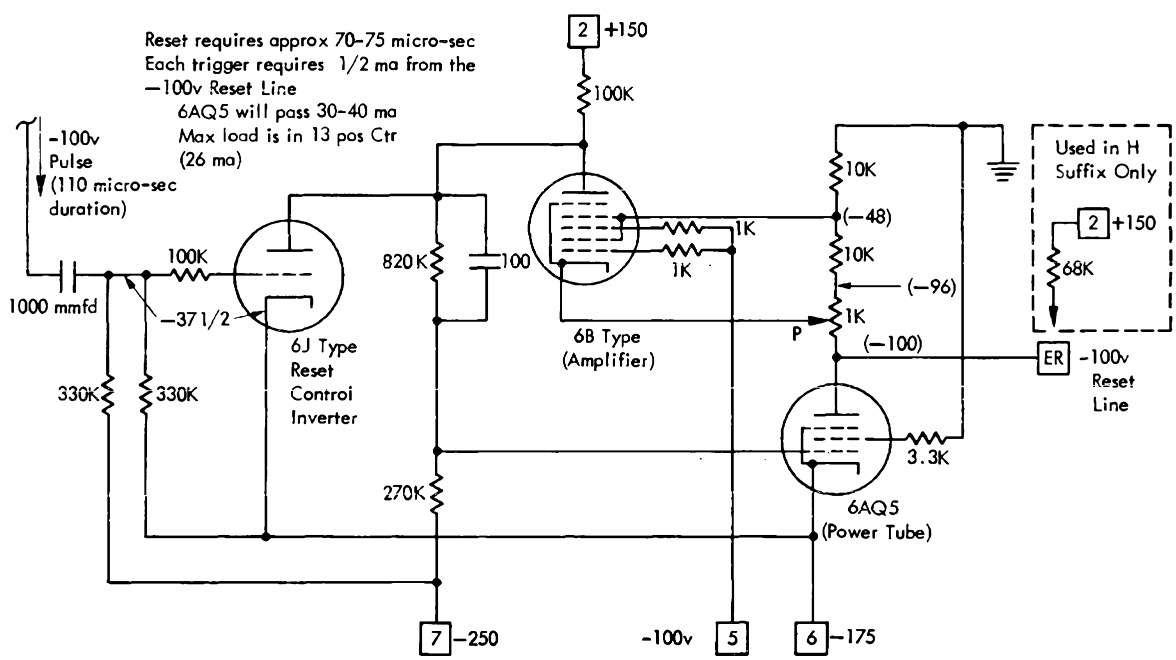


Figure 71. Schematic Diagram of the 604 Reset Circuit

conduct heavily. The plate of the 6J type tube will then drop to about minus 150 volts. This action shifts the grid potential of the 6AQ5 to minus 225 volts with respect to ground (50 volts more negative than its cathode) and cuts off electron flow through the tube. At such time the reset line will shift rapidly upward to zero and reset any triggers connected to it. In the 604H a 68k resistor is connected between the reset line and plus 150 volts as shown in the dotted box in Figure 71. This addition makes the reset line rise more rapidly and settle at plus ten volts (with normal loading from the triggers being controlled). While any individual trigger can be reset in five to ten microseconds, a group of coupled triggers being reset can produce a "ripple" of instability that might last for 70 microseconds. 110 microseconds allows a good safety factor. The 1000 mmf input capacitor to the 6J tube will couple an entire 110 microsecond reset gate. If a long duration gate is applied to this capacitor (such as a CB impulse from the 521), it will couple the shift for about 200 microseconds. This fact is used when reading into storage units from the 521: an electronic type of reset occurs under 521 control panel direction to clear the unit before the card holes are read.

The regulating action of the Amplifier tube is similar to that of the Control Inverter, but not as drastic; it will merely alter electron flow through the 6AQ5, not cut it off. Both control grids of the 6B tube are connected to the minus 100 volt power supply through 1000 ohm parasitic suppressor resistors. The 6B tube becomes a high gain amplifier with a fixed grid reference point. The screen grids are connected to a point between the Reset Line and ground that will make them about 50 volts positive with respect to the cathode.

The variable signal is applied to the *cathode* of this tube from the arm of a 1000 ohm potentiometer fed by the reset line. A screwdriver adjustment of the potentiometer arm permits manually setting the cathode potential. This in turn can set the normal level of the reset line to exactly match the minus 100 volt supply. Any variation of the 100 volt reset line from other influences will also be passed on to the cathode of the 6B Amplifier. Several examples will show how the circuit responds to these influences. The 6J Control Inverter is cut off and need not be considered in these descriptions.

If the Reset Line tends to become less negative (move toward zero volts), as might result from extra loading or from the weakening of the emission from the 6AQ5 cathode, the voltage at the arm of the 1000 ohm potentiometer will also become less negative. This makes the cathode of the 6B Amplifier move in a positive direction which has the same effect on the cathode to plate electron flow as making the grid more negative. That is, the 6B tube electron flow is reduced. The plate thus moves in a positive direction. This in turn couples to the 6AQ5 grid and makes it move in a positive direction. Electron flow through the 6AQ5 increases, making the plate (and the Reset Line attached to it) move negatively, balancing out almost completely the original change. The same type of control would occur for an attempted *negative* shift on the Reset Line, though the potential shift at each point in the loop would be in the opposite direction.

As a second example assume the reset line is found to be two volts more negative than the minus 100 volt power supply. This can be corrected by an adjustment of the potentiometer. A greater voltage drop through the 6AQ5 power tube is needed to let the Reset Line shift two volts positively. This will require a more negative 6AQ5 grid. A more negative potential at the grid can be obtained by increasing the electron flow through the 6B Amplifier tube (which will lower the potential at its plate). To increase the electron flow through the 6B Amplifier tube, the cathode will have to be made more negative by shifting the potentiometer arm downward (on Figure 71), nearer to the 6AQ5 plate. (When actually done in practice, a voltmeter is connected between the Reset Line and the minus 100 volt power supply. The 1000 ohm potentiometer is simply turned until the instrument reads zero, indicating balance.)

As a final example assume that the minus 100 volt power supply is shifted to minus 90 volts for testing purposes. The two control grids of the 6B Amplifier will also shift to minus 90 volts, a ten volt change in the positive direction. Electron flow through the 6B Amplifier will increase and the plate potential will drop. This negative shift at the plate will couple to the 6AQ5 grid and reduce electron flow through it, increasing its effective resistance, and letting the plate go nearer ground level. When the plate (and the Reset Line) gets near minus 90 volts, balance in the circuit is restored. Both the Reset Line and the altered output of the minus 100 volt supply are again nearly matched.

UNIVAC® SCIENTIFIC GENERAL-PURPOSE COMPUTER SYSTEM

SYSTEM MAINTENANCE

PX 23

FEBRUARY 1957

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b. TUBE ELEMENT CONNECTIONS. - Symbols for the various tube element connections are shown in Figure 2. These symbols are used on all three types of diagrams and should be memorized by maintenance personnel.

c. SHORTHAND SCHEMATIC SYMBOLS. - The specific symbols used on schematic and unit signal diagrams are discussed in the following subparagraphs. If a stage or subcircuit is used repeatedly throughout the equipment, and is identical wherever it appears, it is called a "standard stage". All standard stages of the same type are identical electrically; for example, two standard stage flip-flops receiving identical input signals, theoretically, produce identical outputs. Each of the principal standard stages explained below in detail will be found represented by its respective "shorthand schematic symbol" when it appears on a schematic-type diagram.

The principal standard stages are flip-flops, cathode followers, inverters, gates, amplifiers, and pulse transformers.

(1) FLIP-FLOP. - The Eccles-Jordan trigger circuit, or flip-flop, is a form of multivibrator employing direct coupling between the plates and grids of two tubes. It is essentially a device which provides an output of a steady d-c voltage when correspondingly triggered by a momentary pulse of relatively short duration. This steady d-c output remains until removed by anotherseparate triggering of the flip-flop. For example, in Figure 3, one condition of equilibrium exists if the triode in side "A" of the flip-flop tube is conducting and the triode in side "B" is cut off, and the other condition of equilibrium exists if the triode in side "A" is cut off and side "B" is conducting. Regardless of which of these two states the flip-flop is in, it remains in the current state until some external impulse causes it to reverse its state. After such a reversal, the flip-flop remains in the second state until another external impulse is applied to revert the flip-flop to its first state. The term "flip-flop" is derived from this property of "flopping" from state to state.

Since the circuitry in both halves of the flip-flop is identical, it seems that equal plate current should flow through the triode in each half when plate voltage is applied; however, slight unbalances are always present. This unbalance causes a greater plate current to flow in one of the tube's twin triodes when plate voltage is applied. If the greater plate current flows in the triode in side "A", a proportionally larger voltage drop occurs across plate resistors R83 and R84, in side "B"; therefore, the voltage at the plate of the triode in side "A" is lower than that at the plate of the triode in side "B". The lower plate potential at the triode in side "A" is applied to the grid of the triode in side "B" through the voltage divider consisting of R88 and R92. The decreasing potential at this grid causes a further decrease in the plate current of the triode in side "B". The decrease of current in side "B" causes a corresponding rise in its plate voltage. This rise in plate voltage is applied to the grid of the triode in side "A" through the voltage divider consisting of R87 and R91. These incremental changes continue until a state of equilibrium is reached, at which time the triode in side "B" is cut off and the triode in side "A" fully conducting.

To reverse the state of equilibrium, a negative going pulse is applied through CR80 to the grid of the triode in side A. The decrease in voltage on the grid of this triode causes a drop in its plate current. The drop in plate

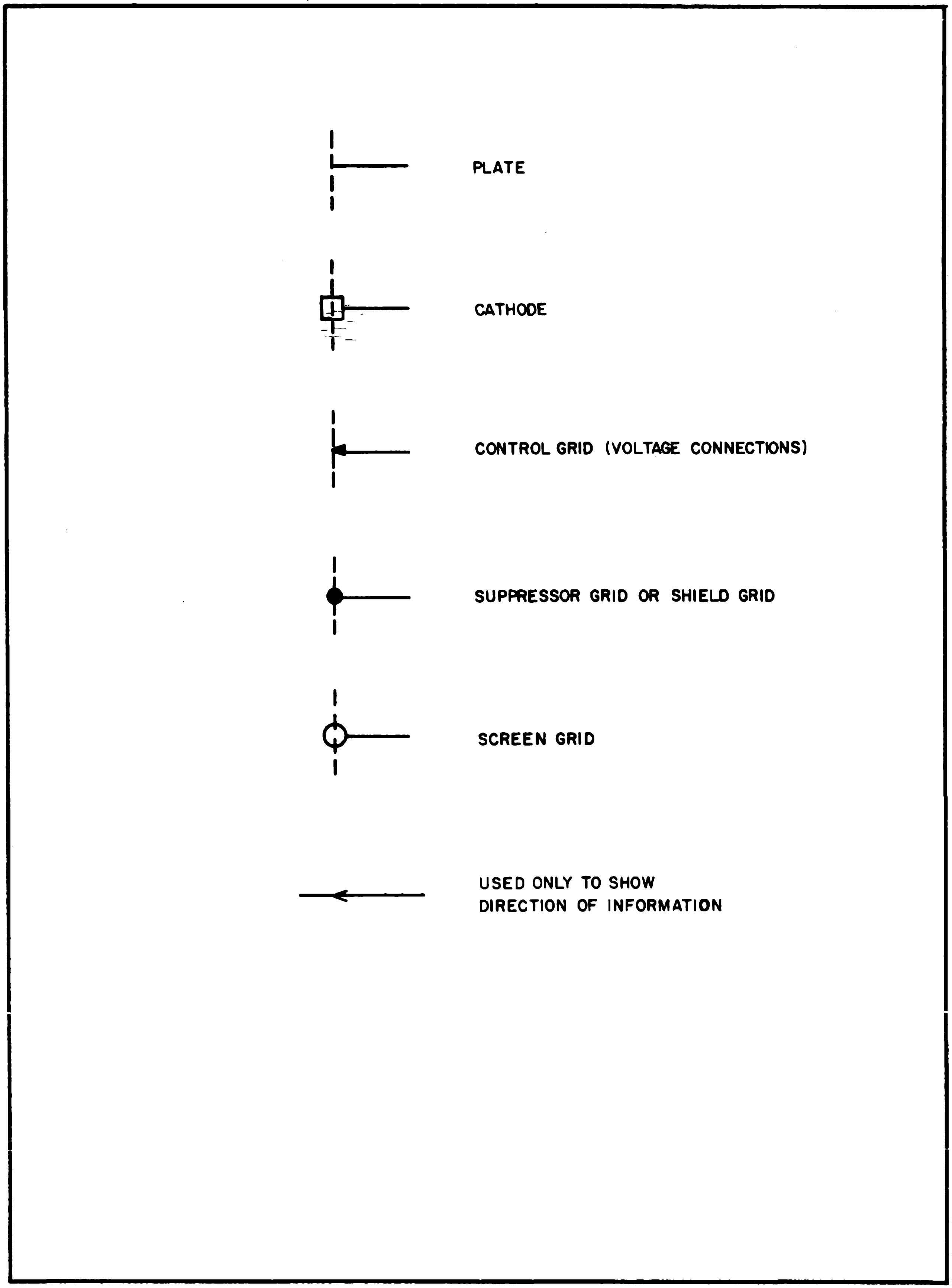


Figure 2. Tube Element Connections.
PX 131

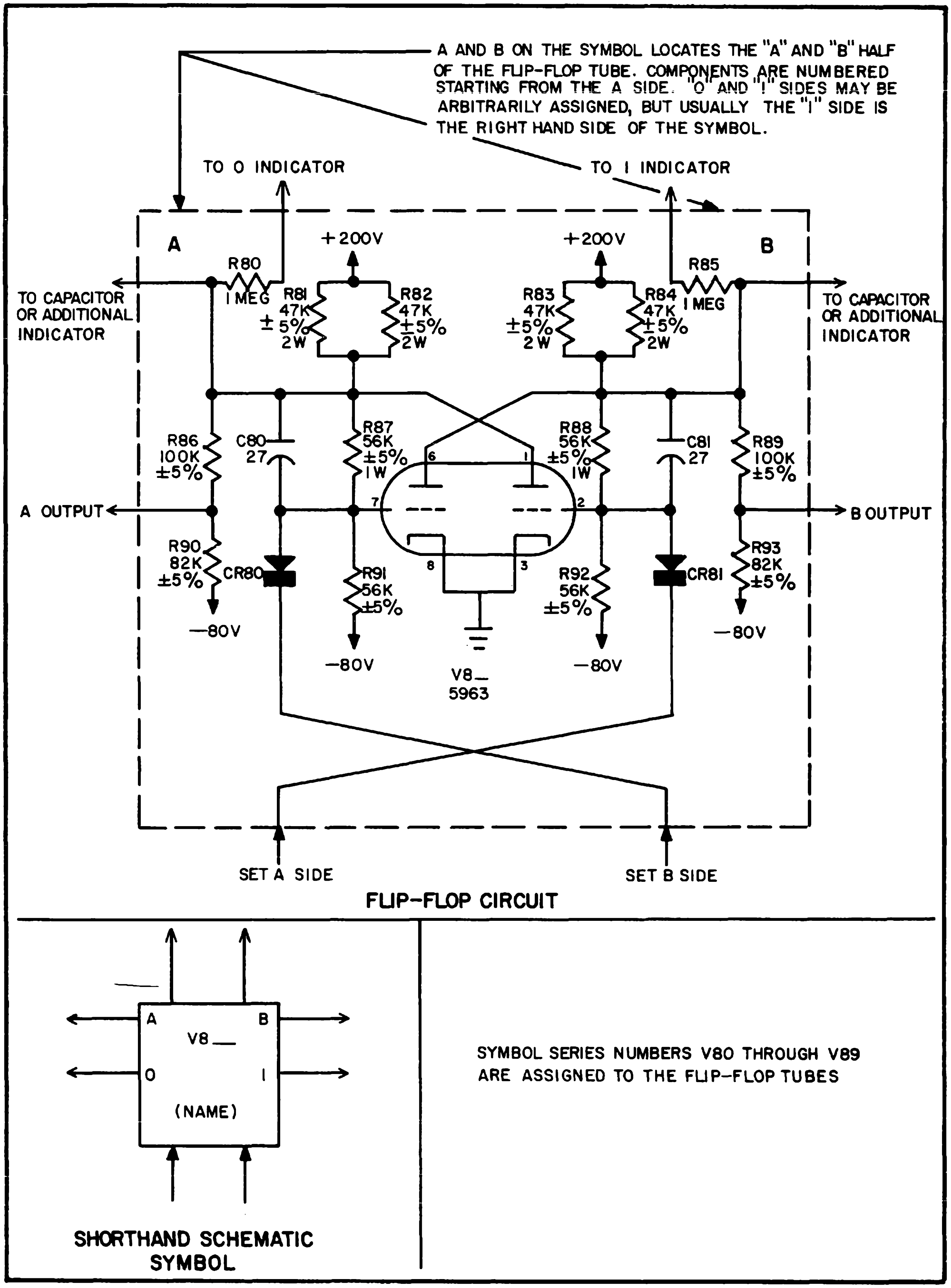


Figure 3. STANDARD Flip-flop Stage
PX 131

current causes a rise in plate voltage, which is applied to the grid of the triode in side B through the voltage divider consisting of R88 and R92. This rise in grid voltage causes the plate of the triode in side B to start to conduct. This triode, when conducting, draws more current and therefore has a lower plate voltage, which is applied to the grid of the triode in side A through the voltage divider consisting of R87 and R91. The reduced voltage at the grid of the triode in side A drives that tube closer to cut-off and the triode in side B to heavier conduction. The process continues until the triode in side A cuts off and that in side B fully conducts. This condition represents the second state of equilibrium.

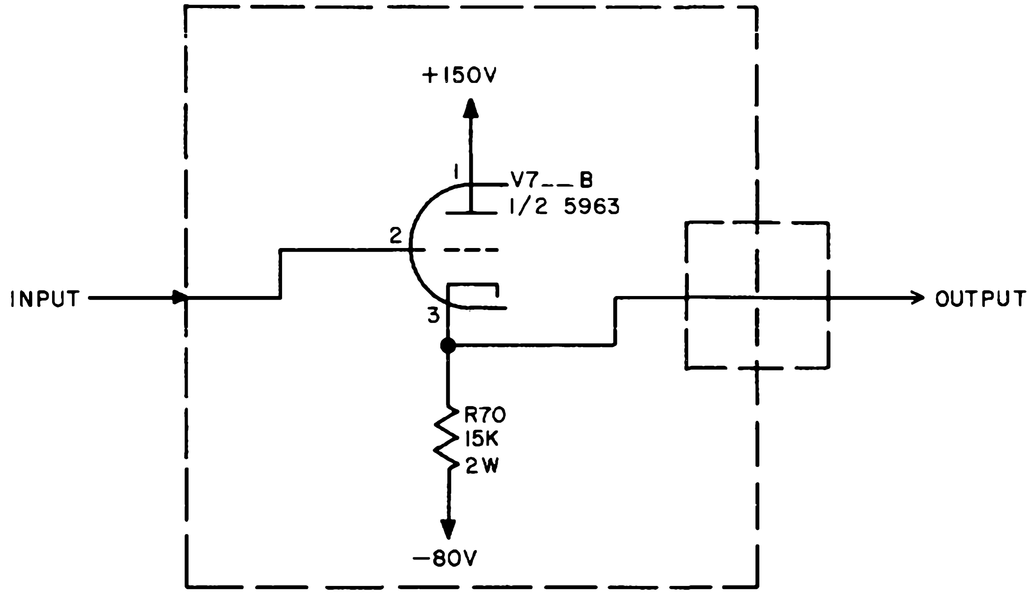
The shorthand schematic symbol for the standard flip-flop stage is also shown in Figure 3. Usually the "A" side of the flip-flop is called the "0" state and the "B" side is called the "1" state. The input line on the "0" side of the flip-flop symbol indicates an input signal to set the flip-flop to "0"; the input line to the "1" side indicates a similar input to set the flip-flop to "1". When the flip-flop is in the "1" state, the "1" output shown on the "1" side of the symbol is positive, and when in the "0" state the output on the "0" side is positive.

It is sometimes desirable to simply reverse the state of a flip-flop by an input signal. This is done by applying a "trigger" signal simultaneously to both input lines through isolation crystals outside the flip-flop circuit. The sample circuit shown in Figure 12 includes a trigger input line, connected to CR05 and CR06. A negative COMPLEMENT X pulse on this line is received, through the crystals, by both sides of the flip-flop. The signal has no direct effect on the non-conducting triode, but proceeds to cut off the conducting triode. As a result, the state of the flip-flop is reversed in the manner described above.

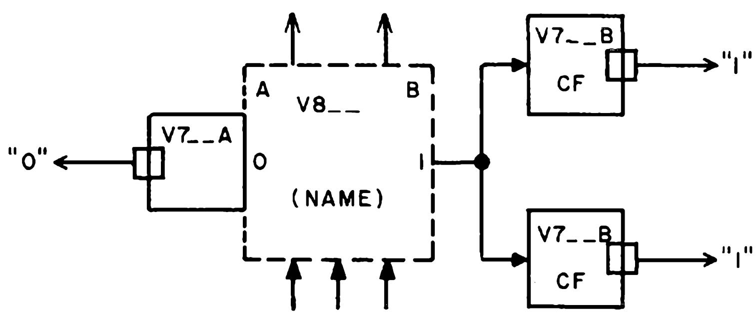
(2) CATHODE FOLLOWER. - The standard cathode follower stage is essentially an impedance matching device. In Figure 4, the low impedance cathode output voltage "follows" closely the changes in potential of the high impedance input, hence the name cathode follower. A triode vacuum tube (1/2-5963) is employed with its plate tied to +150vdc. The cathode is connected through a resistance to -80vdc. The output of the cathode follower is taken across the cathode resistor.

In actual operation, a positive signal from the output of a flip-flop is fed directly into the grid of the cathode follower tube. This causes the cathode to draw current and results in a voltage drop across the cathode resistor. Since the output voltage is taken across the cathode resistor, this voltage drop causes the output to change relative to the input signal. When the flip-flop changes state and the input signal is removed, the cathode ceases to draw current and the output signal is correspondingly removed. The particular side, A or B, of the 5963 tube used is included in the tube's symbol series number.

(3) INVERTER. - The standard inverter circuit is essentially a phase inverter which is used to reverse the polarity of the input signal. A signal triode (1/2-5963) is used and it is shown with its associated circuitry in Figure 5.



CATHODE FOLLOWER CIRCUIT

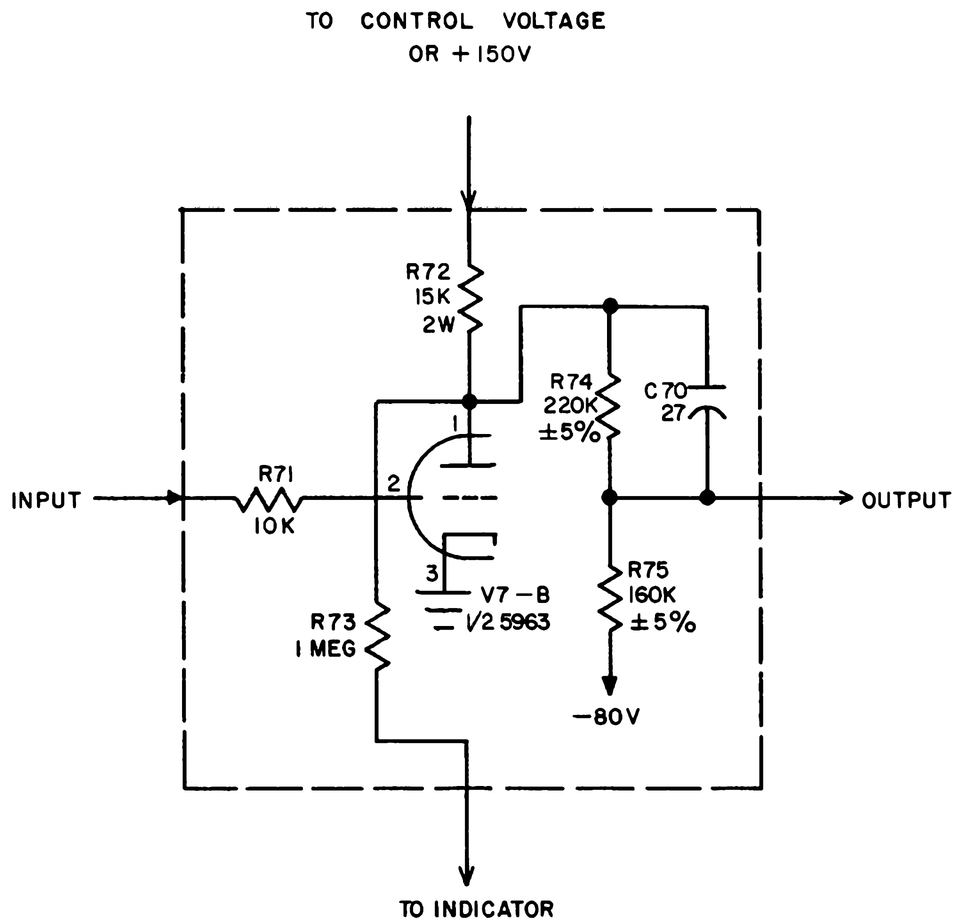


SHORTHAND SCHEMATIC SYMBOL *

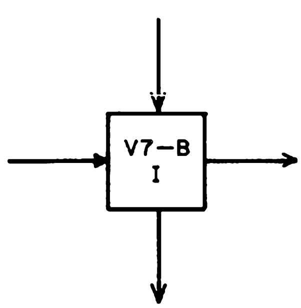
SYMBOL SERIES NUMBERS V70 THROUGH V79 AND V90 THROUGH V99 FOLLOWED BY "A" OR "B" ARE ASSIGNED TO THE CATHODE FOLLOWER AND INVERTER TUBES.

* WHEN MORE THAN ONE CATHODE FOLLOWER IS USED ON A SINGLE FLIP-FLOP OUTPUT, THE CATHODE FOLLOWER SYMBOLS ARE SHOWN DETACHED FROM THE FLIP-FLOP BLOCK ON SCHEMATIC-TYPE DIAGRAMS

Figure 4. STANDARD Cathode Follower Stage
PX 131



INVERTER CIRCUIT



SHORTHAND SCHEMATIC SYMBOL

SYMBOL SERIES NUMBERS V70 THROUGH V79 AND V90 THROUGH V99 FOLLOWED BY A OR B ARE ASSIGNED TO THE INVERTER AND CATHODE FOLLOWER TUBES.

Figure 5. STANDARD Inverter Stage
PX 131

In actual operation, a positive signal arrives at the input and is fed into the grid of the inverter. This increase in grid voltage causes the plate circuit to draw current with a resulting decrease in plate voltage. The decrease in plate voltage is distributed in the voltage divider R74, R75 and causes the output to be driven to a negative state.

When the positive signal is removed from the input, the grid voltage is reduced. This reduction causes the plate current to decrease and the plate voltage to increase. The resultant increase in plate voltage is distributed in the voltage divider R74, R75 and causes the output to return to its positive state. Thus, when a positive signal is applied to the input, a negative signal results in the output. Conversely, when no signal is applied to the input, a positive signal results in the output. The particular side, A or B, of the 5963 tube is included in the inverter's symbol series number.

(4) GATE. - The standard gate circuit regulates the passage of signal pulses. It may either pass or block a signal pulse depending upon the presence of a positive d-c potential called the "enable" at the suppressor grid. A pentode (7AK7) is used in the circuit shown in Figure 6. The plate is connected to +150vdc through a load. The screen grid is tied to +100vdc.

In actual operation, a pulse arrives at the input and is fed into the control grid. If a positive d-c potential (enable) is coincidently fed into the suppressor grid via the external enable circuit, the plate then draws current and a resultant pulse signal is formed in the output circuit. Thus the tube has effectively passed the pulse signal. If the pulse signal arrives at the input and a d-c enable is not fed into the suppressor grid, the plate does not draw current and no resultant signal is produced in the output circuit. Thus the tube has effectively blocked the pulse signal.

(5) AMPLIFIER. - The standard amplifier is used to produce voltage gain. A 6AN5 tube is used and is shown in its typical circuit in Figure 7.

In operation, a pulse signal arrives at the input and is fed into the control grid. The pulse causes the control grid to be driven to a relative positive state which causes the plate circuit to draw current. A voltage drop is formed across the plate load, which is much larger than the original input signal. In this manner, voltage gain has been produced, and the original input signal has been amplified.

(6) PULSE TRANSFORMERS. - Standard pulse transformers are used primarily for impedance matching and phase inversion purposes.

In actual operation, the pulse transformer does not differ greatly from an ordinary transformer. However, care was taken in construction to provide the pulse transformer with sufficient high and low frequency response to avoid distorting the pulse wave shape as it passes.

Winding ratios, as well as other symbols, are shown on each diagram as indicated in Figure 8.

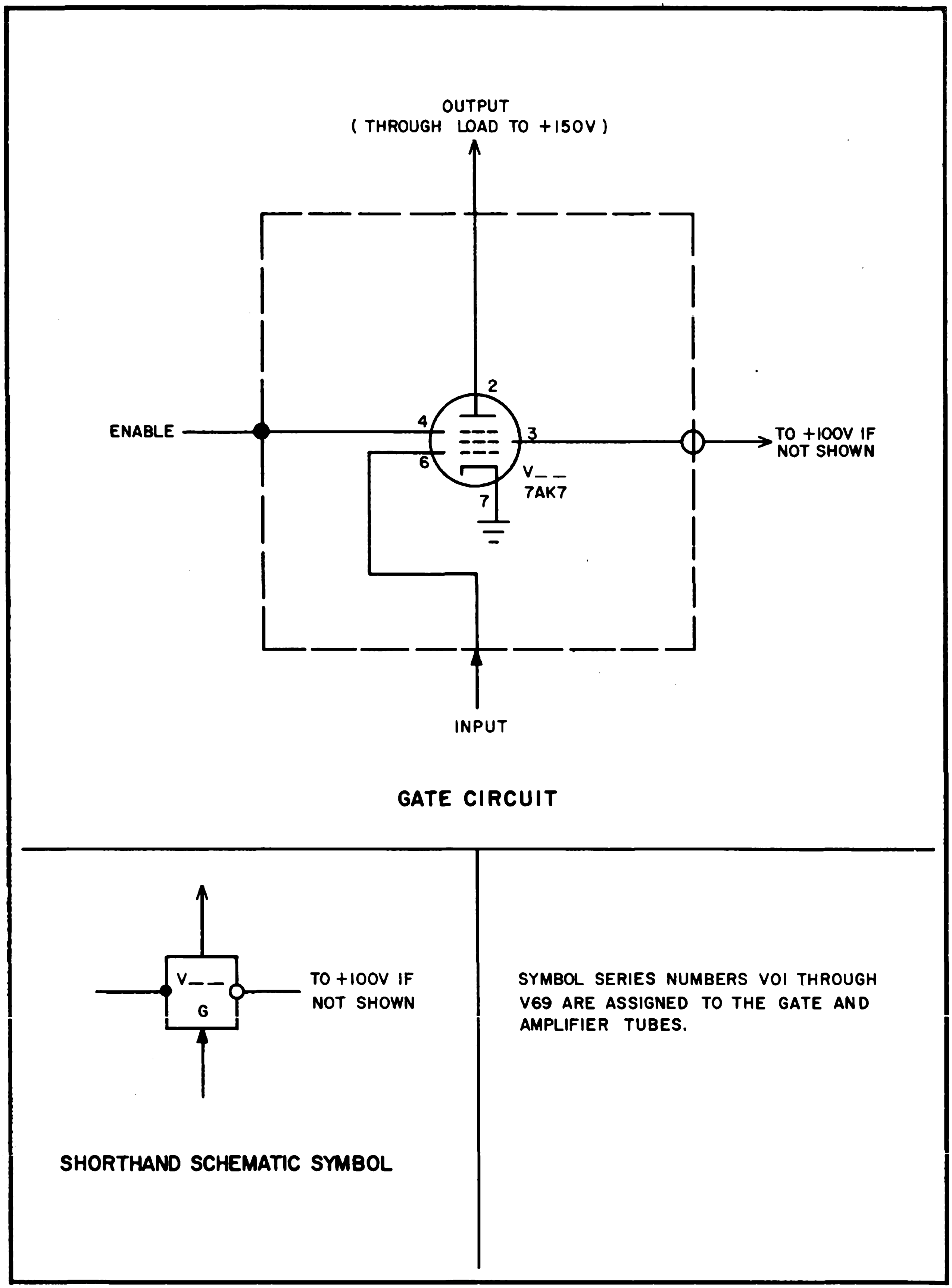
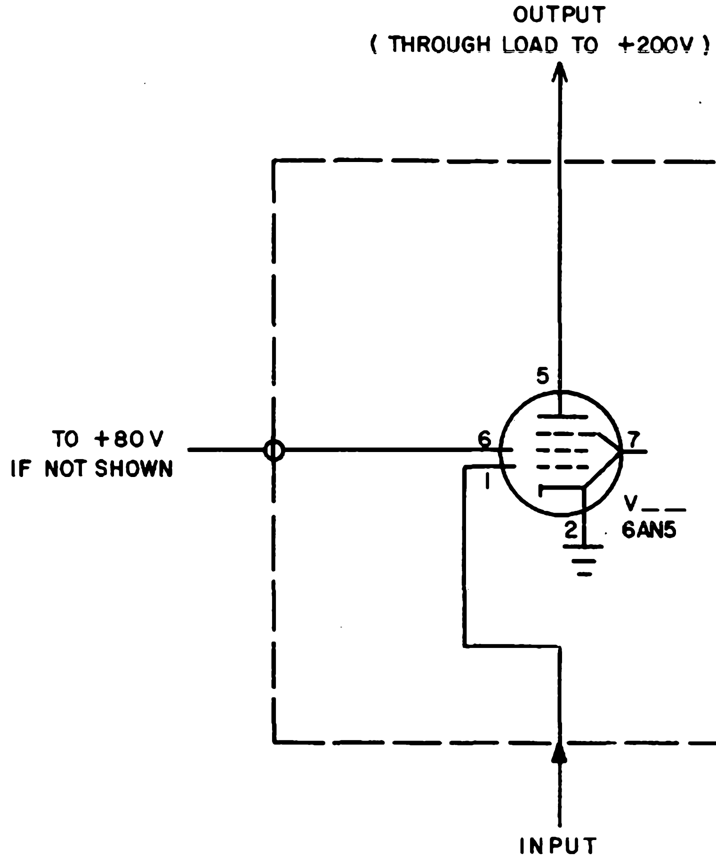
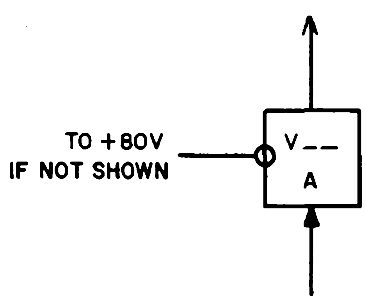


Figure 6. STANDARD Gate Stage
PX 131



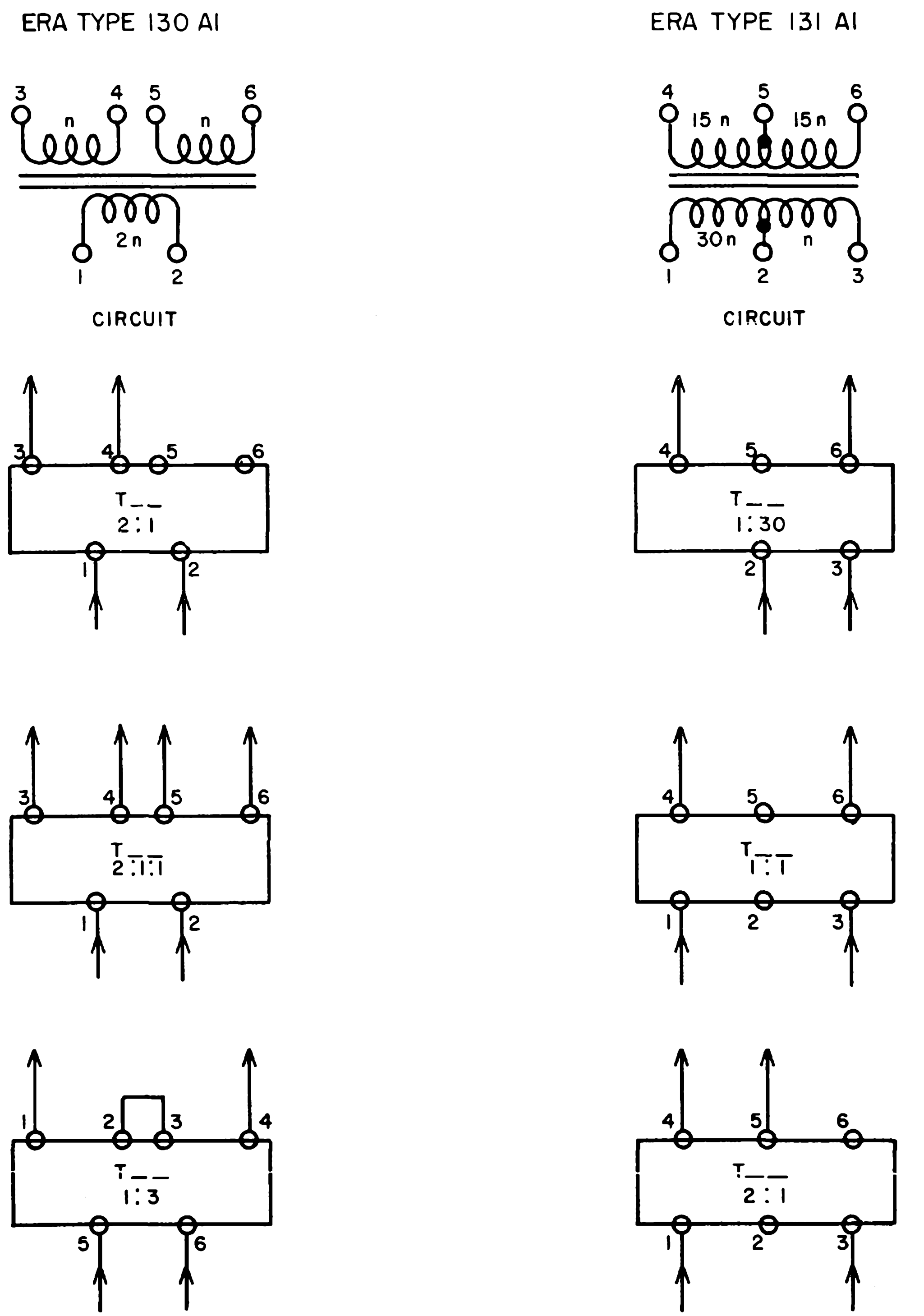
AMPLIFIER CIRCUIT



SHORTHAND SCHEMATIC SYMBOL

SYMBOL SERIES NUMBERS V01 THROUGH V69 ARE ASSIGNED TO THE AMPLIFIER AND GATE TUBES.

Figure 7. STANDARD Amplifier Stage
PX 131



SYMBOL SERIES NUMBERS T01 THROUGH T99 ARE ASSIGNED TO THE PULSE TRANSFORMERS. TURNS RATIOS USED ARE PRINTED BELOW THE SYMBOL SERIES NUMBERS. (TYPE 130 A1 IS INTERCHANGEABLE WITH TYPE 130 A2. TYPE 131 A1 IS INTERCHANGEABLE WITH TYPE 131 A2.)

Figure 8. STANDARD Pulse Transformer Stages
PX 131

(7) SHAPER. - A shaper is used to change the form of a pulse to a desired level, duration, or shape. This is done in order to facilitate the use of the pulse in a special application or circuit. Shapers differ in their purpose and circuitry. For this reason, shapers are indicated by the symbol shown in Figure 9, and their operations are not detailed unless necessary for the explanation of an associated circuit.

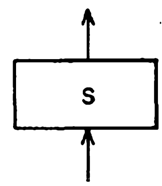


Figure 9. Shaper Symbol

(8) SINGLE PULSE CIRCUIT. - A standard single pulse circuit is used to provide a single pulse output when its input has been triggered by a positive d-c potential. It generally consists of a thyratron type 2D21 tube and its associated circuitry as shown in Figure 10.

In actual operation, the input signal is fed into the control grid. The characteristics of a thyratron are such that, if the input signal potential is great enough, the tube suddenly discharges and forms a short but strong output pulse in the cathode circuit. An output signal is also produced in the plate circuit, but it is not used in this application. After the discharge, the thyratron returns to its original state and is ready for the next input signal.

(9) DELAY (VACUUM TUBE). - The standard vacuum tube delay network causes a short delay to the passage of an input pulse. A 5963 tube is used and is shown with its associated circuitry in Figure 11.

In actual operation, the B section of the tube is normally conducting, while the A section is normally cut-off. When a negative going pulse is fed into the input, the grid of the B section is driven negatively and causes it to be cut off. The plate voltage increase, resulting from the cut off of section B, is fed into the grid of section A, which causes it to conduct. The result is a reduction in the plate voltage of section A. Simultaneously with the above operations, the capacitor (C09) was discharged by the input pulse. It begins immediately to recharge and, upon its recovery, causes the tube to switch back to its original state. This causes an increase in the plate voltage of section A.

The momentary reduction and resultant restoration of the plate voltage of section A is fed through the capacitor (C11), which translates the reduction and restoration into a single negative and single positive pulse. The actual delay in time is represented by the interval between these two pulses. When these pulses are fed into the cathode follower circuit, the negative pulse is ignored and the positive pulse is passed. The resultant pulse, which appears at the output, is delayed, as compared to the original input pulse.

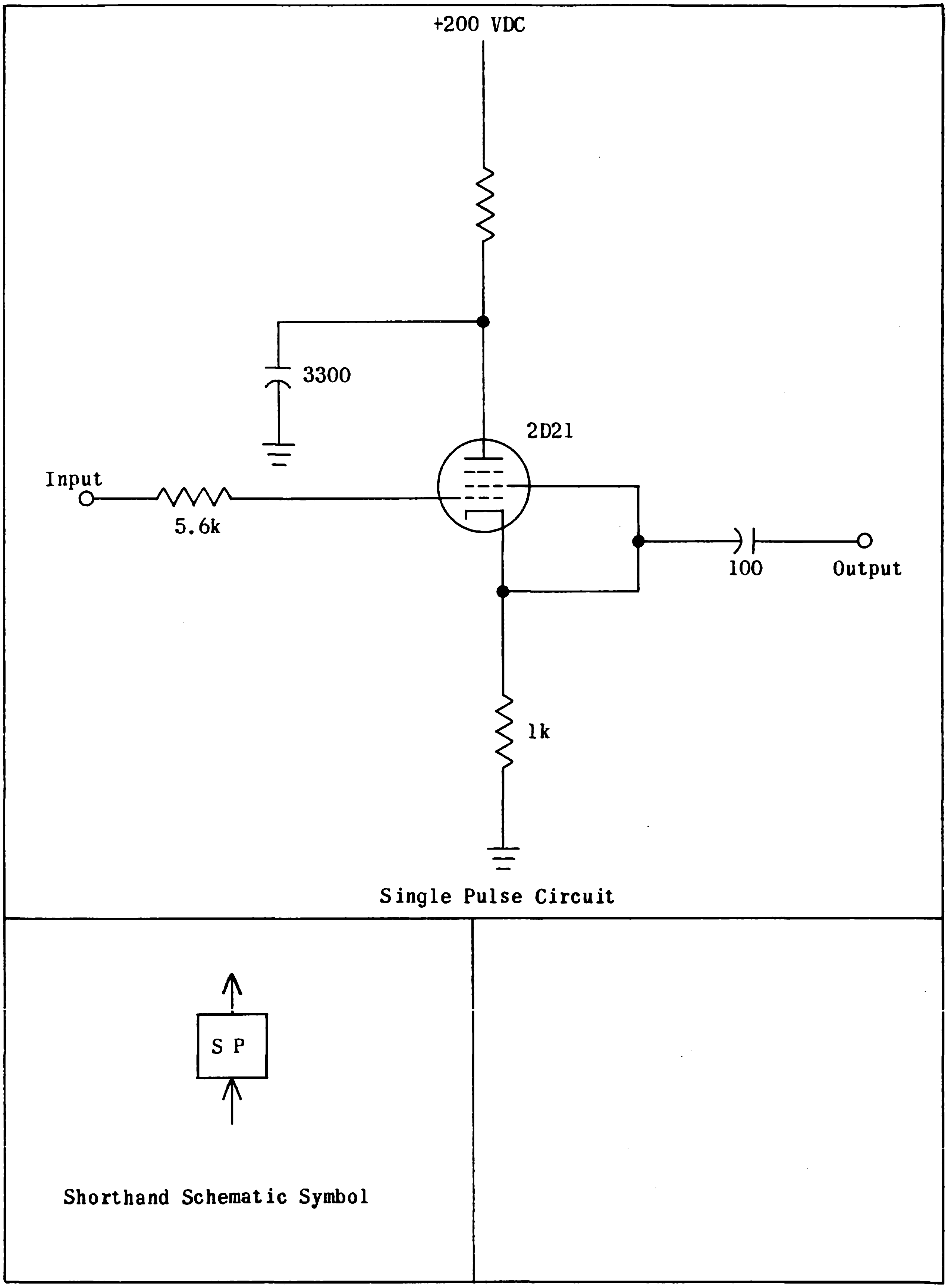
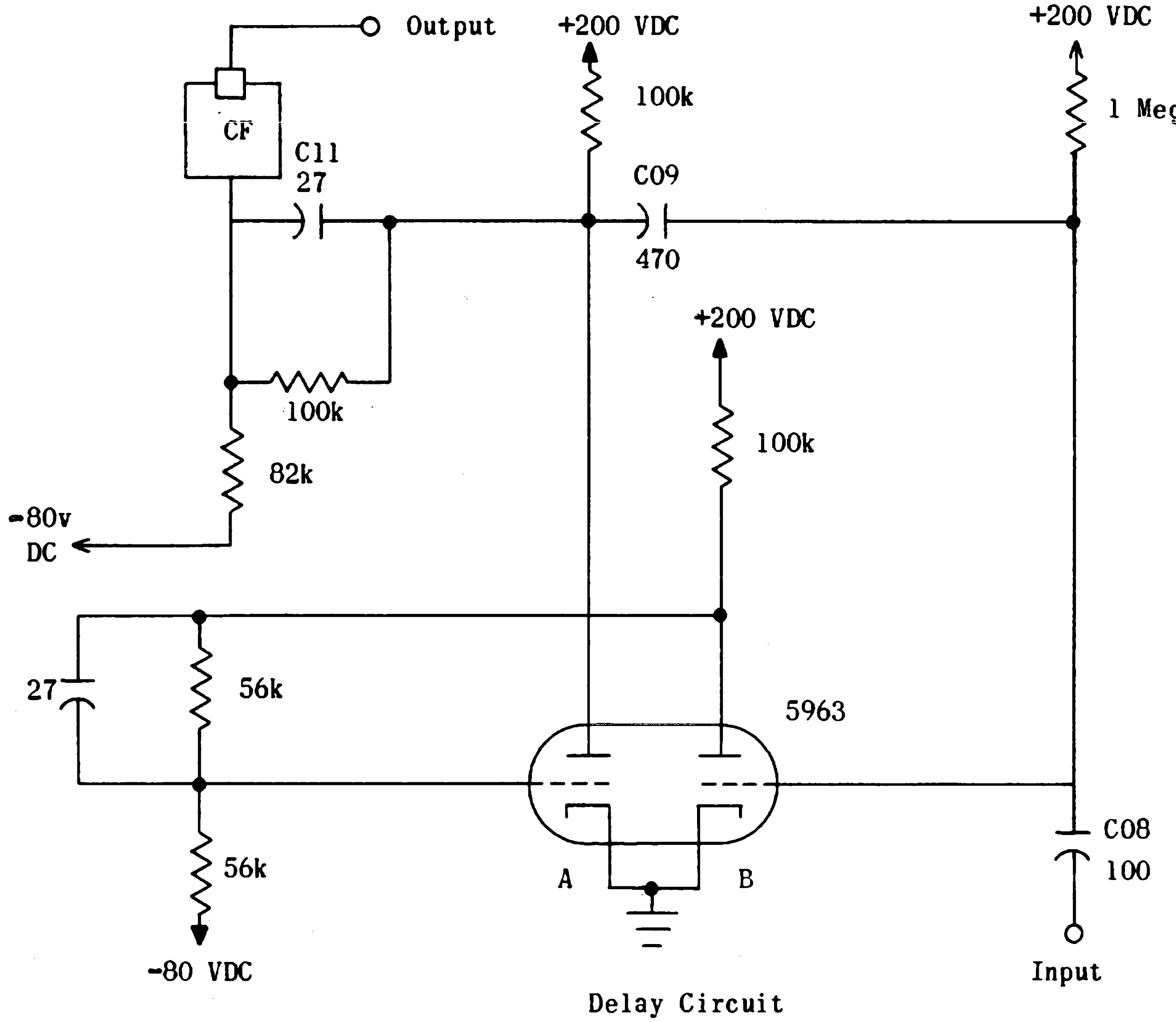


Figure 10. STANDARD Single Pulse Circuit
PX 131



NO SHORTHAND

SCHEMATIC SYMBOL

Figure 11. STANDARD Delay Circuit (Vacuum Tube)
PX 131

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PART 4

CHAPTER 1

ARITHMETIC COMPONENTS

1.1 LOGICAL CIRCUITS

1.1.1 General

The three logical operations AND, OR and NOT are introduced in Part 2, Chapter 3. The operations may be characterized in terms of binary numbers as follows:

a. Assume that a number of inputs $x_1, x_2, x_3, \ldots, x_n$ are applied to the input terminals of an AND block. Then if each of these inputs is 1, the output of the block is 1. If, on the other hand, any of the inputs is 0, the output of the block is 0.

b. Assume that a number of inputs $x_1, x_2, x_3, \ldots., x_n$ are applied to the input terminals of an OR block. Then, if any of these inputs is 1, the output of the block is 1. If all the inputs are 0, then the output is 0.

c. Assume that an input, x, is applied to the input terminal of a NOT block. Then, if x is 1, the output is 0. On the other hand, if x is 0 the output is 1.

Circuits which perform the AND and OR functions are presented in this section. A NOT circuit isn't developed. However, a study of the flip-flop circuit developed in the following section (Section 1.2) reveals that a NOT function can be obtained from this circuit by proper choice of output terminals. The inverter, which is presented in Chapter 3 of this Part, also performs the NOT function.

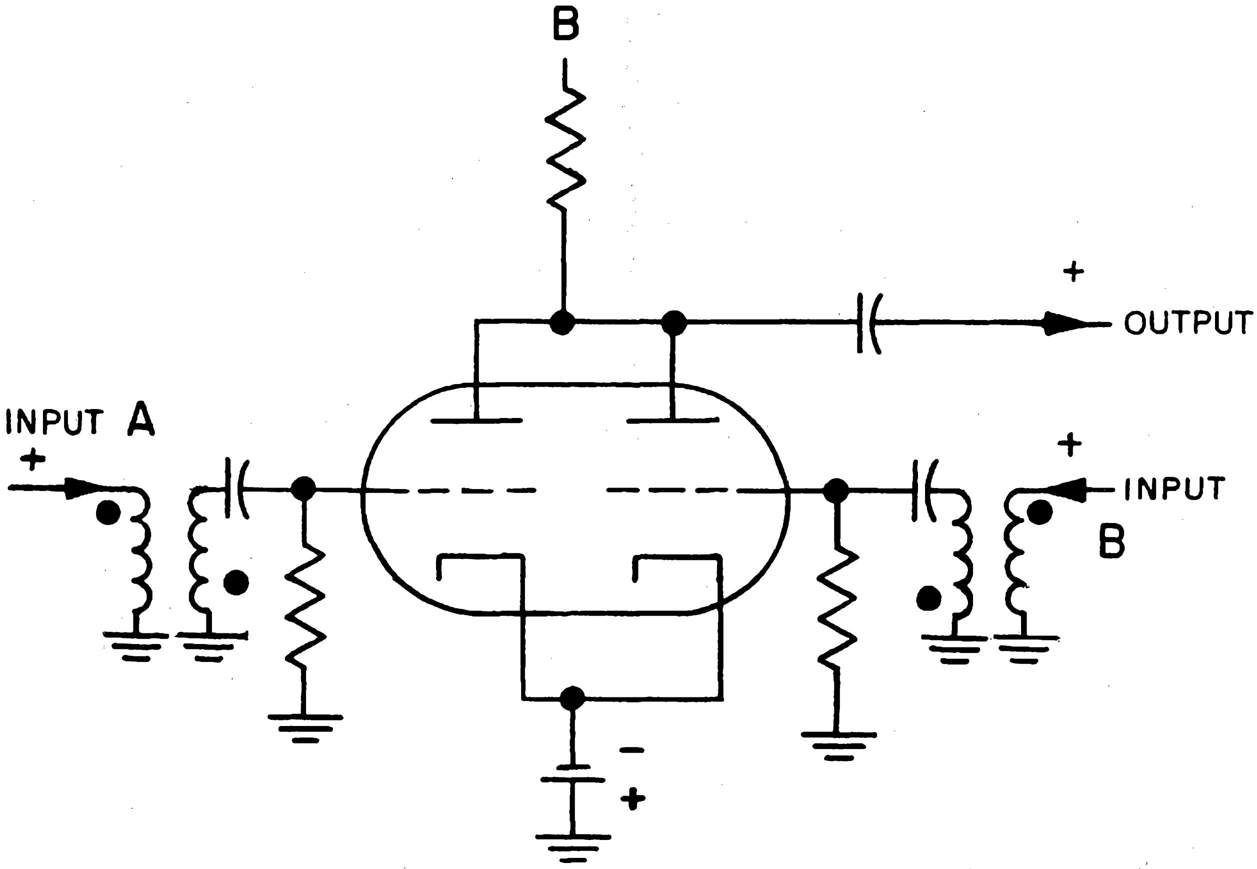


Figure 4-1

1.1.2 Positive and Negative Logic

In the logical circuits developed in this chapter, 1's and 0's are represented either by steady-state voltage levels or by the presence or absence of pulses at particular instants. The representation of a 1 by a positive voltage level and a 0 by a negative voltage level is defined as positive logic. Also, the representation of a 1 by a positive pulse appearing at a particular instant, or of a 0 by the absence of a pulse at that instant is defined as positive logic. On the other hand, the representation of a 0 by a positive voltage level and a 1 by a negative voltage level, or the representation of a 0 by a positive pulse appearing at a particular instant or of a 1 by the absence of a pulse at that instant is defined as negative logic. Unless otherwise specified positive logic is assumed in the discussion which follows.

1.1.3 AND Circuits

An AND circuit employing a twin troide is illustrated in Figure 4-1. The two sections of the tube share a common plate load resistor and a common cathode supply. The grid of each section of the tube is returned to ground through a resistor. Since the cathode supply is negative with respect to ground, plate current is drawn through both sections of the tube in the absence of an input to either grid. Inputs to the grids are applied through phase-inverting input transformers. A positive pulse applied to the input of either section thus appears as a negative pulse on the grid of the section causing the section to be cut off. However, the plate and battery supplies and

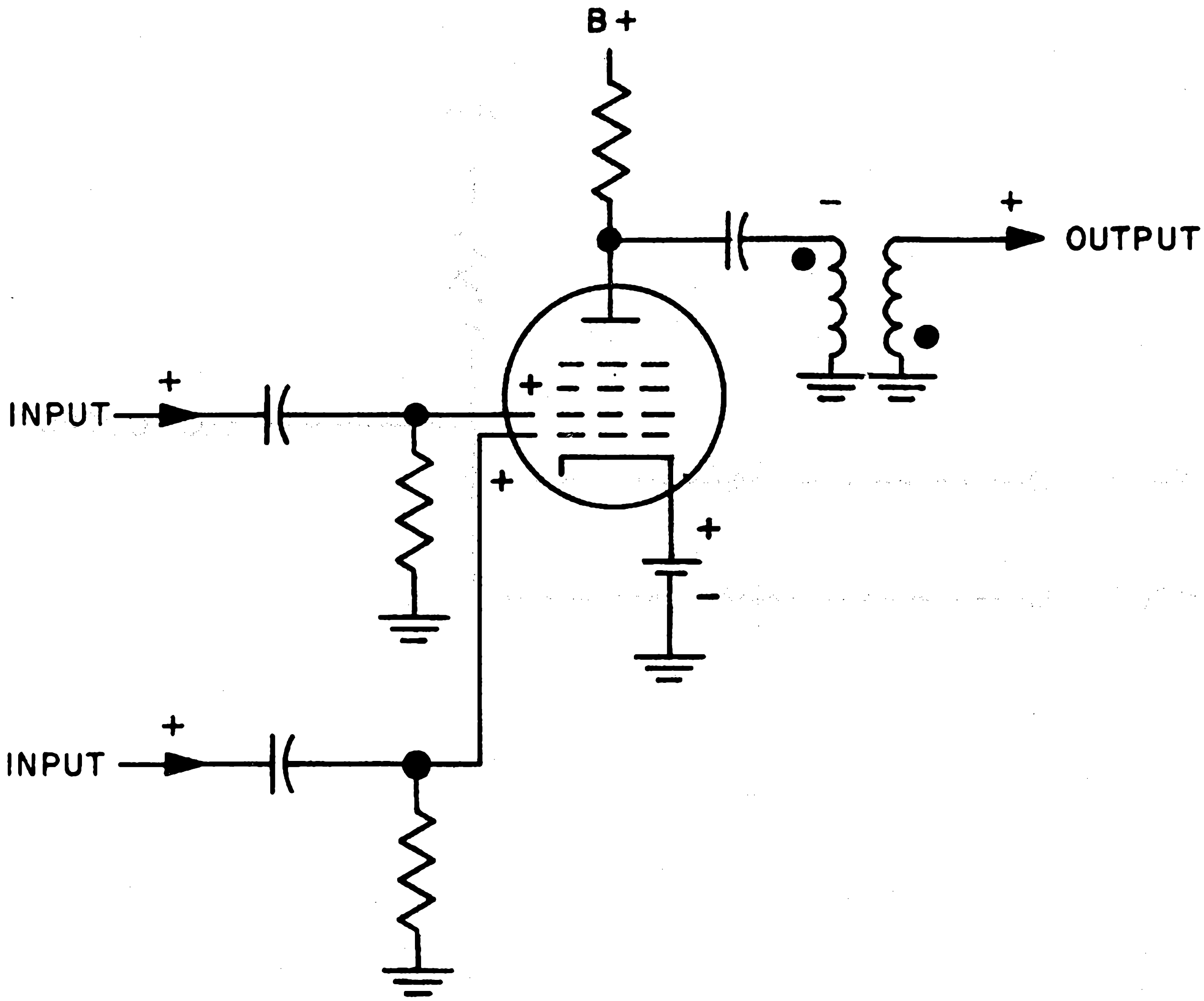


Figure 4-2

plate load resistance are so chosen that either section of the tube alone is capable of drawing approximately the same magnitude of current as can be drawn by both sections conducting simultaneously. Thus, an input applied to one section of the tube, causing that section to be cut off, has a negligible effect on the total current through the circuit and therefore the voltage drop through the plate load is only slightly affected. If, on the other hand, both sections of the tube are simultaneously cut off (by the simultaneous appearance of input pulses on both input lines) then the plate voltage rises to the level of the plate supply, producing a positive pulse on the output line. In terms of positive logic, then, the circuit performs the AND function; that is, a 1 appears at the output if and only if 1's are applied to both inputs simultaneously.

An AND circuit employing a single multi-grid tube is illustrated in Figure 4-2. Both grids are biased negatively with respect to the cathode so that the tube is normally cut off. A positive signal applied to either one of the grids is not sufficient to cause conduction through the tube. However, if positive pulses appear simultaneously at both inputs, the tube conducts, causing a voltage drop through the plate load. The resultant negative signal at the plate is coupled through a capacitor and a phase-inverting output transformer so that it appears as a positive pulse on the output line. Thus, in terms of positive logic, the circuit performs the AND function; that is, a 1 appears at the output if and only if 1's are simultaneously applied to both inputs.

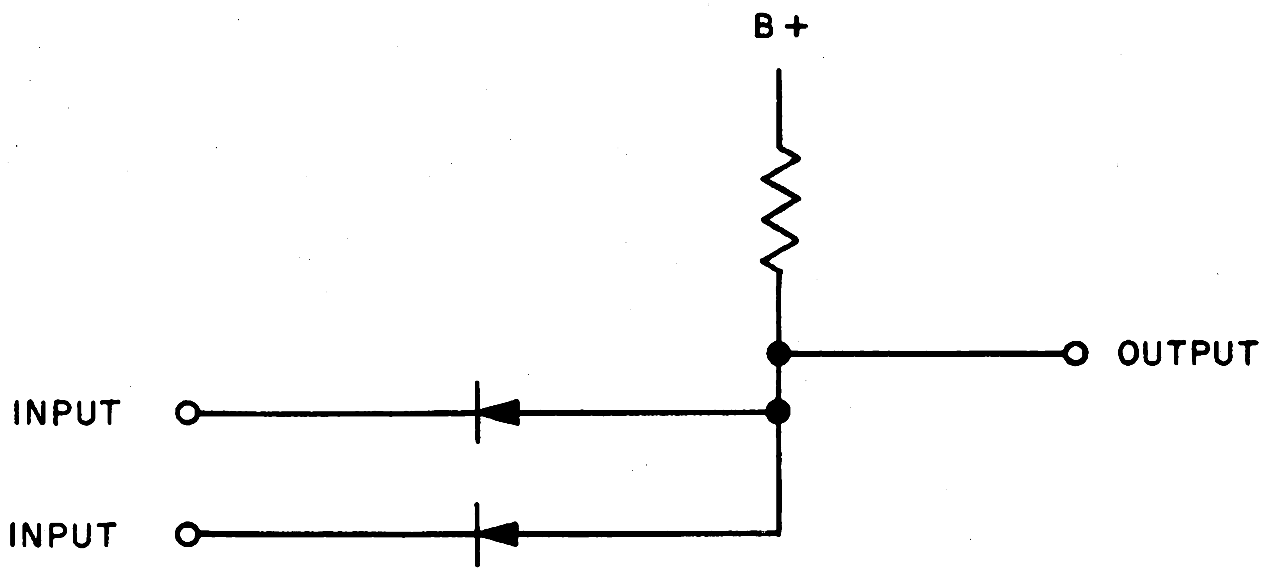


Figure 4-3

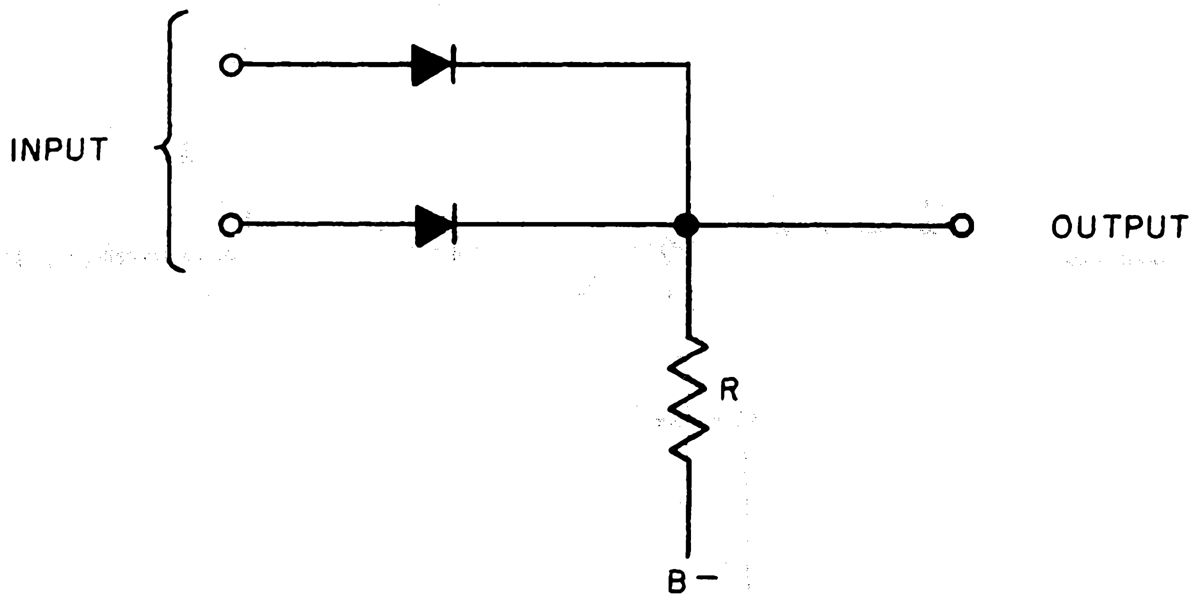


Figure 4-4

The AND circuits of Figures 4-1 and 4-2 are RC coupled. Thus they supply transient outputs in response to transient inputs. An entirely different kind of AND circuit is illustrated in Figure 4-3. This circuit comprises two diodes and a dropping resistor. If both of the inputs are positive (1's), then the output is positive (1). However, if either of the inputs is negative (0), current is drawn through the dropping resistor and through the corresponding diode. Since the forward resistance of the diode is small compared to the dropping resistance, the output falls virtually to the level of the negative input (0). Current from the positive input terminal is blocked by the associated diode. If both inputs are negative, current is drawn through both diodes and the effect is the same. This circuit, therefore, is capable of generating a steady-state AND output in response to steady-state inputs.

1.1.4 OR Circuits

As noted above, the circuits of Figure 4-1 through 4-3 are defined in terms of positive logic as AND circuits. It should be understood that in terms of negative logic they are OR circuits. For example, in terms of negative logic, the circuit of Figure 4-3 generates a steady-state 1 output (negative voltage level) in response to a steady-state 1 input (negative voltage level) on either of its input lines.

A diode network which functions as a positive OR circuit is shown in Figure 4-4. Comparing this network with the circuit of Figure 4-3, it can be seen that the direction of the diodes has been reversed and that, moreover, the polarity of the reference voltage applied to the dropping resistor has been reversed. If a 1 (positive voltage level) appears on either of the input lines, then a 1 (positve voltage level) appears on the output line. This follows from the fact that a positive voltage on either of the input lines causes current to flow between the input terminal and the reference supply. Since the forward resistance of the diodes is very small with respect to the dropping resistor, the output terminal is raised to essentially the potential of the input terminal. If both input terminals are positive, the effect is substantially the same. If both input terminals are negative, no current flows through either diode and the output terminal assumes the potential of the reference supply (i.e. a negative potential). Thus the circuit satisfies the definition of the OR function. It should be understood that in terms of negative logic, the circuit of Figure 4-4 is an AND circuit just as the circuit of Figure 4-3 is an OR circuit.

1.1.5 Adders, Subtractors and Multipliers

The AND and OR circuits discussed in the preceding sections provide the means for implementing the blocks of the half-adders, full-adders, multipliers and so on that were discussed in block form in Chapter 3 of Part 2. However, there is more to these combinations than just the logical circuits. The diode AND and OR circuits for example are passive elements, that is they dissipate rather than generate power. This implies the need for amplifiers to be used in conjunction with them. The dual triode and multi-grid logical circuits are active elements; however, their transient action implies the need for subsidiary timing

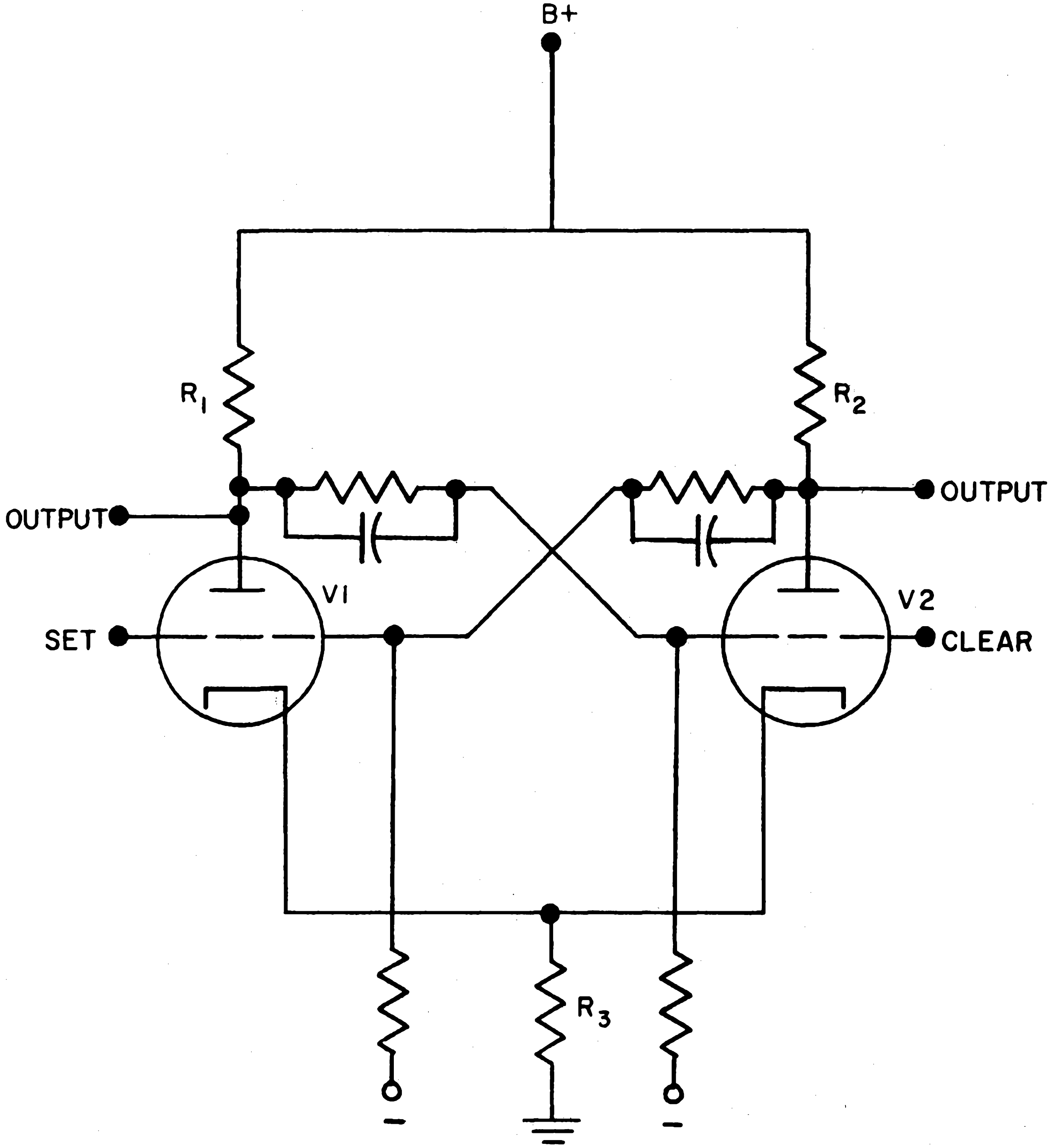


Figure 4-5

circuitry. The voltage and power amplification circuits that are required for use in conjunction with passive elements are discussed in Chapter 3 of this Part. A timing and ordering circuit is presented in the succeeding section. Timing is considered in more general terms in Part 5.

1.2. FLIP-FLOP CIRCUITS

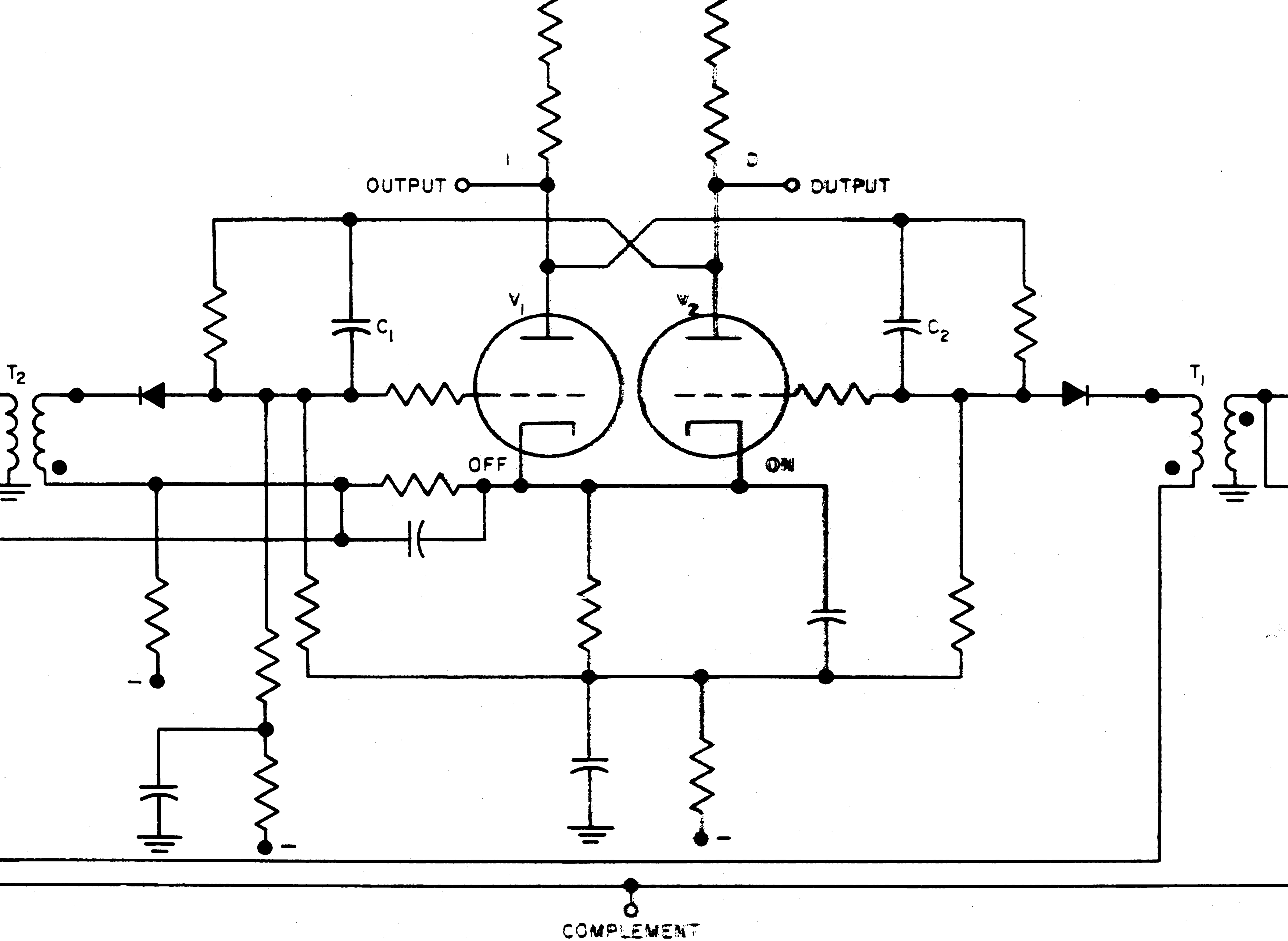
1.2.1. General

The flip-flop is a bi-stable multivibrator; i.e. it is a circuit which has two stable states. This implies that an external input signal is required to drive it from one state to the other. The basic circuit which is shown in Figure 4-5, comprises two vacuum tubes (or two tube sections in a single envelope) and its stable states are characterized by the condition that one of the tubes is cut off and other is conducting. By associating one of the stable states of a flip-flop with 1 and the other with 0, the circuit can be employed to provide representation of a single binary digit or bit. A group of flip-flops, each one associated with a particular order of significance (i.e. 2^0, 2^1, 2^2 etc.), can be used to represent a binary number.

Such a group is called a register. The condition of a flip-flop can be sensed in terms of the voltage levels at the plates of either one or both of its tubes. For example, if the condition characterized by tube v^1 cut off and tube v^2 conducting is associated with a 1; then a positive voltage at the plate of V^1 or a negative voltage at the plate of V^2 is interpreted as a 1, while a positive voltage at the plate of V^2 or a negative voltage at the plate of V^1 is interpreted as a 0. This corresponds to the fact that the plate voltage of a tube is lowered when it conducts, by virtue of the voltage drop through the plate load resistance. Thus the terms positive and negative are used above in the relative sense, that is the two voltage levels are positive and negative with respect to each other, but not necessarily with respect to ground.

As already noted, the two stable states of the flip-flop are characterized by the condition that one tube is conducting and the other tube is cut off. In order to make the condition characterized by both tubes conducting and unstable one, the plate of each tube is coupled to the grid of the other tube as shown in Figure 4-5.

To understand the operation of the circuit, assume that V1 is conducting and V2 is cut off. Assume further that a negative input pulse is applied (through the Set input) to the grid of V1. This causes a decrease in the plate current through V1 which appears as an increase of potential on the plate of the tube. This positive going signal is capacitively coupled to the grid of V2 allowing V2 to conduct. As plate current starts to flow through V2, the plate potential of the tube decreases. This negative going signal is capacitively coupled to the grid of V1 where it causes a further decrease in the plate current. In the limit, this unstable condition causes V1 to be driven to cut off. If, now, a negative signal is applied to the grid of V1 it will have no effect since the tube is already cut off. If, on the other hand, a negative signal is applied to the


1
OUTPUT
0
OUTPUT
V1
V2
C1
C2
T2
T1
OFF
ON
COMPLEMENT

grid of V2, the circuit will pass through the condition of instability described above and will arrive at the opposite stable condition (i.e. V1 conducting and V2 cut off). Thus the circuit can be driven back and forth between its two stable states by applying a negative pulse first to the grid of one tube and then to the grid of the other. An alternative method of driving the circuit back and forth between its two stable states is to use only one of the input grids but to alternate the polarity of the input signal applied to that grid. Assume for example, that V1 is conducting. The application of a negative pulse to its grid will reverse the state of the circuit as noted above. Thus V1 will be driven to cut-off. If, now, a positive signal is applied to the grid of V1 the circuit will be driven through the condition of instability to its opposite stable state; that is to say, the application of a positive pulse to the tube which is cut off is equivalent to the application of a negative pulse to the grid of the tube which is conducting.

1.2.2. Set, Clear and Complement Inputs

A flip-flop circuit with three input terminals is shown in Figure 4-6. This circuit is designed to accept only positive input pulses. However these pulses are coupled to the grids of the tubes through input transformers which provide a phase inversion. Thus the pulses applied to the grids are always negative. It is assumed that for the circuit of Figure 4-6, the state in which V1 is cut off and V2 is conducting represents a 1. With this convention established, the three input terminals can be defined as the Set, Clear and Complement inputs.

A positive pulse applied to the Set input of the circuit passes through diode CRI and appears across the primary of transformer T2. This causes a negative pulse to appear at the grid of V1. The pulse applied to the Set line is blocked by diode CR2 so that it does not reach the primary of transformer T1 which is the input transformer for the other side of the circuit. Thus a positive pulse applied to the Set line reverses the state of the Flip-flop if and only if it is storing a o, that is if and only if V1 is conducting. Just the opposite is true, if a positive pulse is applied to the Clear input of the circuit. This pulse reaches input transformer T1 through CR3 but is blocked from reaching input transformer T2 by CR4. Thus, it causes a negative pulse to appear on the grid of V2 (by virtue of the phase inversion through T1) so that the state of the circuit is reversed if and only if it is storing a 1, that is if and only if V2 is conducting.

A positive pulse applied to the Complement input of the circuit is passed by diode CR2 and by diode CR4 so that it appears across the primary windings of both T1 and T2. Thus negative pulses appear simultaneously on both grids. The negative pulse arriving at the grid of the tube which is cut off has no effect; however the negative pulse arriving at the grid of the tube which is conducting causes the circuit to reverse its state regardless of which state it is in. This corresponds to the rule given in Part 2 for forming the 1's complement of a binary number, i.e. change all 0's of the number to 1's and all 1's of the number to 0's.

1.2.3 1 and 0 Outputs

As already noted, the condition of a flip-flop can be sensed in terms of the voltage levels on the grids of either one or both of its tubes. For the circuit of Figure 4-6, a positive voltage on the plate of V1 or a negative voltage on the plate of V2 indicates that the circuit is storing a 1, while the reverse conditions indicate that the circuit is storing a 0. In terms of the conventions concerning polarity of logic which are introduced in Section 1.1.2 of this Part, the output from V1 represents the contents of the circuit in terms of positive logic while the output from V2 represents the contents of the circuit in terms of negative logic. The positive logic output line is called the 1 output while the negative logic output line is called the 0 output.

Sometimes only one of the output lines of a flip-flop is used. This is called single line transfer. Sometimes, on the other hand, both lines are used. This is called double line transfer.

1.2.4. Registers

1.2.4.1 General

As noted above, a group of flip-flops used to store the bits of a single number are called a register. Each flip-flop in a register is associated with a particular order or column. In a computer using flip-flop registers, all kinds of essentially non-numeric as well as numeric information is represented

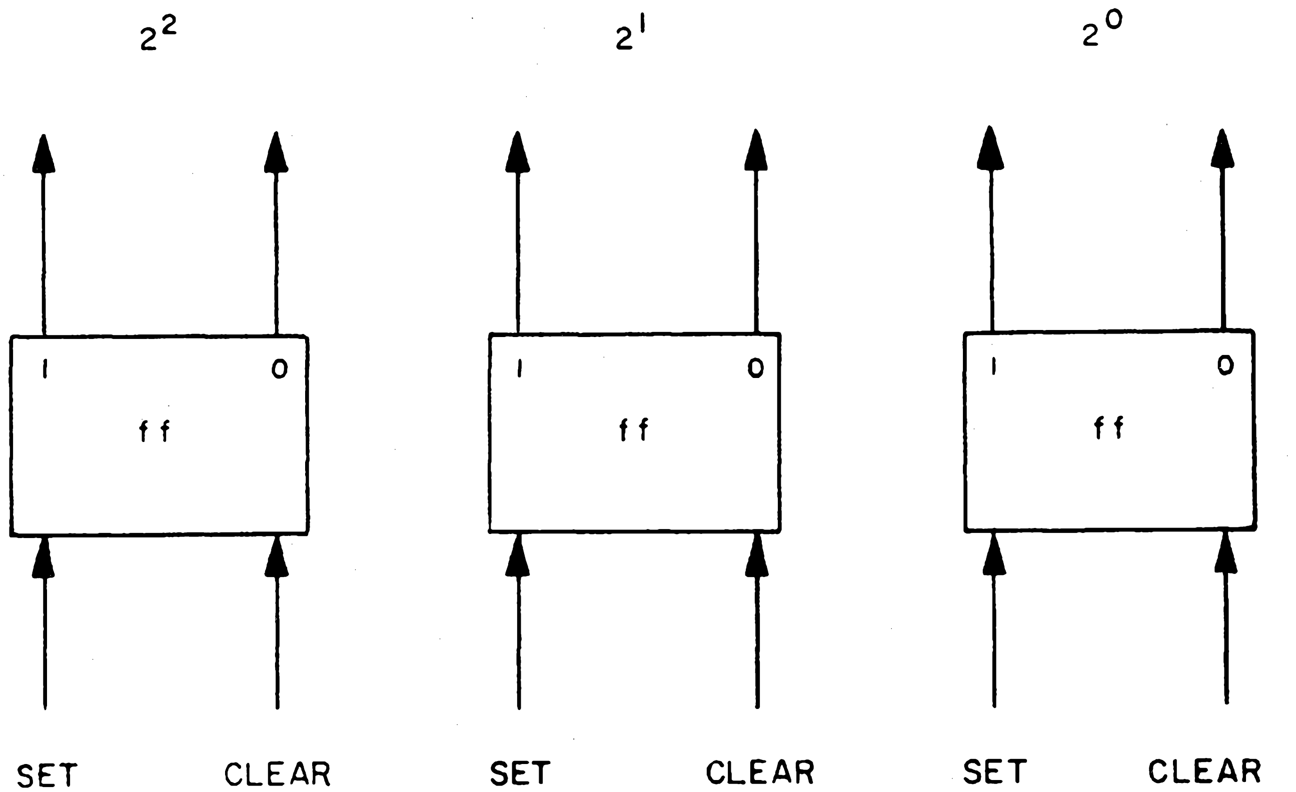
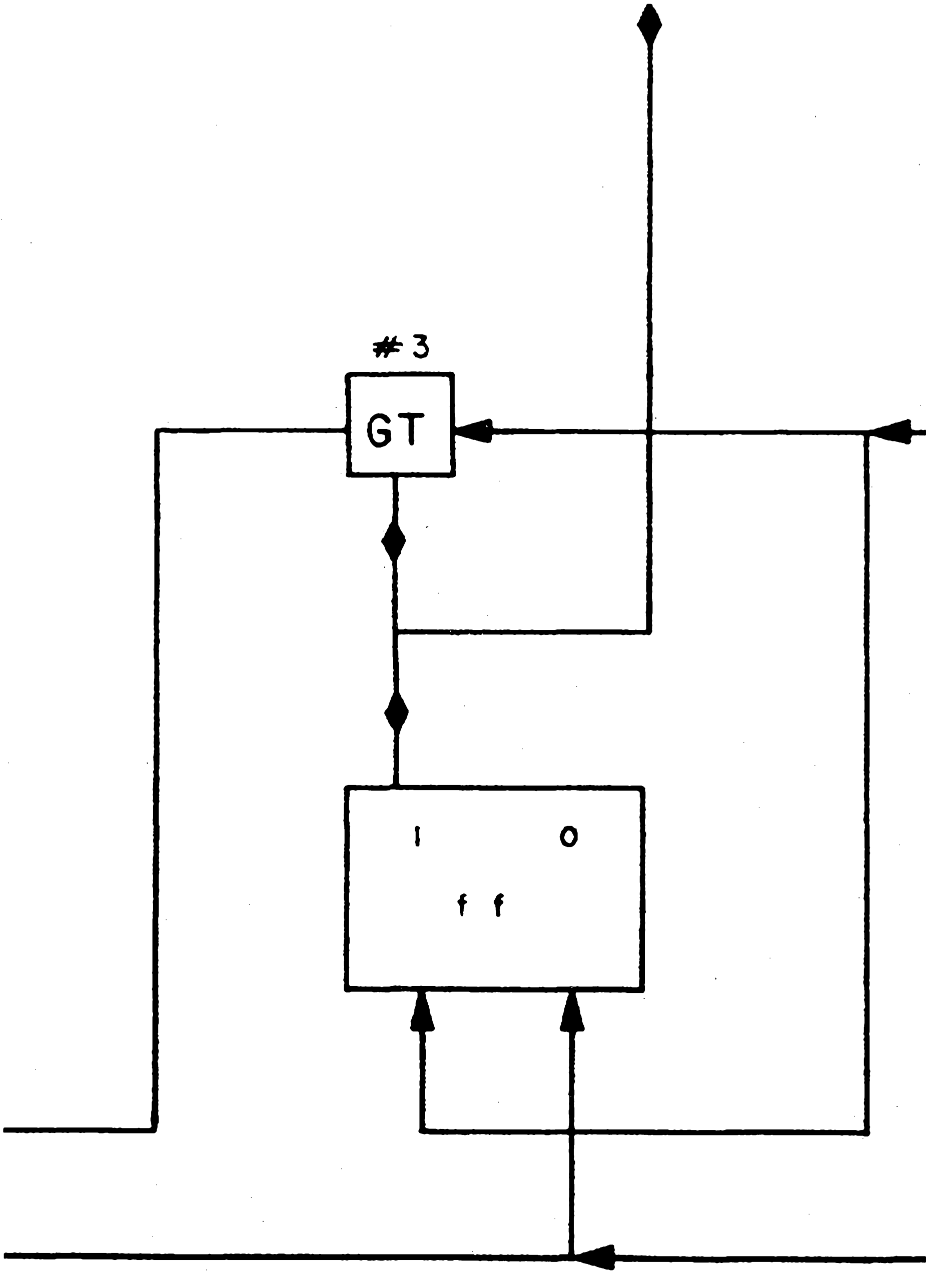


Figure 4-7

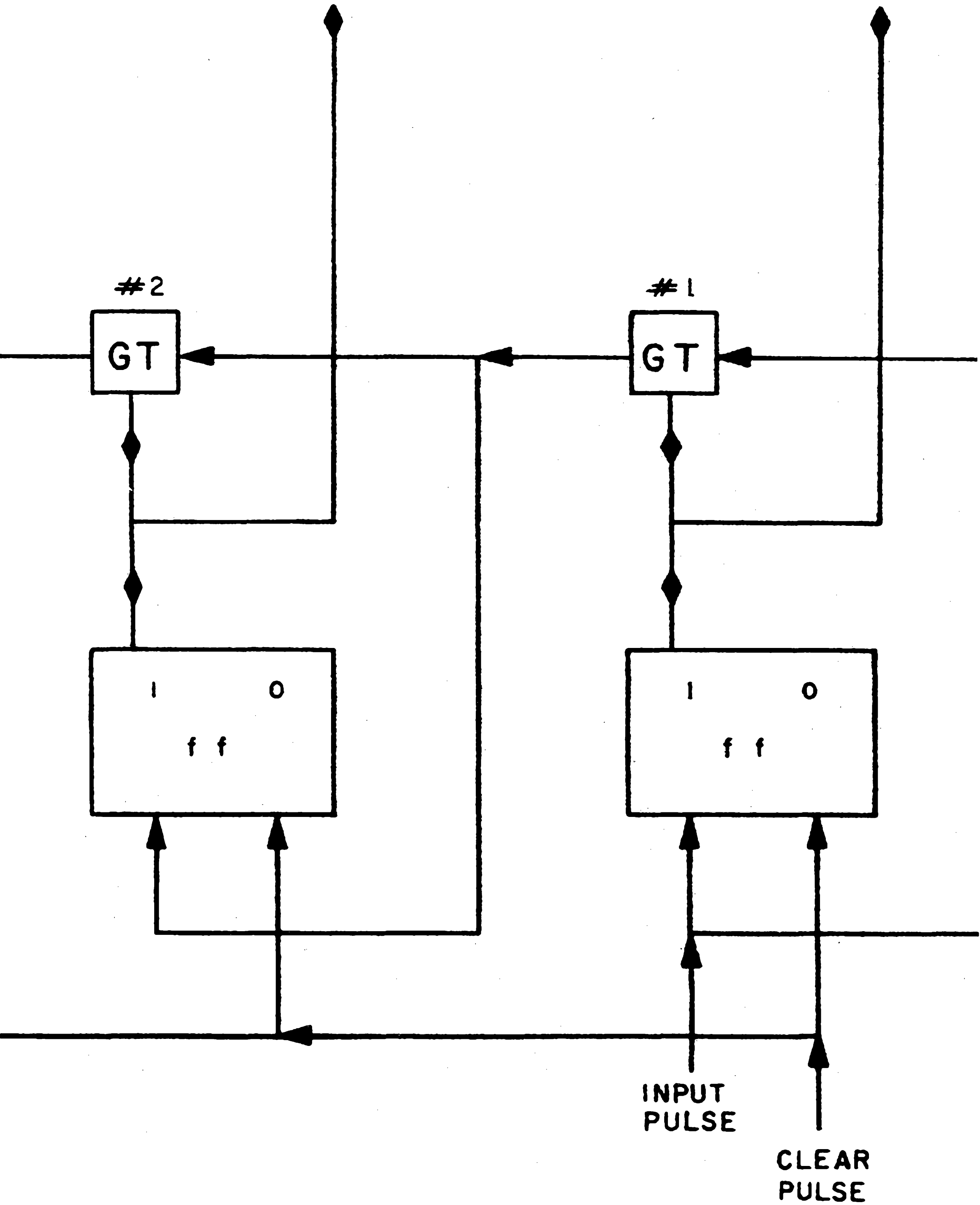
by binary codes. Thus a unit of information is usually called a word rather than a number, in order to indicate that it may represent either a number of an item of non-numeric information. In order to conform to this convention it can be stated that each register is associated with a bit position of a word rather than with an order of a number. However, when discussing operations upon numbers, it is more convenient to speak in terms of numbers and orders.

The bi-stable character of the flip-flop circuit makes it capable of storing a single bit of information. For example, when a positive pulse is applied to the Set input of the circuit of Figure 4-6, the circuit is driven to the state representing 1, if it is not already in that state, and remains in that state (i.e. stores a 1) until it receives a pulse on its Clear or Complement input, the simplest register is a storage register. Here, a flip-flop is provided for each required bit position as shown in Figure 4-7. In order to write a word into the register, a positive pulse is applied to the Set input of each flip-flop which is to store a 1 and to the Clear input of each flip-flop which is to store a 0. Another way to write into a register is first to clear each flip-flop and then to apply inputs to the Set lines of those flip-flops which are to hold 1's. This is the method employed when single line transfer of information into the flip-flop is desired.

If suitable interconnections are provided between the flip-flops of a single register, the register can be used to perform



#3
GT
1
0
ff


#2
GT
1
0
f f
#1
GT
1
0
f f
INPUT
PULSE
CLEAR
PULSE

counting and shifting functions in addition to the storage function. Counting and shifting registers are discussed in the succeeding sections.

1.2.4.2 Counting Registers

A binary counting register is shown in Figure 4-8. Here, each of the blocks marked FF is assumed to be a flip-flop circuit such as is illustrated in Figure 4-6.

Each of the blocks marked GT is a gate tube. Gate tubes are discussed in some detail in Section 1.3 of this Part. However, in order to understand the action of the counter it is necessary only to understand that a gate will pass a positive pulse if and only if it is receiving a steady-state positive signal at the instant when the positive pulse arrives. Since each gate in the counting register is connected to the 1 output of a flip-flop, this means that it will pass a positive pulse only if the contents of the flip-flop at the instant that the pulse arrives is a 1.

The counting input to each of the flip-flops of the register is to its complement input line. Assume that each of the flip-flops of the register is in the 0 condition (i.e. that the register is storing 0000). Then a positive pulse applied to the input pulse line appears simultaneously at the complement input of the 2^0 flip-flop and at the pulse input of the #1 gate. Since, at the instant when the pulse arrives, the flip-flop is storing a 0, the pulse is not passed through the gate. However, it does cause the 2^0 flip-flop to reverse its state (i.e. to store a 1). When a second pulse appears on the input pulse line, it is passed by gate #1, since the 2^0 flip-flop is storing a 1 at the instant when the pulse arrives. Thus the second pulse reaches simultaneously the #2 gate and the complement input line of the 2^1 flip-flop. Since the 2^1 flip-flop is storing a 0 at the instant when the pulse arrives, the pulse does not pass through the #2 gate. However, it does cause the 2^1 flip-flop to reverse its state. Since the 2^0 flip-flop complement input line receives every input pulse directly, it also reverses its state. Thus, after the second pulse, the condition of the register is 0010 which is binary two. A third pulse is not passed by gate #1, since the 2^0 flip-flop is storing a 0 at the instant when it arrives. Thus, the third pulse merely reverses the state of the 2^0 flip-flop. The condition of the register is now 0011 which is binary three. A fourth pulse is passed by both gate #1 and gate #2 and thus reverses the state of the first three flip-flops. The condition of the register is now 0100 which is binary four. The count continues in this manner until the register is storing 1111 which is binary fifteen. When the sixteenth input pulse arrives it is passed by all three gates so that it reverses the state of all four registers; that is, the count is returned to 0. Thus the register is a modula 2^4 binary counter that is, it can store any of the dictinct numbers 0000 through 1111.

The register can be cleared (that is, made to store 0000) at any time by applying a pulse to the clear pulse line. This line is connected to the Clear input of each flip-flop. Thus, each flip-flop is driven to its 0 state (if it is not already in that state) when a pulse appears on the clear pulse line.

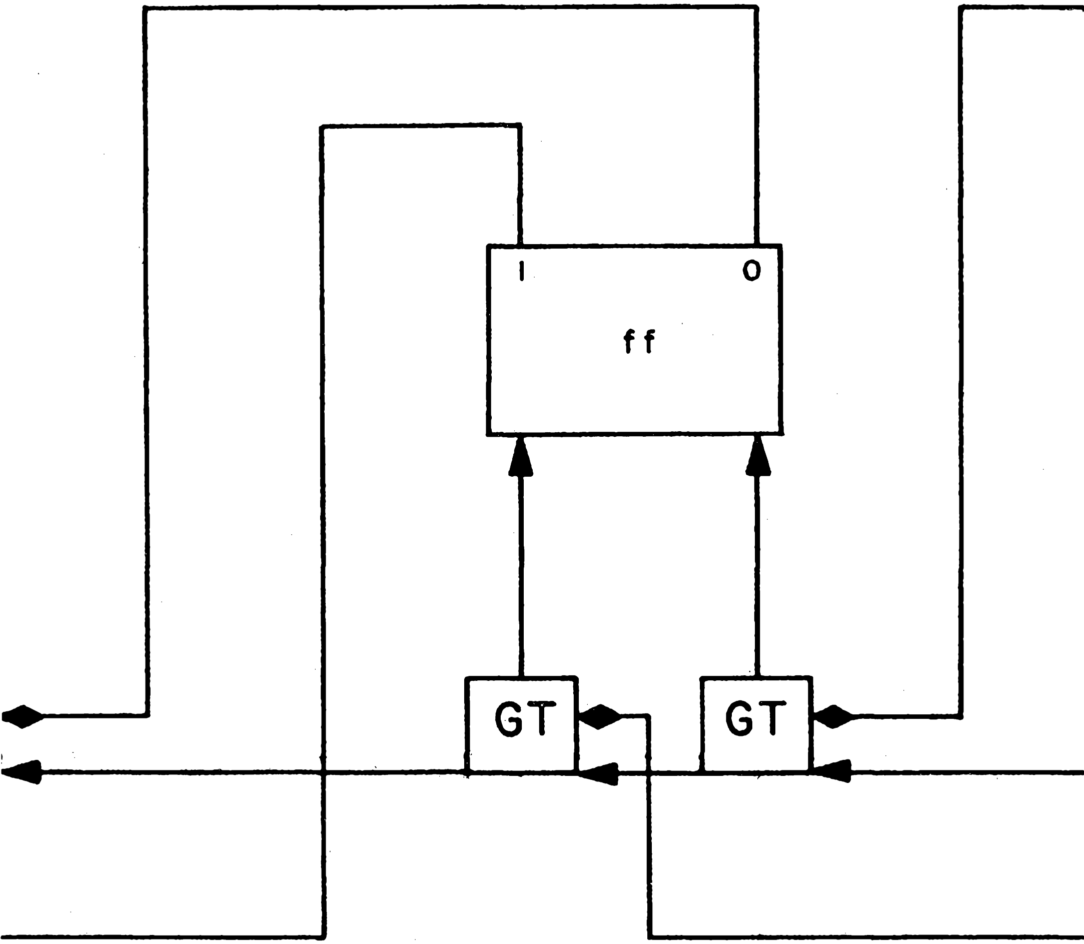
1.2.4.3 Shifting Registers

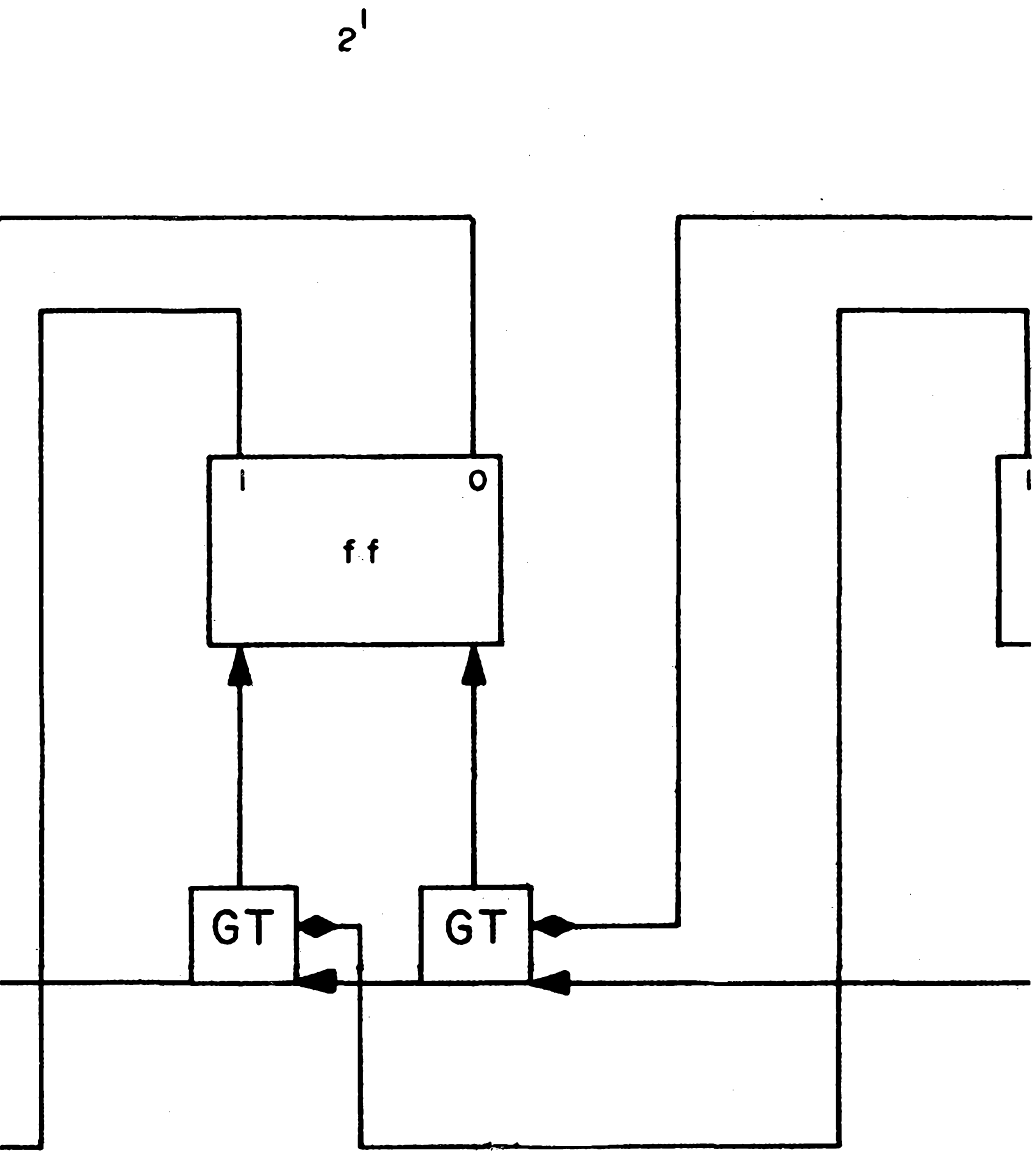
As discussed in Part 2, Chapter 3, a shift left operation in terms of binary arithmetic corresponds to a multiplication by two while a shift right operation corresponds to a division by two. These operations are required as a part of the routines connected with more general multiplication and division operations.

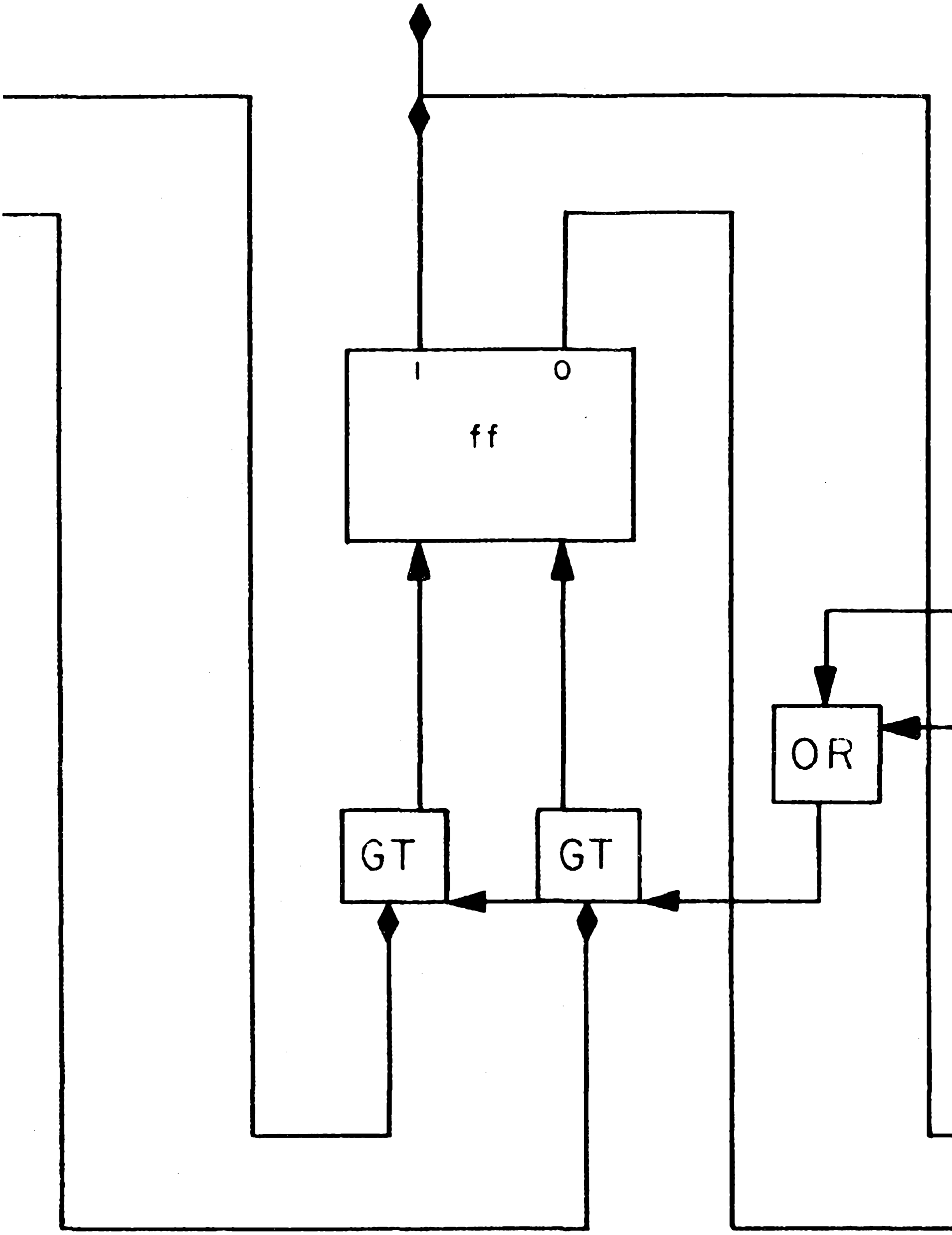
A register capable of providing a shift tothe left is illustrated in Figure 4-9. The 1 and 0 outputs of each flip-flop of this register are coupled to the Set and Clear inputs respectively of the flip-flop on the left through gate tubes. If the 2^0 order flip-flop is storing a 1 when the shift pulse is applied, a pulse is passed to the Set input of the 2^1 flip-flop. On the other hand, if the 2^0 order flip-flop is storing a 0, then a pulse is passed to the Clear input of the 2^1 flip-flop. Thus, the bit initially held in the 2^0 flip-flop is shifted to the 2^1 flip-flop. Subtituting 2^n for 2^0 and 2^{n+1} for 2^1, the above remarks can be generalized to apply to any two flip-flops of the register. Thus the register of Figure 4-9 performs a shift left operation for each shift pulse it receives. Notice that the shift pulse is applied directly to the reset input of the 2^0 order must contain 0 after a shift left has been performed. It is also possible to connect the circuit so as to shift the bit initially held in the left-hand flip-flop into the 2^0 flip-flop. This is called a cycling operation.

A register which shifts right rather than left can be formed by connecting the outputs of each flip-flop to the inputs of the flip-flop on its right rather than the flip-flop on its left. The connection is made through gate tubes just as in the case of the left shift register. For this register a shift right occurs each time a pulse is received.

2^2




2^1
1
0
f.f
GT
GT



I
0
ff
GT
GT
OR

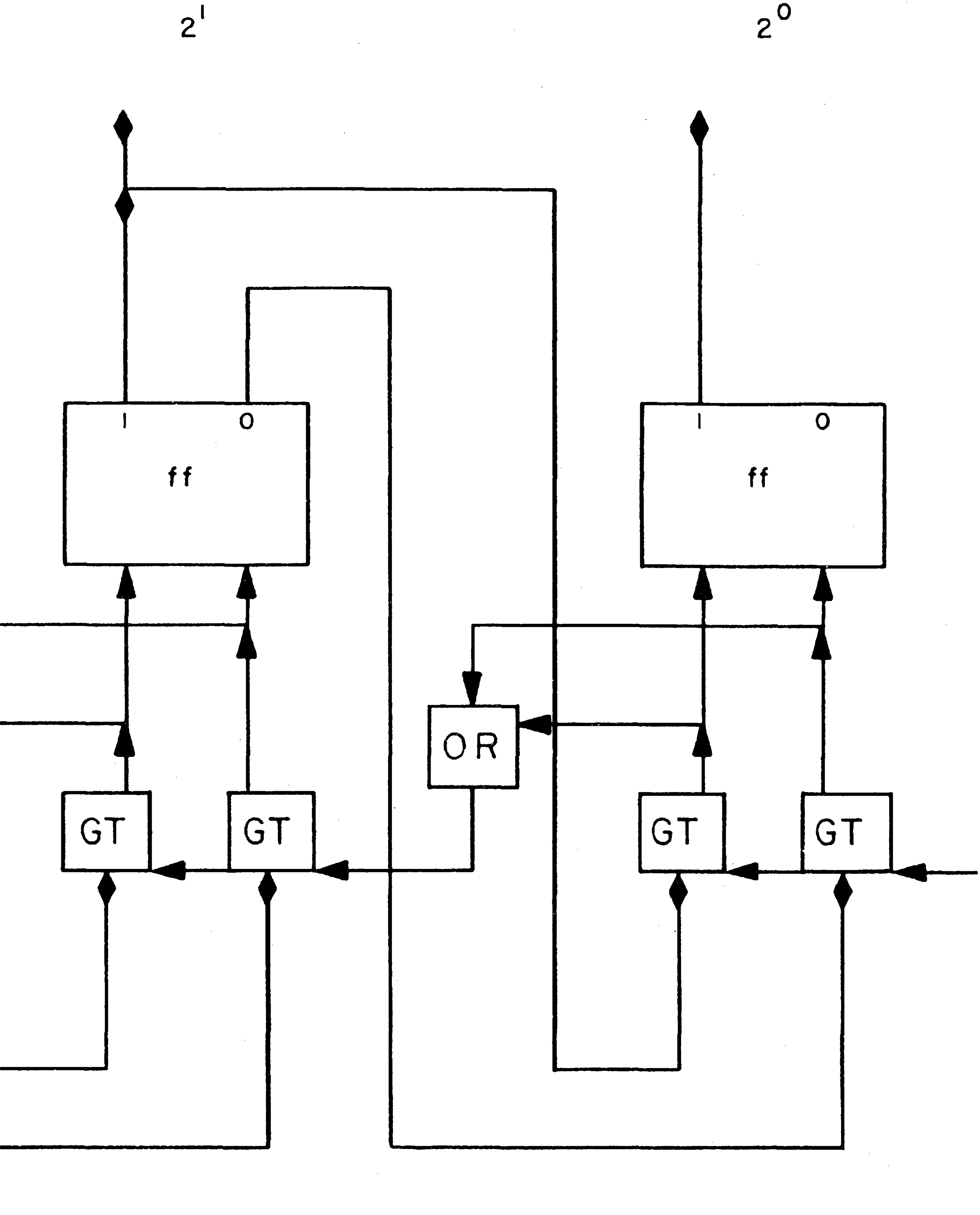


Figure 4-10

The register of Figure 4-9 provides a simultaneous shift of the contents of each flip-flop to the flip-flop on its left in response to a shift pulse. Another type of shift, called ripple shift is illustrated by the register shown in Figure 4-10. The particular register shown in this figure happens to provide a shift to the right rather than to the left. However, ripple shift register like simultaneous shift register can be designed to provide a shift in either direction. The ripple shift proceeds as follows: The shift signal is applied only to the gates between the two input lines of the 2^0 flip-flop and the output lines of the 2^1 flip-flop. Thus, a pulse is passed onto one input line or the other of the 2^0 flip-flop (depending upon whether the 2^1 flip-flop is storing a 1 or a 0). This shifts the contents of the 2^1 flip-flop to the 2^0 flip-flop. At the same time, regardless of which input line of the 2^0 flip-flop the pulse appears on, it is applied to the input of an OR circuit whose output provides a shifting pulse to the gates between the input lines of the 2^1 flip-flop and the output lines of the 2^2 flip-flop. As a result of this, the contents of the 2^2 flip-flop is shifted to the 2^1 flip-flop. The pulse on the input line of the 2^1 flip-flop, in turn, is applied through an OR circuit to the gates between the input lines of the 2^2 flip-flop and the output lines of the 2^3 flip-flop. Thus the shift right pulse is said to ripple through the register from right to left, each flip-flop receiving the contents of the flip-flop on the left an instant after its own contents

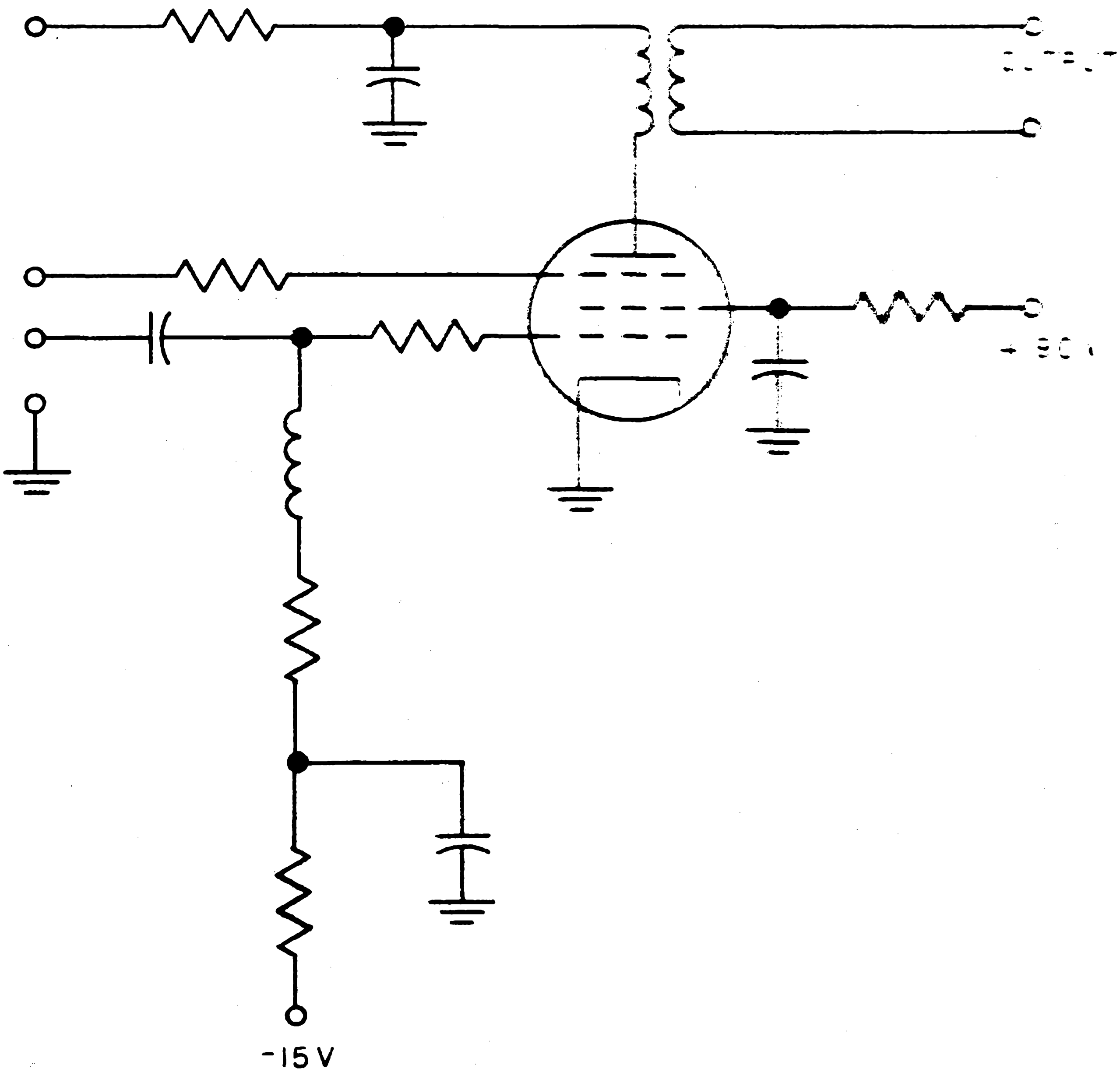


Figure 4-11

have been transferred to the flip-flop on its right.

It may appear that the simultaneous shift saves time. However, it turns out that, in certain situations, the ripple shift is the faster of the two. This results from the fact that a ripple shift can be initiated at the same time that some other signal (such as a carry signal) is propogating through the register. A simultaneous shift, on the other hand, cannot be initiated until all transient effects of a previous signal have been allowed time to die out.

1.3 GATE TUBE

Gate tubes are required to operate the shift register of the preceding section. As noted, their function in this application is to connect the outputs of each flip-flop in a register to the flip-flop on the left (or on the right depending upon the type of shift required) in response to a shift pulse. It is by a variety of command pulses such as this one that a computer executes instructions. Thus, the execution of an instruction requires the setting up of a specific set of signal paths. These paths may not be completed simultaneously but may be specified in an ordered sequence. The gate tube is the primary electronic switch which is used to complete specified signal paths.

A pentode gate tube circuit is shown in Figure 4-11. The circuit accepts one steady-state input which is directly coupled to the screen grid of the tube and another transient input which is RC-coupled to the control grid. The tube is biased so that it is normally cut off. It conducts only if a positive transient input is received at a time when the steady-state input is positive. The transformer coupled output of the tube circuit produces a positive pulse in response to the transient plate current through the tube.

The gate tube is a special case of the AND circuit. Thus, assuming positive logic, it generates a 1 pulse at its output only if it receives a 1 pulse AND a 1 level. In a computer which uses diode AND and OR circuits, it is important to be able to distinguish a diode AND circuit from a gate tube circuit when they are represented on block-level diagrams, since the one provides steady-state logic and the other provides transient logic. For such a computer the diode circuit is usually represented on block diagrams by the name AND while the gate tube circuit receives some such designation as GT. This corresponds to the fact that it is the diode circuit which usually provides the AND functions required by adders, multipliers, etc., while the gate circuit applications are more in the nature of control functions such as ordering and timing the occurrence of sequences of operations.

XVIII CAPACITOR STORAGE

Capacitor storage is used for the three high-speed storage registers of the 650 — the Program Register, the Distributor, and the Accumulator, which have information capacities of one, one, and two ten-digits-plus-sign words, respectively. These registers are in the program and arithmetic control section of the 650 system. As such they handle information in the bi-quinary code, as previously mentioned.

For the data flow logic of the 650 system, refer back to Figure 3. As this figure illustrates, the registers just described are essential units without which the system would be incapable of computing. These registers are the unique production-system application of capacitor storage in IBM, and certainly merit a study of their operating principles.

The essential components involved in the implementation of one "cell" or bit-position of capacitor storage are shown in schematic form in Figure 28A. Binary "zeroes" are stored in a low-loss ceramic capacitor (500 mmf) in the form of a charge of nearly 50 volts, static. However, this charge will not remain in even the best capacitor for an infinite period of time. Thus it becomes necessary to periodically regenerate this charge to restore it to its desired voltage level.

There are only two ways to sense this charge as information. The more straightforward of the two ways is to "look" at the charge with the grid of a class A vacuum tube. However, with a signal swing of nearly 50 volts, this is impractical since vacuum tubes normally have a cutoff to zero bias range of just a few volts, with the exception of the low-nu power triodes (2A3, etc.) and the beam power pentodes, both of which present other serious design problems. The alternative method of sensing the charge on the capacitor is to attempt to charge it through a resistor and sense the voltage drop produced by the resulting current "spike."

Such a method is used in the 650. Its primary side effect is that charging the capacitor will place a binary "zero" in it if the capacitor had had a "one," necessitating the removal of the charge before the information it represented is lost. This is done by immediately, not instantaneously, discharging the capacitor.

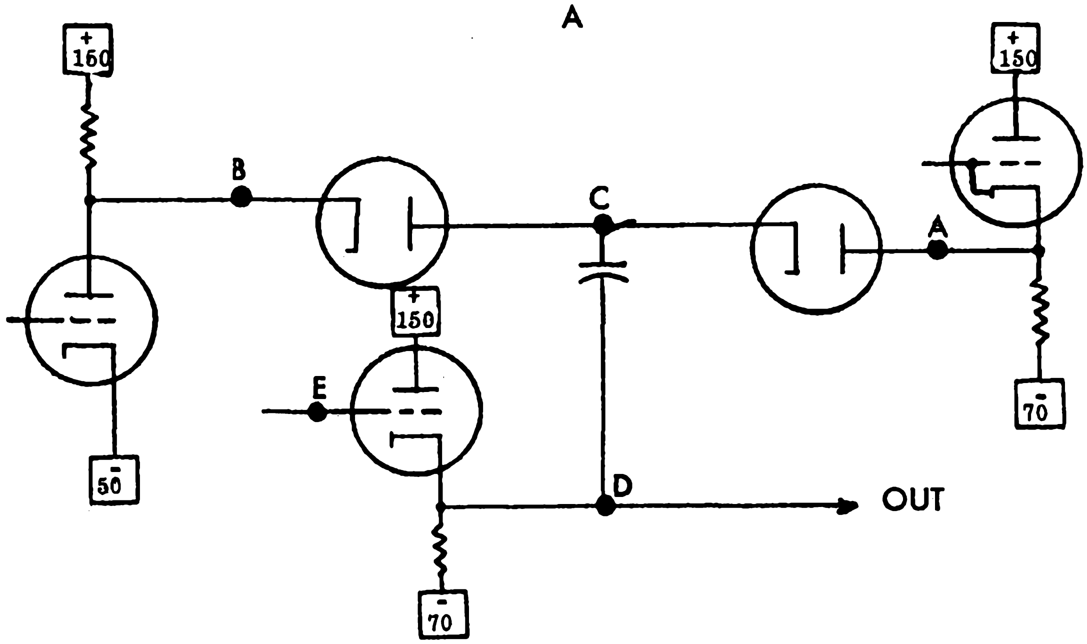
Naturally the capacitor cannot be charging and discharging at the same time since this would presume current simultaneously flowing in both directions. What is required is a short time delay between "readout" and "regeneration." This is performed by what amounts to a two-stage open-ended latch ring. During readout, the information is stored in the first-stage latch, which is turned on by the amplified readout spike. Eight microseconds later, the information is transferred to the second-stage latch by resetting the first stage. This latch then has its output sampled by a timing pulse after it has stabilized to recharge the capacitor.

Let us consider now the details of Figure 28. The triode cathode follower on the extreme right is pulsed every time the capacitor should read out. In the distributor and program register, this is once a word time during a specific digit time. As the CF output voltage rises, it unblocks the right-hand vacuum diode and provides a circuit to charge the capacitor from +150V to -70V via points A, C, and D in the sketch. The "1" is sensed as a position spike on the OUT line. During the immediately-following digit time the inverter at the extreme left goes into conduction; its plate voltage drops and unblocks the left-hand diode. If a"1"is to go back into the capacitor, the output of the CF driving point D comes up at the same time, literally "squeezing" the charge out of the capacitor from -50V via points B, C, and D to +150V through the CF. If the capacitor is not discharged, it will not recharge during the next readout operation, resulting in no output spike. This produces a binary "0" by not turning the latch on. The lower part of the figure shows the voltage signals at the labeled points in the circuit.

Figure 29 is merely a demonstration of how these capacitor storage cells are combined into a matrix, permitting the driving, sensing, and storage devices to be time-shared by many positions. If this were not done, capacitor storage would be hopelessly uneconomical since the necessary part of the job could be done with just one of the two latches in the delay circuit with no capacitor at all. In the 650 matrix, the only items that need be repeated 77 times (seven bits x 11 digits) are the capacitor and the pair of diodes (a 6AL5). This part of the circuit is packaged two sets to a one-socket preassembled pluggable unit.

Capacitor storage has been regarded traditionally by experienced computer designers as unfeasible commercially because of the charge-leakage problems and the drive requirements. But so was the trigger back in the days of Eccles and Jordan when triodes were hard to match in production quantities. Be that as it may, capacitor storage has been a success in the 650.

A



B

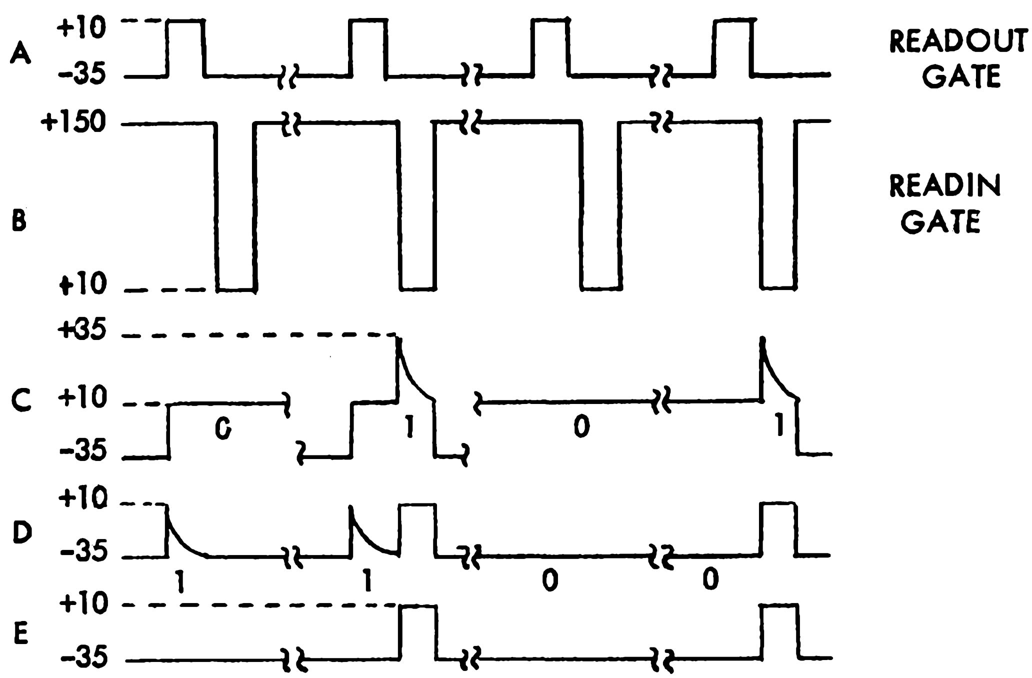


Fig. 28 - Capacitor storage

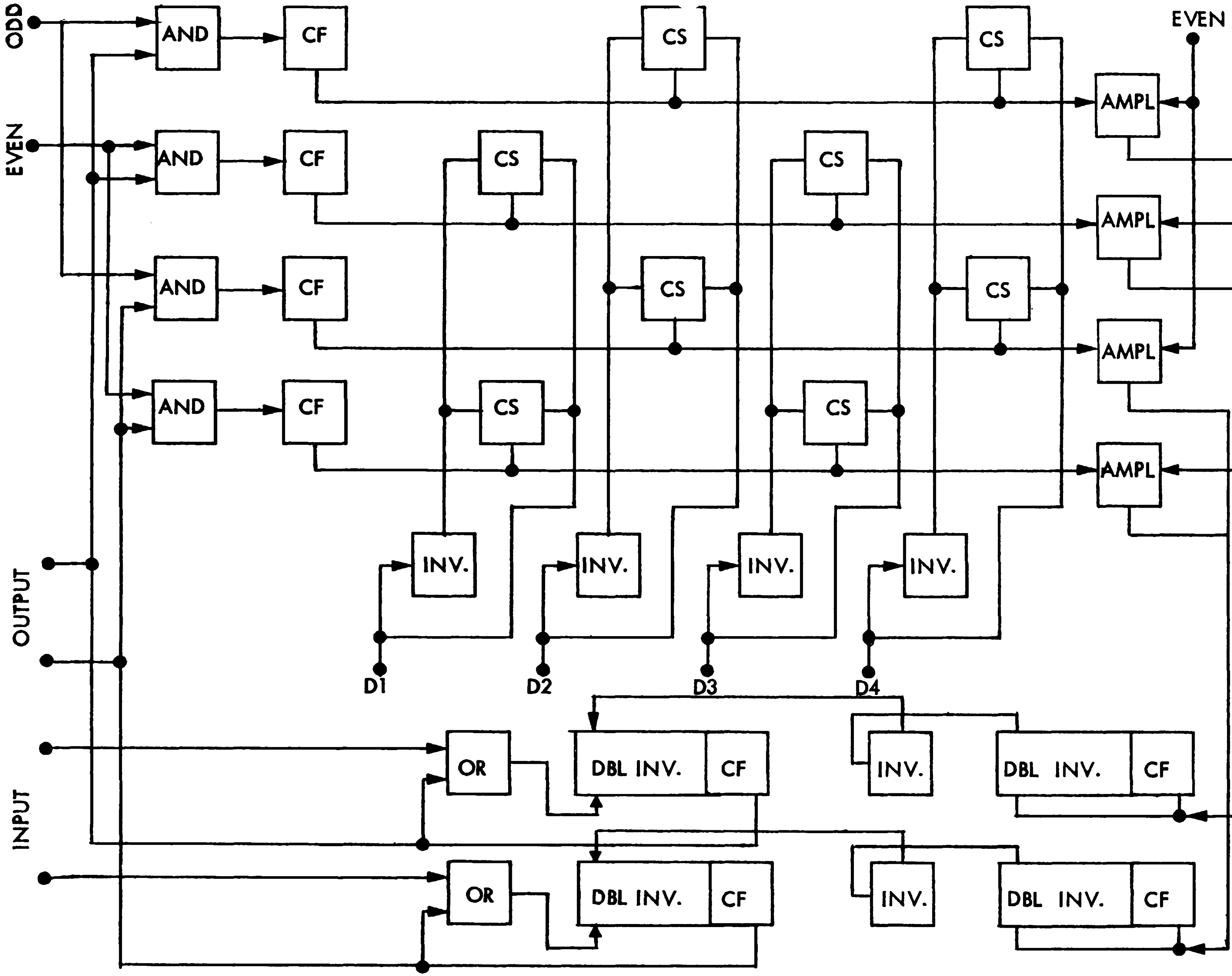


Fig. 29 – Capacitor Storage Cells Combined into a Matrix

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BASIC CIRCUITS

FOR

AN/FSQ-7
COMBAT DIRECTION CENTRAL

15 November 1956

Revised 1 April 1957

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All pages revised	1 April 1957

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T.O. 31P2–2FSQ7–2	Basic Theory of Computers AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–12	Introduction to AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–32	Theory of Operation of Central Computer for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–42	Theory of Operation of Drum System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–52	Theory of Operation of Input System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–62	Theory of Operation of Display System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–72	Theory of Operation of Output System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–82	Theory of Operation of Power Supply System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–92	Theory of Operation of Marginal Checking for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–102	Theory of Operation of Warning Light System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–112	Theory of Programming for AN/FSQ-7, Combat Direction Central
INSTALLATION	
T.O. 31P2–2FSQ7–5	Installation of AN/FSQ-7, Combat Direction Central

LIST OF RELATED MANUALS (cont'd)

Manual	*Title*
	OPERATING PROCEDURE
T.O. 31P2–2FSQ7–21	Operating Procedure for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–122	Operating Procedure for Maintenance of AN/FSQ-7, Combat Direction Central
	MAINTENANCE
T.O. 31P2–2FSQ7–132	Introduction and Philosophy of Maintenance for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–142	Maintenance Techniques and Procedures of Central Computer for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–152	Maintenance Techniques and Procedures of Drum System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–162	Maintenance Techniques and Procedures of Input System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–172	Maintenance Techniques and Procedures of Output System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–182	Maintenance Techniques and Procedures of Display System for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–192	Maintenance Techniques and Procedures of Power Supply and Marginal Checking for AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–202	Maintenance Techniques and Procedures of Warning Light System for AN/FSQ-7, Combat Direction Central
	SCHEMATICS
T.O. 31P2–2FSQ7–212	Schematics for Central Computer of AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–222	Schematics for Drum System of AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–232	Schematics for Input System of AN/FSQ-7, Combat Direction Central
T.O. 31P2–2FSQ7–242	Schematics for Output System of AN/FSQ-7, Combat Direction Central

LIST OF RELATED MANUALS (cont'd)

Manual	*Title*
T.O. 31P2-2FSQ7-252	Schematics for Display System of AN/FSQ-7, Combat Direction Central
T.O. 31P2-2FSQ7-262	Schematics for Power Supply and Marginal Checking of AN/FSQ-7, Combat Direction Central
T.O. 31P2-2FSQ7-272	Schematics for Warning Lights of AN/FSQ-7, Combat Direction Central
PLUGGABLE UNITS	
T.O. 31P2-2FSQ7-282	Pluggable Units for AN/FSQ-7, Combat Direction Central
PARTS CATALOG	
T.O. 31P2-2FSQ7-4	Illustrated Parts Catalog for AN/FSQ-7, Combat Direction Central
SPECIAL TEST EQUIPMENT	
T.O. 31P2-2FSQ7-31	Test Set, Memory Driver Panel TS-986/FSQ
T.O. 31P2-2FSQ7-41	Test Set, Plug-In Unit TS-985/FSQ
T.O. 31P2-2FSQ7-51	Power Supply PP-1589/FSQ
T.O. 31P2-2FSQ7-61	Test Set, Cathode Ray Tube TS-987/FSQ
T.O. 31P2-2FSQ7-71	Test Set, Amplifier TS-988/FSQ
T.O. 31P2-2FSQ7-81	Dummy Load, Electrical DA-155/FSQ
T.O. 31P2-2FSQ7-91	Test Set, Metallic Rectifier TS-989/FSQ
T.O. 31P2-2FSQ7-101	Test Set, Diode Semiconductor Device TS-990/FSQ
T.O. 31P2-2FSQ7-111	Calibrator, Oscilloscope FR-112/FSQ
T.O. 31P2-2FSQ7-121	Marginal Check Control, Remote C-2022/FSQ
T.O. 31P2-2FSQ7-131	Test Set, Electron Tube TV-11/FSQ
T.O. 31P2-2FSQ7-141	Distribution Box J-779/FSQ

PART 1
INTRODUCTION

1.1 SCOPE OF MANUAL

This manual presents the theory of operation for the basic circuits in AN/FSQ-7 Combat Direction Central and AN/FSQ-8 Combat Control Central. Electronically, these equipments are a complex combination of many circuits. They have been subdivided into seven functional systems: the Input, Output, Drum, Central Computer, Display, Power Supply and Marginal Checking, and Warning Light Systems. By definition, a basic circuit is used in more than one system; a special circuit is used in only one system.

Figure 1–1 illustrates the relationship between a basic circuit and a part of the equipment. As shown, the basic circuit represents a fundamental building block of the electronic portion of the equipment. The schematic drawing is a model C cathode follower. Behind it is the logic block symbol which represents the model C cathode follower in logic block schematics. The logic block schematic is the functional diagram of the electronic operation of a pluggable unit, which is, in turn, a small replaceable unit of the equipment.

This circuit is a member of the cathode follower group, which is a part of the 14 groups discussed in Part 3 of this manual. Since they are used in one form or other throughout the entire equipment, the 14 groups constitute a large majority of the circuits in the equipments. This fact emphasizes their importance as fundamental building blocks.

The logic block symbol is designed to facilitate the explanation of equipment operation. It permits the presentation of relatively simple logic block schematics to describe equipment function. A comparison (fig. 1–1) of the electrical symbol presentation of the circuit and its equivalent logic block symbol will indicate the degree of simplification introduced by the logic block symbol. Equipment function (logic) is explained in other manuals in terms of these symbols. This manual presents the theory of operation of the basic circuits represented by certain logic block symbols.

1.2 ORGANIZATION OF MANUAL

1.2.1 General

This manual consists of three parts. Part 1 introduces the manual. Part 2 discusses circuit elements with a common function; the extensive repetition of these circuit elements throughout the AN/FSQ-7 and AN/FSQ-8 Systems permits a separate treatment of their function, thereby adding to the simplification of basic circuit theory discussion. Part 3 presents the theory of operation of 14 basic circuits.

1.2.2 Contents of Part 1 — Introduction

Part 1 explains the organization of the manual and introduces the basic circuit, demonstrating the significance of the basic circuit in the equipment and relating the circuit to the equipment.

1.2.3 Contents of Part 2 — Common Circuit Characteristics

Certain mechanical and electrical information necessary in the study of the basic circuits is discussed in Part 2. Common signals are identified and discussed. The physical characteristics of the basic circuits are investigated, and the electrical limitations that result are noted. The compensation of these electrical limitations is resolved, and parasitic suppression and resistance-capacitance (RC) decoupling are thoroughly analyzed.

Common circuits employed in the clamping and coupling of levels are discussed and supported with mathematical calculations where such support is applicable. Finally, speedup circuits are analyzed as to their application in the basic circuits.

1.2.4 Contents of Part 3 — Theory of Operation

Part 3 describes the theory of operation of the 14 basic circuits employed throughout the AN/FSQ-7 and AN/FSQ-8 equipments. The circuits fall into two general groups: logic and nonlogic circuits.

Note

Logic and *nonlogic* (as applied to basic circuits) are terms used to differentiate functionally between electrical circuits. Logic circuits are those that perform the operational functions of the equipment. Nonlogic circuits are those that facilitate the signal transfer between logic circuits, ensuring system dependability.

Chapters 1 through 6 include the nonlogic circuits, arranged in the following order: cathode follower, d-c level setter, pulse amplifier, register driver, thyratron relay driver, and vacuum-tube relay driver. Chapters 7 through 14 include the logic circuits, arranged in the

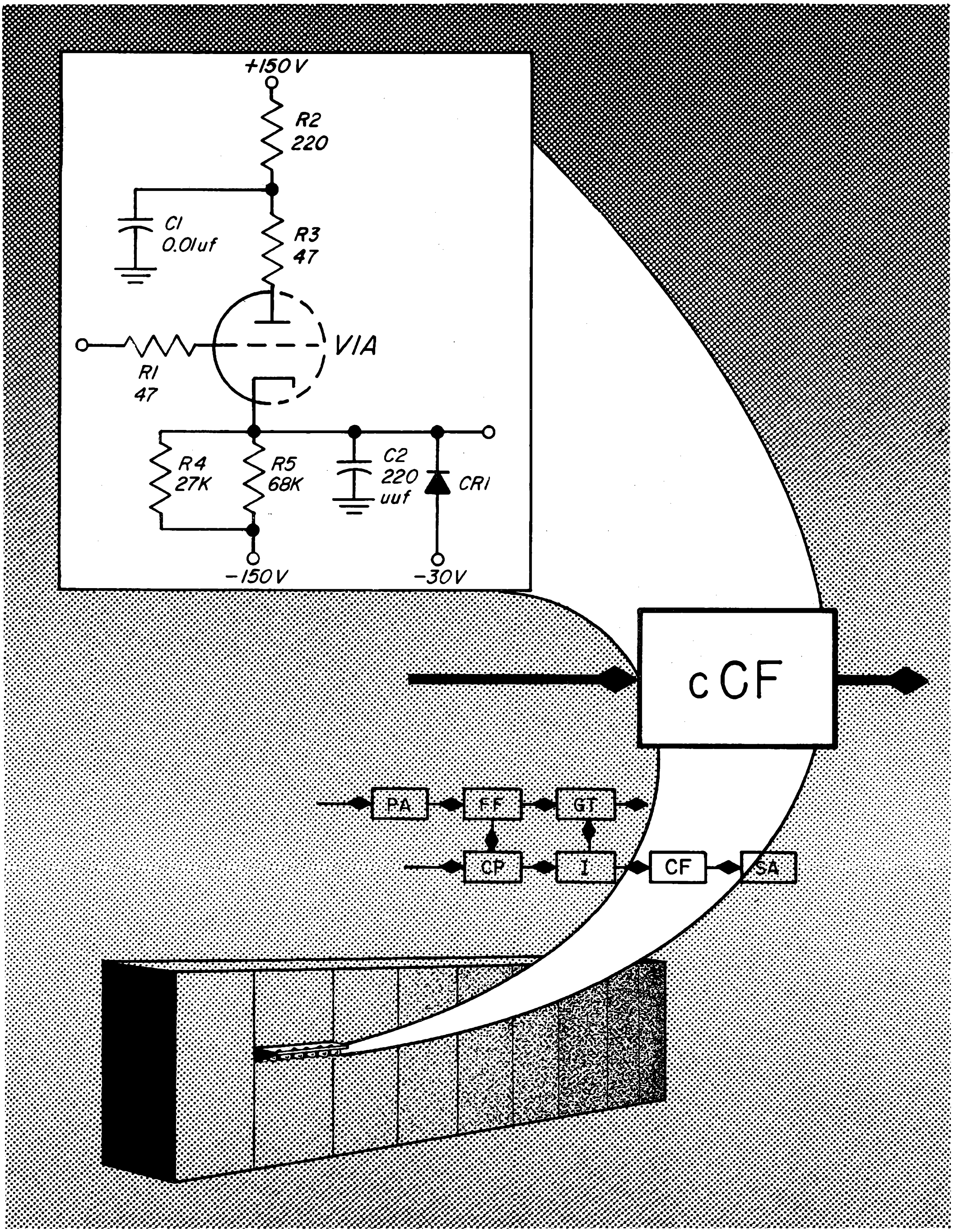


Figure 1—1. Basic Circuit, A Fundamental Building Block

following order: AND, OR, gate, inverter, flip-flop, single-shot multivibrator, pulse generator, and delay unit.

Each chapter follows the same format and comprises, in general, three paragraphs. The first paragraph (Definition and Description) identifies the circuit logic block symbol, describes circuit function, and enumerates the significant differences between the models in terms of capabilities, limitations, or operational characteristics.

The second paragraph (Principles of Operation) discusses the operation of the circuit. The treatment of each circuit proceeds from basic considerations to specific functions of detail parts. Where circuit complexity requires such treatment, each circuit is reduced to its simplest operating elements, and the fundamental principles of operation are explained in terms of this circuit. A detailed discussion follows in terms of a specific model of the circuit, which consists of the simplified circuit and the added refinements used to adapt the simple circuit to its operational environment.

The third paragraph (Circuit Refinements) may or may not appear in a chapter. The complexity of a circuit and the nature of its refinements dictate the need for a separate detailed discussion. Wherever possible, the circuit refinements are discussed under principles of Operation; otherwise, they are discussed in the third paragraph.

Generally, each chapter will contain one complete schematic for each model of a circuit. In many cases, these schematics have been simplified to reduce the number of detail parts shown. For example, parallel and series resistors are combined in a representative single resistor of equivalent value. For this reason the schematics, though electrically correct, are not wiring diagrams of the actual circuit. The distinction between the simple or fundamental circuit and its refinements is made on the complete circuit schematics by drawing the parts of the fundamental circuit with a heavier line.

Table 1–1 lists the 14 basic circuits in their logic and nonlogic categories and groups them in their general classifications.

The voltages discussed in this manual are approximate, and nominal values are assumed. When voltage levels are specified, they are referenced to ground unless otherwise indicated. Waveforms are idealized and deviate slightly from the actual. Current flow from negative to positive potentials (electron flow) is assumed unless otherwise specified.

TABLE 1–1. FUNCTIONAL BREAKDOWN OF BASIC CIRCUITS

	POWER AMPLIFIERS		CONTROL	RESTORER
NONLOGIC	Cathode followers Pulse amplifiers Register drivers		Thyratron relay drivers Vacuum-tube relay driver	D-C level setters
	COINCIDENCE	**CONVERSION**	**TIMING**	**STORAGE**
LOGIC	Diode AND Diode OR Gate	Inverter Pulse generator	Delay unit Single shot	Flip-flop

PART 2
COMMON CIRCUIT CHARACTERISTICS

2.1 INTRODUCTION

A thorough knowledge of signal inputs and outputs is a prerequisite in the study of basic circuits. These inputs and outputs are pulses and levels, which are further categorized as standard and nonstandard.

2.1.1 Standard Pulses

The standard pulse (fig. 2–1) is a +30-volt pulse

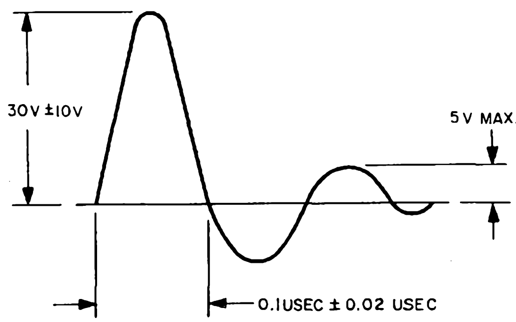


Figure 2–1. Standard Pulse

(nominal) with a tolerance of ±10 volts. The pulse shape approaches that of the positive half of a sine wave, with a negative tail of indefinite value. The pulse width measured at the base has a nominal value of 0.1 microsecond and a tolerance of ±0.02 microsecond. It is evident that a standard pulse is defined by its amplitude, pulse width, and shape.

2.1.2 Standard Levels

There are two standard levels (fig. 2–2): the up level is a d-c potential of +10 volts (nominal); the down level is a d-c potential of —30 volts (nominal). Rise time (T_R) is the period during which the potential climbs 40 volts from a down level to an up level. Fall

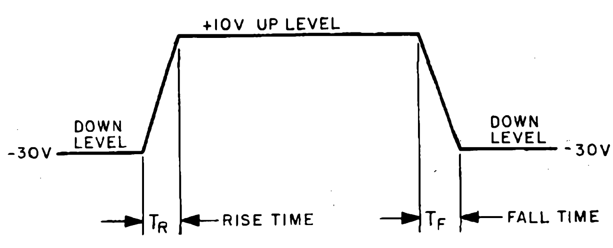


Figure 2–2. Standard Levels

time (T_F) is the period during which the potential drops 40 volts from an up level to a down level. The standard signals just discussed are represented as logic lines with characteristic terminating symbols (fig. 2–3).

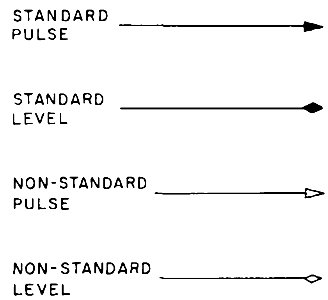


Figure 2–3. Signal Symbols

The standard pulse is indicated by a line terminated in a solid arrowhead. The standard level, either up or down, is indicated by a line terminated in a solid diamond.

2.1.3 Nonstandard Signals

A nonstandard pulse is indicated by a line terminated in an open arrowhead. Any other nonstandard signals will be indicated by a line terminated in an open diamond.

2.2 PHYSICAL CHARACTERISTICS

Several electrical circuit refinements are dictated by the physical layout and by the techniques employed in the packaging of the circuits of the AN/FSQ-7 and AN/FSQ-8 Systems. To appreciate the necessity of the electrical requirements peculiar to this equipment, it would be advantageous to become acquainted with the physical characteristics of the machine.

A basic circuit consists of one or more card assemblies, together with other detail parts and wiring. The card assembly consists of a card detail upon which detail parts are automatically mounted and automatically dip-soldered. Figure 2–4 presents front and rear views of a typical card detail. The card is composed of a phenolic base which has been tooled as indicated in this figure. Both sides of the card detail contain printed circuitry which interconnects the appropriate lands. A typical card assembly, depicted in figure 2–5, has the detail parts and lugs mounted. A number of these card assemblies are then mounted in a mechanical assembly and electrically connected to various detail parts, such as vacuum-tube sockets, individual resistors, capacitors, and electrical connectors. This complete assembly is called a pluggable unit (fig. 2–6). The pluggable unit may consist of several basic and special circuits which are electrically connected.

This method of physical construction makes possible the automatic manufacture of the card assembly (which contains most of the detail parts employed) and easy removal and replacement of the pluggable unit. There are two standard types of pluggable units: one accommodates a maximum of nine vacuum tubes (shown in fig. 2–6); the other, a maximum of six tubes (not shown). The electrical connectors mounted along the bottom of the pluggable unit provide a means of supplying service voltages and inputs to the unit. Outputs are also taken off at these points.

2.3 PARASITIC SUPPRESSION

The manufacturing and packaging techniques just discussed result in lead lengths longer than those in common use. (See fig. 2–6.)

The basic circuits, for the most part, include vacuum tubes; in circuits of this type, where long leads are prevalent, parasitic oscillations result. Parasitic oscillations are undesirable, self-generated, cyclic voltages, produced by unplanned resonant circuits appearing in the grid, plate, and screen circuits of a vacuum tube. Figure 2–7 illustrates the effects of lumping long leads into equivalent inductances and of lumping stray wiring and tube capacitances into equivalent capacitors. This circuit,

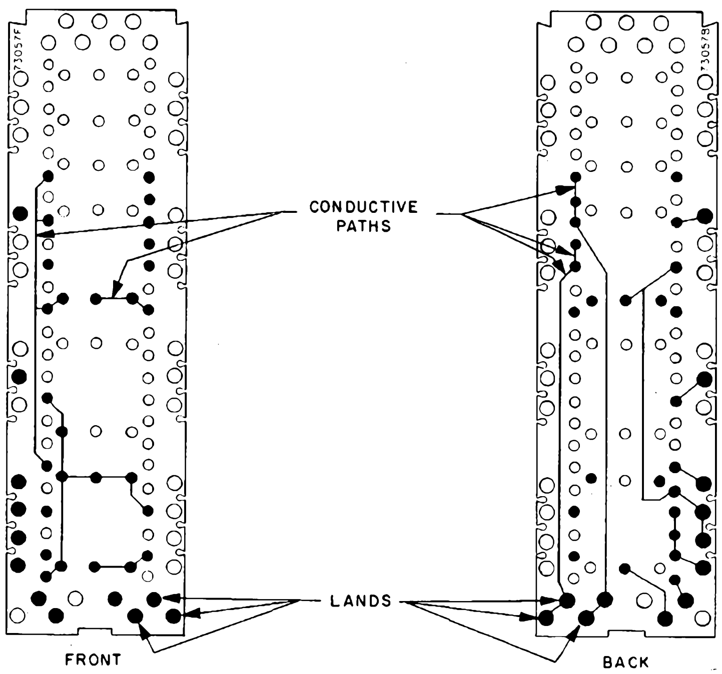


Figure 2–4. Typical Card Detail

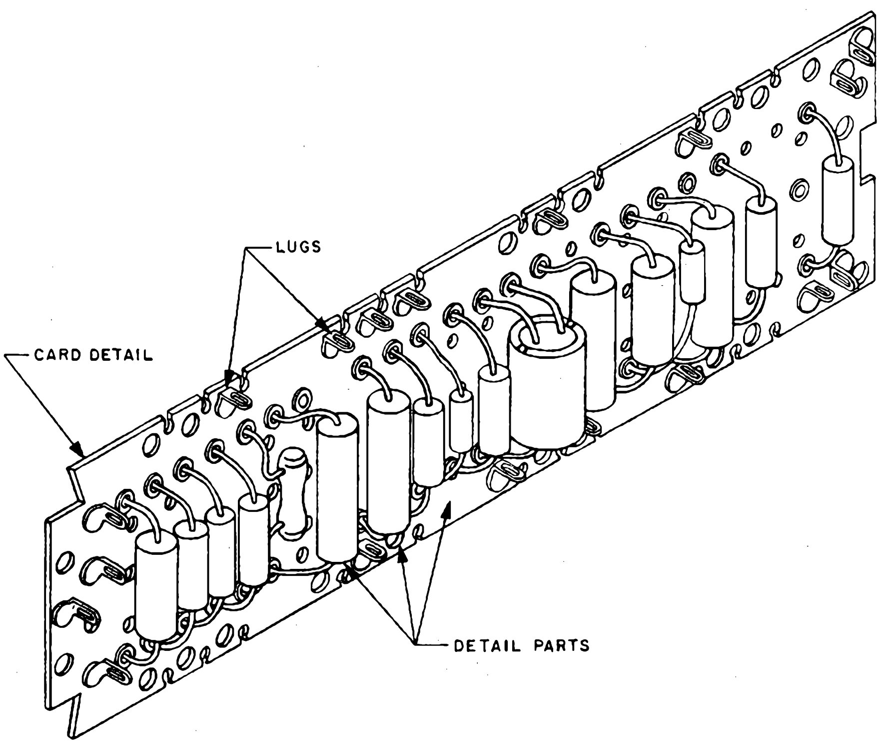


Figure 2–5. Typical Card Assembly

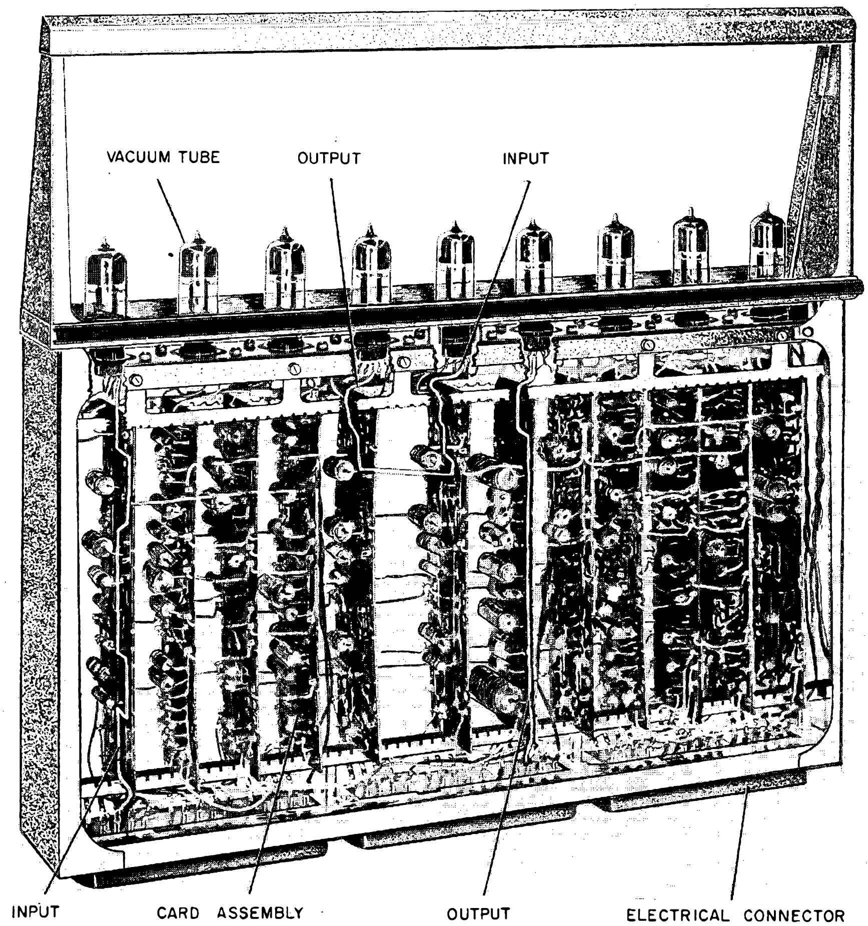


Figure 2–6. Typical Pluggable Unit

which closely resembles a tuned-grid tuned-plate oscillator, could support oscillations.

To eliminate parasitic oscillations in this and in comparable circuits, parasitic suppressing resistors are used. Such resistors add loss into an undesirable resonant circuit, reducing the circuit's efficiency to such a degree that parasitic oscillation is no longer possible.

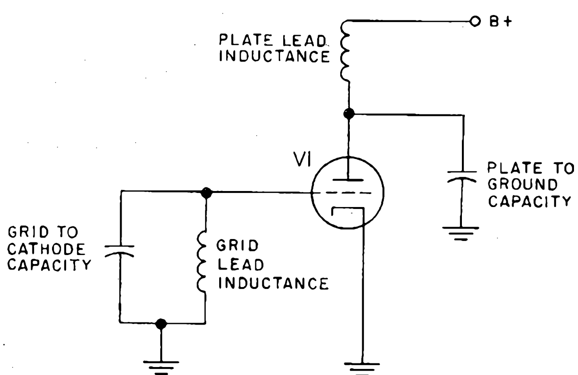


Figure 2–7. Lumped Constants, Equivalent Circuit, Simplified Schematic Diagram

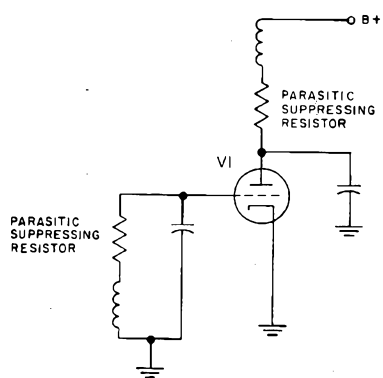


Figure 2–8. Lumped Constants, Equivalent Circuit with Parasitic Suppressing Resistors Added, Simplified Schematic Diagram

Figure 2–8 shows the circuitry of figure 2–7 with the parasitic suppressing resistors added. For maximum effectiveness, resistors are mounted at the vacuum-tube socket. They will be found in all the plate and control grid leads of the vacuum tubes employed in the basic circuits and also, where necessary, in basic circuit vacuum-tube cathode and screen leads.

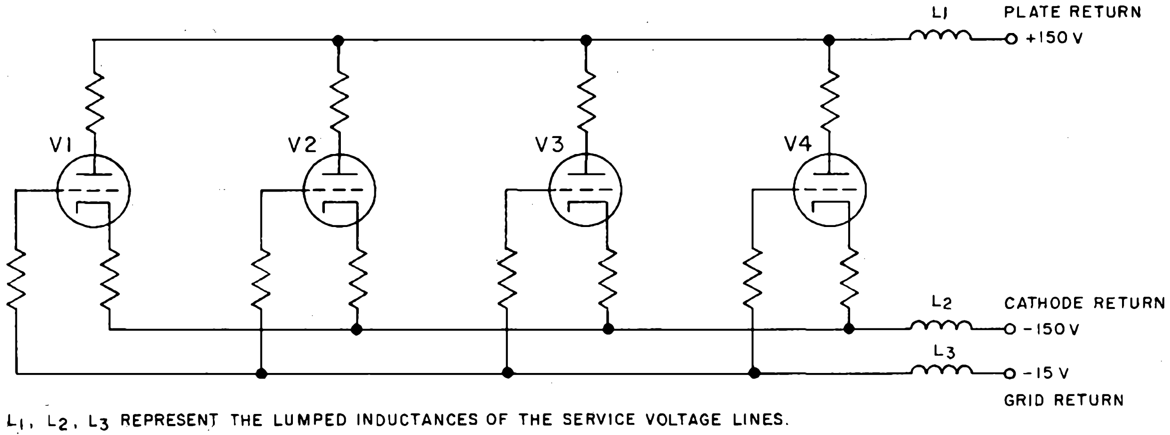


Figure 2–9. Common Return Paths, Simplified Schematic Diagram

2.4 RC DECOUPLING

The various circuits that constitute the AN/FSQ-7 and AN/FSQ-8 Systems, of which the basic circuits are a major part, derive their service voltages from common power supplies. For this reason, numerous vacuum-tube circuits have their plate, control grid, cathode, and screen grid circuits returned through common leads (see fig. 2–9). Long power leads and the fact that a large number of circuits share a common return contribute to the generation of undesired signals. Because these signals would affect machine dependability, resistance-capacitance (RC) decoupling circuits are employed in all the vacuum-tube return circuits to attenuate them. Figure 2–10 is a simplified schematic of one vacuum-tube circuit employing an RC decoupling filter in each of its return paths. These RC filters attenuate undesirable signals appearing at the plate, cathode, control grid, and screen grid return circuits to such a degree that machine dependability is no longer threatened.

Figure 2–11 presents a typical RC decoupling circuit, with the associated mathematics to explain its operation. It can be shown that, if an RC decoupling filter functions satisfactorily at the lowest frequency (the frequency for which it was designed), its effectiveness will increase at higher frequencies. It should be noted that, although the attenuation of one of the RC filters has been calculated to be approximately 15, the attenuation between any two circuits, each employing one of these filters, is 15^2, or 225 (fig. 2–12).

Note

The d-c potential at the output of the RC decoupling filter is assumed to be the same as the input or supply potential. The ohmic value of the decoupling resistor, R, is small when compared with the resistance of the circuit returning at this point. For the same reason, this point is considered to be at a-c ground because of the extremely low value of reactance of decoupling capacitor C.

2.5 COMMON CIRCUITS FOR CLAMPING AND COUPLING LEVELS

There are a number of circuit techniques dictated by the functional requirements of the equipments. Two of these techniques, diode clamping and d-c coupling, are repeated in several of the basic circuits and are treated, therefore, as a general circuit consideration.

2.5.1 Diode Clamping

Diode clamping is treated by considering this function in the output circuit of a model C flip-flop. (For a detailed discussion of crystal diode characteristics, refer to Part 3, Ch 7.)

Figure 2–13 shows the output circuit and the associated triode section of a model C flip-flop. For the purpose of this discussion, two states of conduction are as-

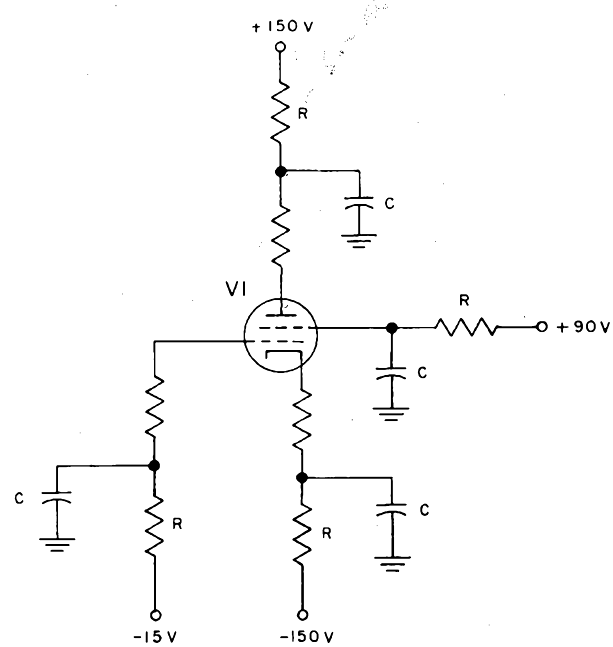
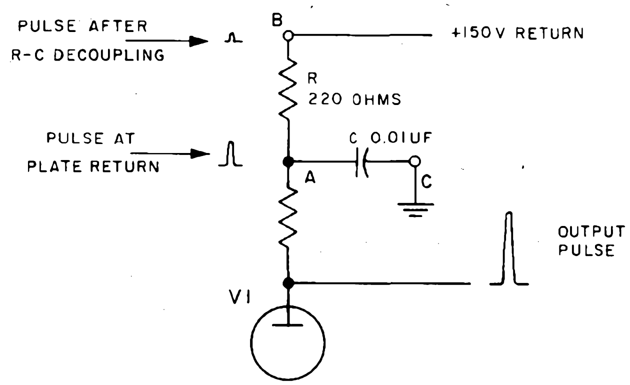


Figure 2–10. RC Decoupled Returns, Simplified Schematic Diagram



REACTANCE OF C IS

$$X_C = \frac{1}{2\pi FC}$$

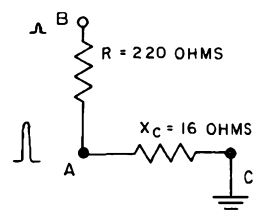
WHERE

$2\pi = 6.28$
$F = 10^6$ CPS (LOWEST FREQUENCY WHERE DECOUPLING IS REQUIRED)
$C = 0.01$ UF

THEN

$$X_C = \frac{1}{6.28 \times 10^6 \times 0.01 \times 10^{-6}} = 15.9 \text{ OHMS}$$

FOR SIMPLICITY LET X_C = 16 OHMS AND CONSIDER IT TO BE RESISTIVE. THEN THE DECOUPLING CIRCUIT MAY BE REDRAWN AS A VOLTAGE DIVIDER.



AN ALTERNATING VOLTAGE (PULSE) AT A, WILL CAUSE CURRENT TO FLOW IN TWO PATHS A-B AND A-C.

IT IS $\frac{220}{16}$ TIMES EASIER FOR CURRENT TO FLOW THROUGH A-C THAN IT IS THROUGH A-B; $\frac{220}{16}$ = 14 APPROX.

THEREFORE 14 TIMES MORE PULSE CURRENT WILL FLOW THROUGH A-C THAN A-B AND THE AMPLITUDE OF THE PULSE REMAINING AT B WILL BE ATTENUATED 15 TIMES.

Figure 2—11. RC Decoupling, Simplified Schematic Diagrams and Calculations

sumed: the unclamped output is either more positive than +10 volts or more negative than —30 volts.

The cathode of diode CR1 is biased at +10 volts. When the output voltage is less positive than +10 volts, diode CR1 is cut off. When the output rises slightly above +10 volts, diode CR1 conducts. The current through CR1 (I1) adds to the current through V1 (I2) to produce a voltage drop across R1 sufficient to maintain the output at +10 volts.

The anode of diode CR2 is biased at —30 volts. When the output voltage is more positive than —30 volts, CR2 is cut off. When the output falls slightly below −30 volts, diode CR2 conducts. Current through R2 (I2 + I3) increases, raising the potential at the output to −30 volts. In this manner, the output of the flip-flop in figure 2—13 is limited to an up level of +10 volts and a down level of −30 volts. Varying loads and aging of components could produce undesirable variations of level at the output if they were not clamped as indicated. Clamping either one or both standard levels is a technique employed in certain applications of cathode followers, level setters, inverters, and flip-flops.

2.5.2 D-C Coupling

In several of the basic circuits it becomes necessary to dc-couple the plate of one stage to the control grid of another. This requirement will be found in the circuits either operating on or producing levels. Included are the flip-flops, d-c inverters, and d-c level setters.

Figure 2—14A is a simplified schematic diagram illustrating a dc-coupling network. Assume that the output levels required are −30 volts and +10 volts, alternately. This would require that the voltages at the control grid of V2 be d-c levels of approximaely −30 volts and +10 volts, alternately. Since levels are being coupled, d-c coupling is indicated (one that will pass direct current); therefore, neither a transformer nor a capacitor may be employed as the primary coupling device. The control grid, on the other hand, cannot be directly connected to the plate, because the level conditions (+10 v and −30 v) could never be reached in this manner. The method of d-c coupling illustrated in figure 2—14A employs a voltage divider consisting of plate resistor V1 (R1), resistor R2, and resistor R3. With vacuum tube V1 cut off, the current flowing through resistors R1, R2, and R3 develops a +10-volt level (E2) at the control grid of vacuum tube V2.

The mathematics supporting this conclusion follows. The voltage (E_1) across R1, R2, and R3 is

$$E_1 = +150\text{ v} - (-300\text{ v})$$
$$= 450\text{ v}$$

and the current (I_1) through resistors R1, R2, and R3 is

$$I_1 = \frac{E_1}{R_1 + R_2 + R_3}$$
$$\frac{450}{10 \times 10^3 + 130 \times 10^3 + 310 \times 10^3}$$
$$= \frac{450}{450 \times 10^3}$$
$$= 1 \times 10^{-3}\text{ amperes}$$

Therefore, the voltage (E_2) developed across resistor R_3 is

$$E_2 = I_1 R_3$$
$$= 1 \times 10^{-3} \times 310 \times 10^3$$
$$= 310\text{ v}$$

and the voltage at the grid of V2 with respect to ground is

$$E_g = E_2 + (-300\text{ v})$$
$$= +310 - 300\text{ v}$$
$$= +10\text{ v}$$

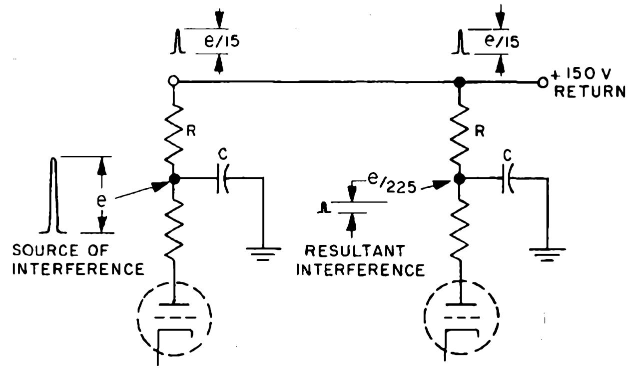


Figure 2—12. Attenuation of Interaction through RC Decoupling, Simplified Schematic Diagram

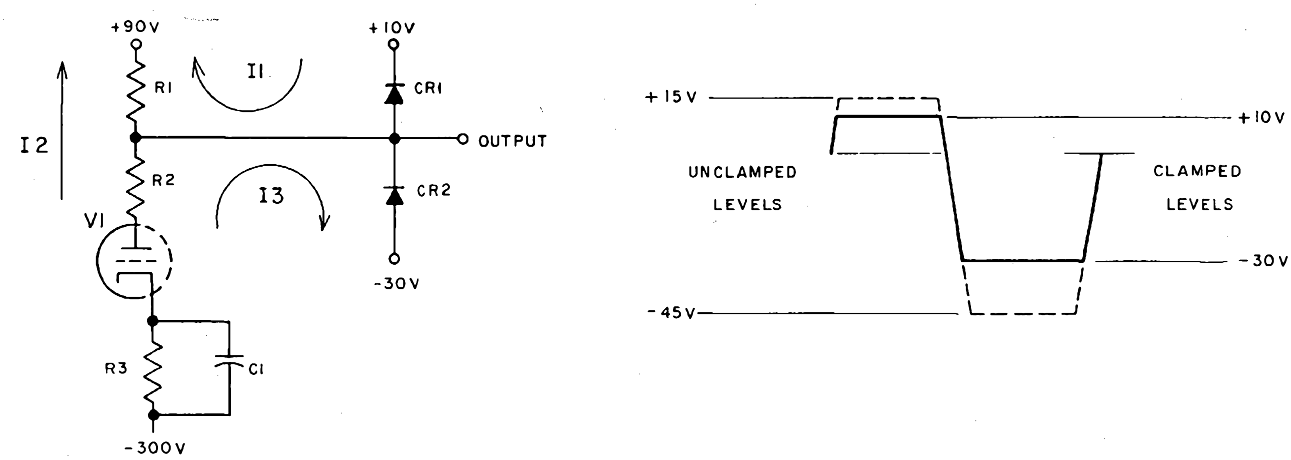


Figure 2—13. Diode Clamped Output Levels, Simplified Schematic Diagram

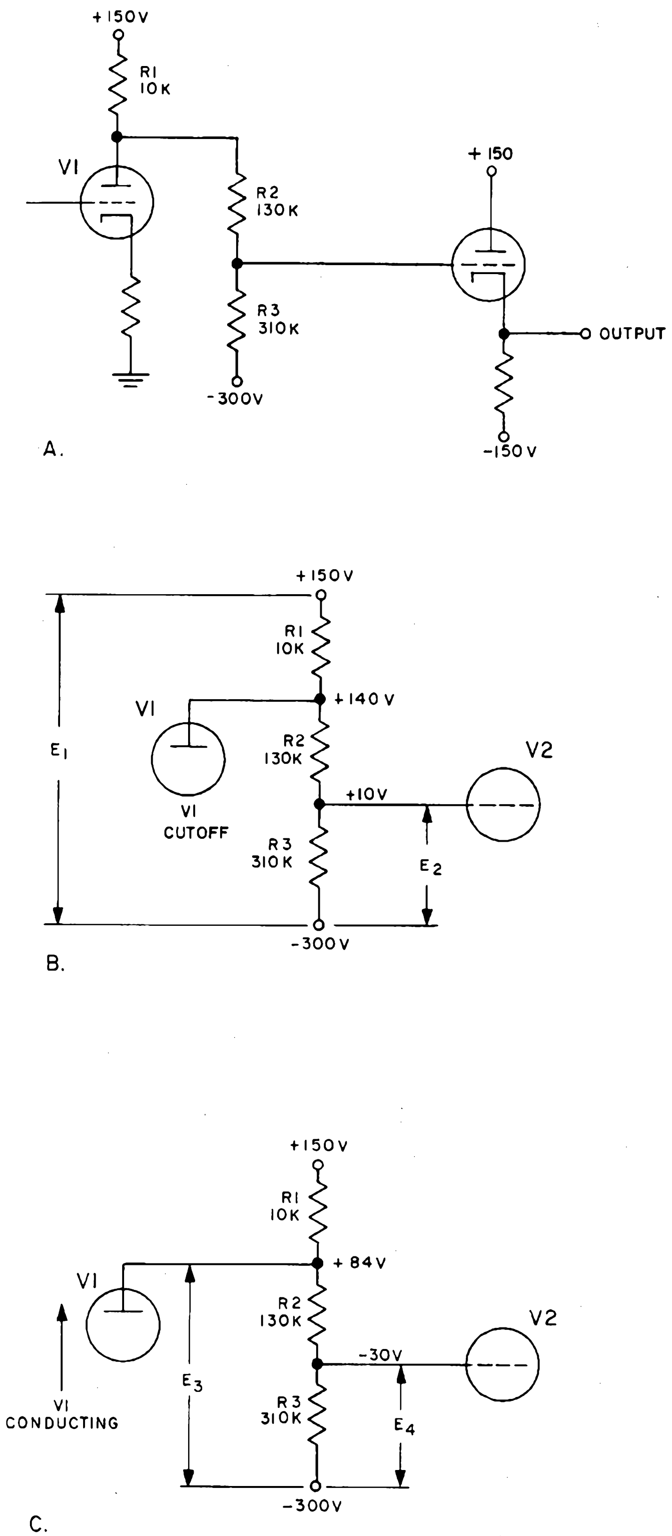


Figure 2–14. D-C Coupling Network, Simplified Schematic Diagram

where

E_g = voltage at control grid of V2 with respect to ground.

With vacuum tube V1 conducting, the additional current flowing through resistor R1 drops the potential at the plate of V1 to +84 volts (fig. 2–14C). As a result, the voltage (E_3) across resistors R2 and R3 becomes

$$E_3 = +84 \text{ v} - (-300 \text{ v})$$
$$= 384 \text{ v}$$

and the current (I_3) through resistors R2 and R3 is reduced

$$I_3 = \frac{E_3}{R2 + R3}$$
$$= \frac{384}{130 \times 10^3 + 310 \times 10^3}$$
$$= 0.873 \times 10^{-3} \text{ amperes}$$

The voltage drop (E_4) across resistor R3 is now

$$E_4 = I_3 \times R3$$
$$= 0.873 \times 10^{-3} \times 310 \times 10^3$$
$$= 270 \text{ v}$$

and the voltage (E_g) at the control grid of V2 with respect to ground is

$$E_g = E_4 + (-300 \text{ v})$$
$$= 270 \text{ v} - 300 \text{ v}$$
$$= -30 \text{ v}$$

It can be seen that this method of returning the plate to a highly negative potential through a voltage divider enables the coupling of levels from a plate operating at a higher bias to a grid operating at a lower bias.

2.6 SPEEDUP CIRCUITS

Machine operation frequently depends on the speed at which levels shift. This makes rise and fall time an important characteristic of level outputs. The speedup of rise and fall time is a requirement satisfied by circuit configurations in certain of the basic circuits which produce levels. Flip-flops, d-c inverters, and d-c level setters are compensated to speed up the rise and fall of level outputs.

2.6.1 Voltage Divider Compensation

One of the most routine methods employed to effect the shortening of rise and fall time is voltage divider compensation. Figure 2–15 is a simplified schematic diagram of a compensated d-c coupling network. This schematic includes two capacitors not included in figure 2–14A, C1 and C2. Capacitor C1 is a compensating capacitor, and capacitor C2 is the input capacity of V2. This input capacity, which must be compensated for, consists of stray capacity plus the effective grid-to-ground capacity of V2. Were it not for compensation, the capacity of C2 would result in a slow rise and fall at the output of V2 (fig. 2–16). It can be seen that, in the uncompensated output, there is considerable curvature at the corners of the waveform. This is caused by the attenuation of the high-frequency components of which level shifts are composed. The level itself is not affected because it consists of low-frequency and d-c components, which are not attenuated by C2 capacitance.

Capacitor C1 bypasses resistor R2 (fig. 2–15), increasing the amplitude of high-frequency components at the grid of V2 by the same amount that they are attenuated by capacitor C2. This results in a compensated (speeded-up) output, shown in figure 2–16.

2.6.2 Peaking Coils

Another method of speeding up rise and fall time entails the use of a peaking coil (fig. 2–17). The various capacities affecting the resultant output at the plate of vacuum tube V1 are represented as capacitor C1. Without compensation, the high-frequency components of the output waveform would be attenuated by the effect of capacitor C1, and the resultant waveform would be that indicated by the broken line.

Including L1 in series with R1 produces an effective plate load

$$Z = R1 + X_L$$

where

Z = the plate load impedance

X_L = the inductive reactance of peaking coil L1

in addition

$$X_L = 2\pi FL = 6.28\ FL$$

where

F = frequency in cycles per second

L = inductance of peaking coil L1 in henries

It is apparent that the load impedance (Z) is a function of frequency: the higher the frequency, the larger X_L becomes and, hence, the larger Z becomes.

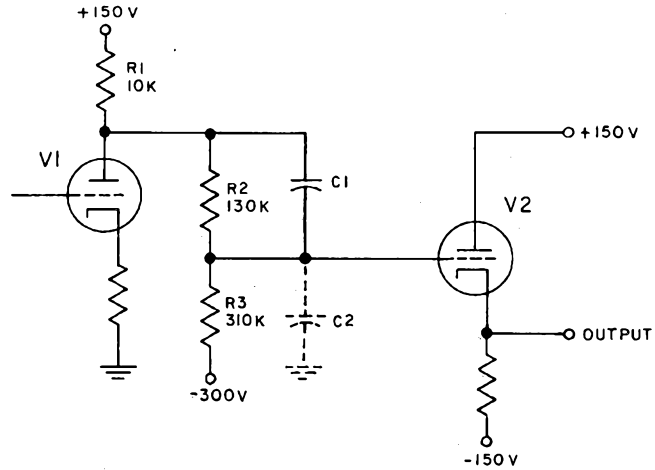


Figure 2–15. Compensated D-C Coupling Network, Simplified Schematic Diagram

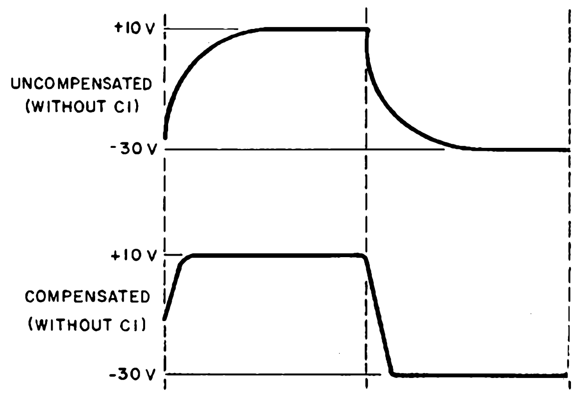


Figure 2–16. Output Waveform (V2 in Figure 2–15)

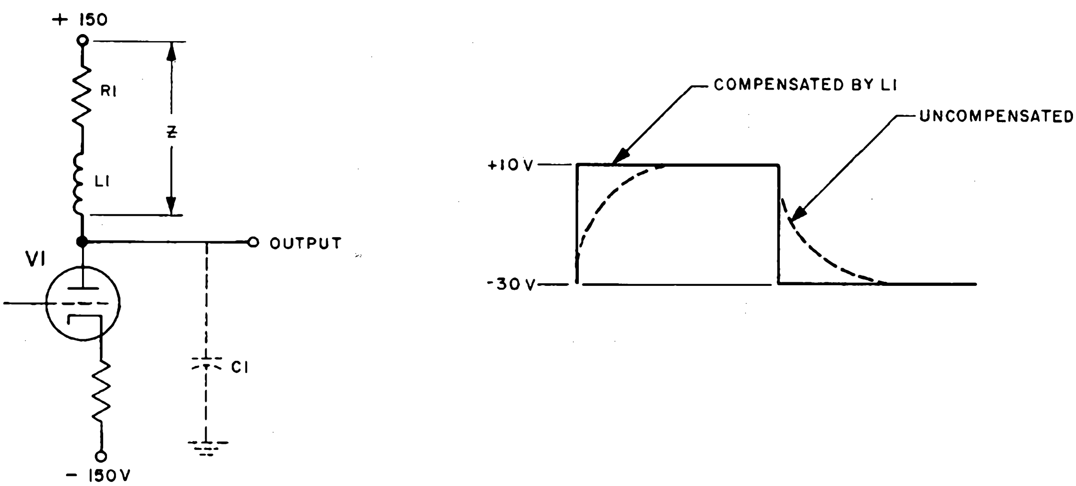


Figure 2–17. Peaking Coil Compensated Plate Circuit, Simplified Schematic Diagram with Waveform

The gain of an amplifier is proportional to the expression

$$\frac{Z}{R_p + Z}$$

where

R_p = plate resistance of V1, a constant.

It therefore follows that the greater Z becomes, the greater the gain of this stage becomes.

As was previously stated, Z increases with frequency. Therefore, the gain and eventually the output of V1 will increase with frequency. This is opposite to the effect of capacitor C1, and the resultant waveform is compensated as indicated by the solid line.

At dc and low frequencies, the reactance (X_{L1}) of peaking coil L1 is of extremely small magnitude and, therefore, has no effect on the circuit. It can be seen that the level output is not affected by the inclusion of peaking coil L1. On the other hand, the rise and fall times which include high-frequency components are effectively shortened (speeded up).

PART 3
THEORY OF OPERATION

CHAPTER 1
CATHODE FOLLOWER

1.1 DEFINITION AND DESCRIPTION

The cathode follower (CF) is a nonlogic circuit which amplifies power. It has a voltage gain approaching 1. Since the cathode follower has high input and low output impedance, it is particularly useful as an isolating device. There are eight basic cathode follower models, identified by the letters B through H and J. Each model contains two $_X$CF circuits. When two circuits of different models are paired, the designations B and F, D and G, etc., are used. The representative cathode follower logic block symbol appears in figure 3—1.

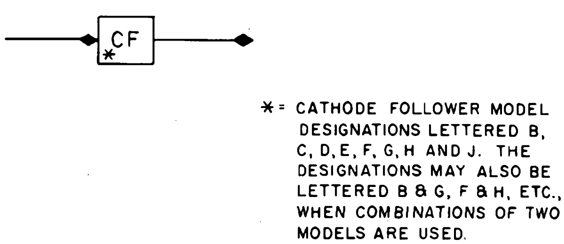


Figure 3—1. Cathode Follower, Logic Block Symbol

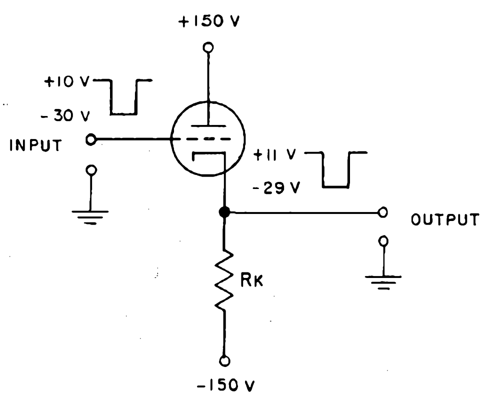


Figure 3—2. Cathode Follower, Simplified Schematic Diagram

1.2 PRINCIPLES OF OPERATION

Figure 3—2 is a simplified circuit schematic diagram of a cathode follower. The cathode follower output is produced across load resistor R_k, which is returned to the —150-volt supply.

A +10-volt level applied to the cathode follower grid causes a rise in plate current flowing through R_k. The increased voltage drop across R_k makes the cathode (output) more positive. A —30-volt level applied to the grid causes a decrease in plate current through R_k, making the output less positive. Although the cathode follower output voltage approaches its input voltage, the voltage gain is always less than 1. The level shift caused by cathode buildup, inherent in cathode followers, produces an output level more positive than the input level (see input and output waveforms in fig. 3—2). However, because of its large input and small output impedance, the cathode follower produces a power gain. The examples that follow show arithmetically the power amplification of a cathode follower.

Note

The values of impedances and potentials used in the examples are nominal, and input and output level potentials are assumed to be equal.

$$Z_{in} \text{ (input impedance)} = 10 \text{ meg}$$
$$Z_{out} \text{ (output impedance)} = 10\text{K}$$
$$E_{in} \text{ (input level)} = 10 \text{ volts}$$
$$E_{out} \text{ (output level)} = 10 \text{ volts}$$
$$\text{Power in} = \frac{E^2_{in}}{Z_{in}} = \frac{10^2}{10 \times 10^6} = \frac{100}{10{,}000{,}000} = 10 \times 10^{-6} = 10 \text{ microwatts}$$
$$\text{Power out} = \frac{E^2_{out}}{Z_{out}} = \frac{10^2}{10 \times 10^3} = \frac{100}{10{,}000} = 10 \times 10^{-3} = 10{,}000 \text{ microwatts}$$
$$\text{Power gain} = \frac{\text{Power Out}}{\text{Power In}} = \frac{10{,}000}{10} = 1000$$

The eight cathode follower models differ basically in the value of R_k for each model. The models, model combinations, and associated types must meet certain load requirements, the load in many cases being resistive and capacitive. Figure 3–3 is a simplified circuit

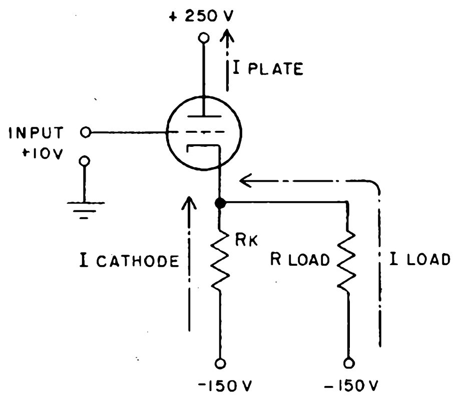


Figure 3–3. Cathode Follower with Resistive Load, Simplified Schematic Diagram

schematic diagram of a cathode follower and of a representative resistive load. The plate current is the sum of cathode and load currents; therefore, the load current equals the plate current minus the cathode current.

$$\text{I plate} = \text{I cathode} + \text{I load}$$

$$\text{and I load} = \text{I plate} - \text{I cathode}$$

Maximum load current results from minimizing cathode current by employing a large value of R_k.

The load also has an inherent capacitance which, although not a physical capacitor, nevertheless exists. A simplified circuit schematic diagram of a cathode follower with a capacitive load is shown in figure 3–4. When a —30-volt level is applied to the cathode follower grid, the capacity charges to —30 volts.

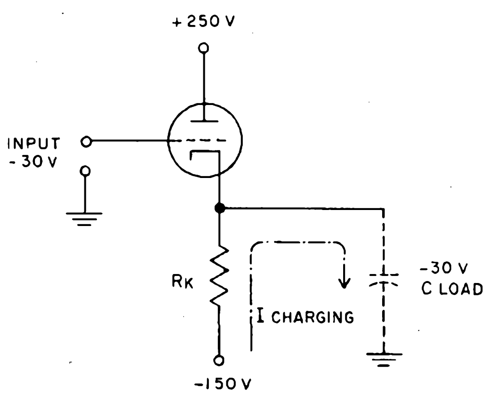


Figure 3–4. Cathode Follower with Capacitive Load, Simplified Schematic Diagram

Since the charging current (electron flow) necessary to establish a —30-volt level on this capacity flows through R_k, the charging time required to reach this potential is a function of the resistor value of R_k. Hence the lower the value of R_k, the shorter this charging (fall) time.

A large value of R_k is desirable when driving a resistive load, and a small value of R_k makes for a last fall time where a capacitive load is considered. It therefore follows that the value of R_k may be selected to produce an optimum condition for either of the two load conditions, or a compromise value may be decided upon to satisfy a resistive, capacitive load.

A circuit schematic of the $_C$CF is shown in figure 3–5A. Table 3–1 is the associated list of detail parts and their functions. The basic operation of a $_C$CF is the same as that of the simplified cathode follower discussed previously.

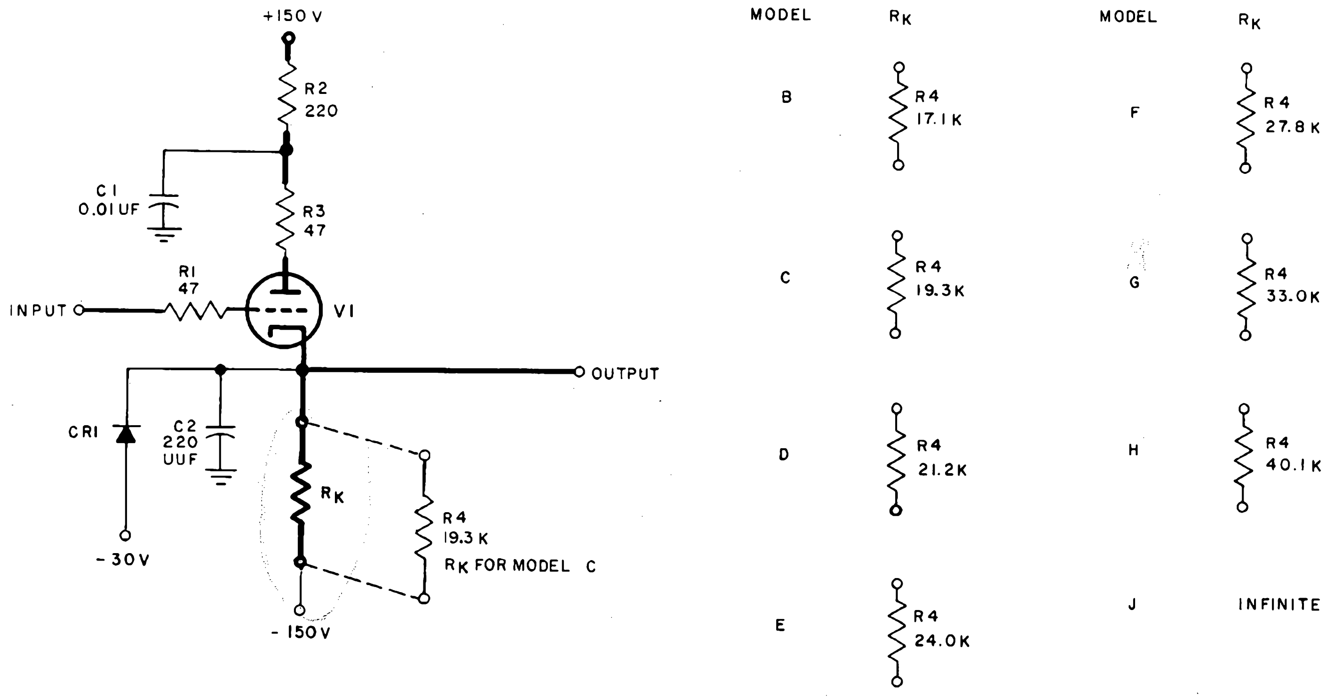
The $_C$CF circuitry shown in the diagram contains all the components found in a particular cathode follower model. A general discussion of these components follows:

TABLE 3–1. CATHODE FOLLOWER, MODEL C, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Part of decoupling network (with R2).
C2	Increases cathode-follower fall time.
CR1	Clamps V1 cathode at —30 volts.
R1	Parasitic suppressor.
R2	Part of decoupling network (with C1).
R3	Parasitic suppressor.
R4	Cathode resistor for V1.
V1	Cathode-follower vacuum tube.

For a particular cathode-follower model, there is a definite value of R_k, the reference symbol being R4. The cathode-resistor values for all cathode-follower models are indicated in figure 3–5B. These resistors are inserted in the cathode of their associated cathode follower as indicated in figure 3–5.

Components CR1 and C2 may be present in the cathode-follower circuitry, depending upon the particular cathode follower model and type. Catcher diode CR1 has a safety function: it "catches" the cathode at —30 volts, thereby preventing it from becoming more negative than this potential if the vacuum-tube filament should open or the plate supply voltage fail. Capacitor



A CATHODE FOLLOWER, MODEL C, SCHEMATIC DIAGRAM

B. RK FOR MODELS B THROUGH H AND J

Figure 3–5. Cathode Followers, Models B through H and J, Schematic Diagram

C2 is used only when a delay in fall time is required. Parasitic suppressor resistors R1 and R3 and decoupling networks C1 and R2 are common to most circuits.

Although there are many cathode-follower models and types, only the $_C$CF is discussed because it contains all the components found in the other models. Refer to table 3–1 for the function of detail parts not discussed.

CHAPTER 2
D-C LEVEL SETTER

2.1 DEFINITION AND DESCRIPTION

The models A and B d-c level setters, ($_x$LA), shown in logic block symbols in figure 3–6, are nonlogic circuits which restore signal levels to their nominal +10- and −30-volt upper and lower limits. Figure 3–7 is a graphic presentation of the typical input and output levels of a level setter. The input levels are plotted to the same time base as the restored output level. In addition to level restoration, the rise and fall times have been shortened. Incorrect levels are the results of level variations as the signal passes through various circuits. Level setters are introduced at points where levels deviate markedly from their +10- and −30-volt levels, eliminating the possibility of logic failure due to improper levels.

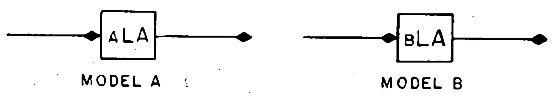


Figure 3–6. D-C Level Setters, Logic Block Symbols

The two models of level setters differ in the minimum input level requirements and rise and fall time restoration. Table 3–2 presents the maximum and minimum input level requirements. It will be seen that the $_A$LA operates over a wider range of input levels and

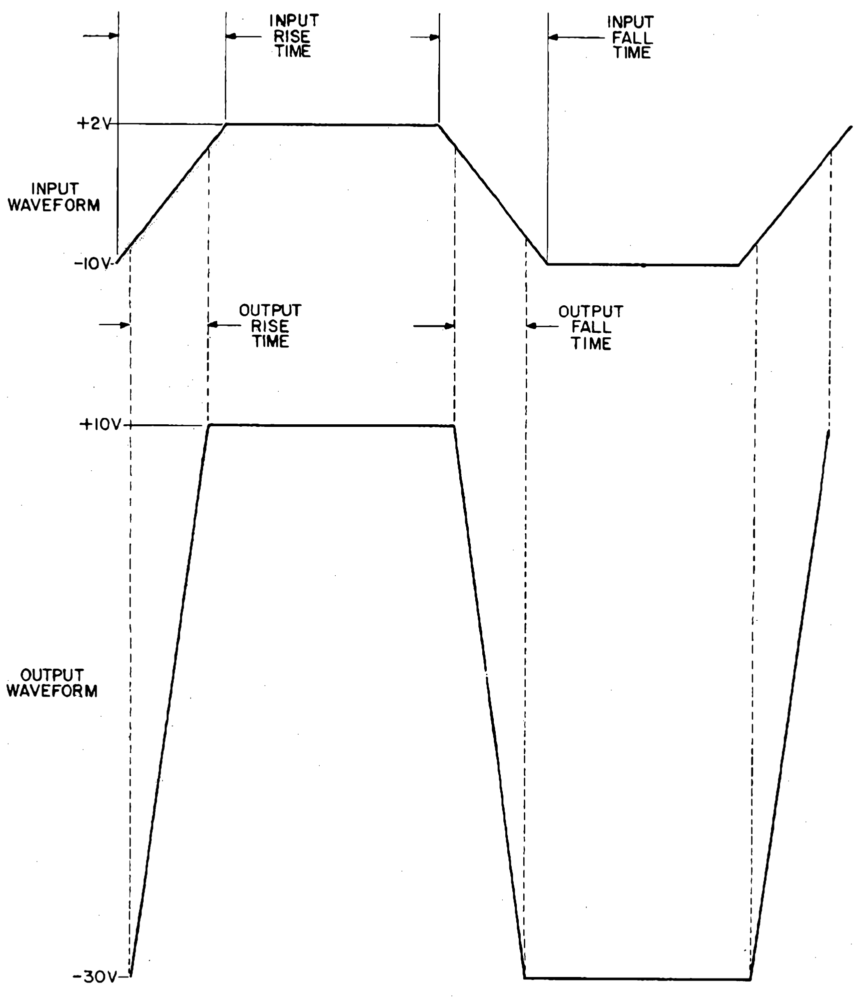


Figure 3–7. Input and Output Levels of a D-C Level Setter

TABLE 3–2. MAXIMUM AND MINIMUM INPUT LEVELS FOR D-C LEVEL SETTER MODELS A AND B

	MODEL			
	$_{A}$LA		$_{B}$LA	
LEVEL	MAX	MIN	MAX	MIN
Upper	+12 volts	0 volt	+12 volts	+6 volts
Lower	—30 volts	—8 volts	—30 volts	—11 volts

that the $_{B}$LA has the advantage of producing a faster rise and fall time.

2.2 PRINCIPLES OF OPERATION

2.2.1 Basic Operation

Figure 3–8 is a block diagram of a d-c level setter. It consists of two cathode followers and a grounded grid amplifier. Figure 3–9 is a simplified circuit schematic of a grounded grid amplifier. An input level is applied to the cathode, and the grid is grounded. When the input level is positive with respect to ground, the grid (maintained at ground potential) is effectively negative with respect to the cathode. This causes the plate current flowing through R to decrease, raising the plate potential to a value approaching B+. When the input drops to a negative potential, the grid is effectively positive with respect to the cathode. Plate current increases, dropping the plate potential in a negative direction.

A positive input results in a more positive output, and a negative input results in a less positive output. Thus the output of a grounded grid amplifier is amplified and in phase with the input.

A level applied to the level setter input cathode follower is matched to the input of the grounded grid amplifier. The grounded grid amplifier amplifies this level and, in turn, drives the output cathode follower, which is alternately clamped at +10- and —30-volt levels. (See fig. 3–8.)

2.2.2 Detailed Operation, Model A Level Setter

Figure 3–10 is a schematic diagram of a model A level setter. Table 3–3 is the associated list of detail parts and their functions. When the level at the grid of input cathode follower V1A is —8 volts, the cathode falls to this potential. The cathode of grounded grid amplifier V1B is also at a —8-volt potential because the cathodes of V1A and V1B are common. A voltage divider consisting of resistors R4 and R6 between ground and —15 volts places the grid of V1B at a —4-volt potential. The grid of V1B is positive with respect to its cathode (at —8 volts). This produces a current flow which drops the plate potential of V1B to +66 volts. A difference of potential of 366 volts across the divider consisting of resistors R7 and R8 would produce a potential of —58 volts at the grid of output cathode follower V2A. However, the grid of V2A is never more negative than —35 volts because of the clamping action of diode CR1. Diode CR3 clamps the cathode of V2A at —30 volts. Cathode resistors R11 and R12 form a voltage divider between —30 volts and —150 volts, placing the anode of CR1 at a potential of —35 volts. The grid of V2A is therefore clamped at —35 volts, preventing the cutoff of V2A on negative excursions.

When the level at the grid of the input cathode follower V1A is +2 volts, the cathodes of V1A and

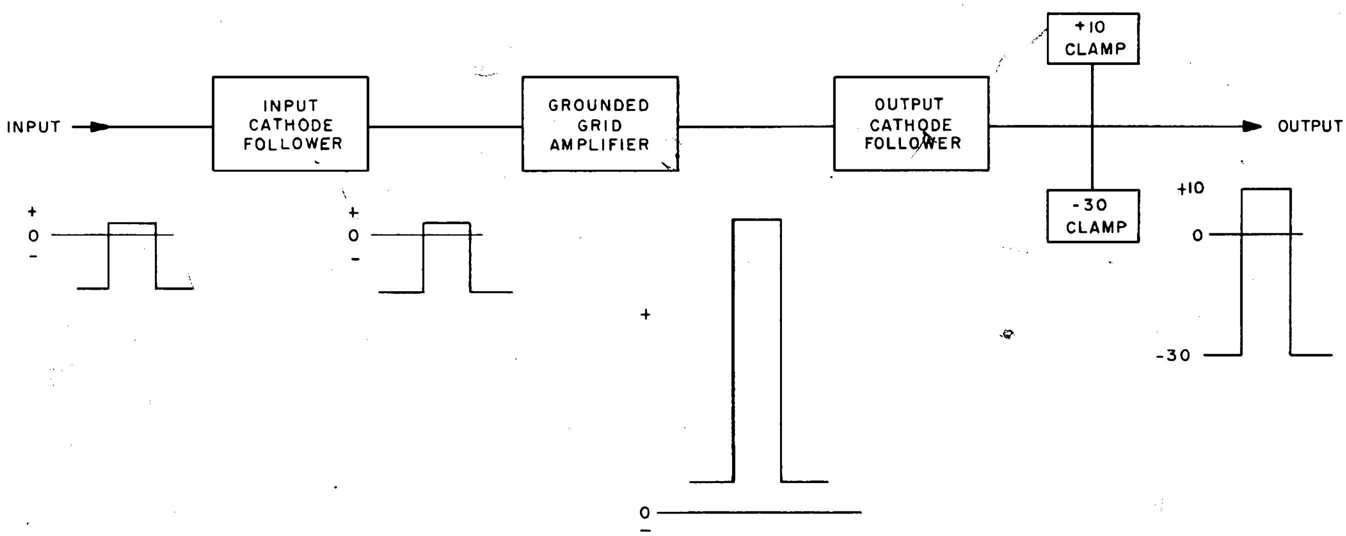


Figure 3–8. D-C Level Setter, Block Diagram

TABLE 3–3. D-C LEVEL SETTER, MODEL A, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Bypass capacitor.
C2	Speeds rise and fall time.
CR1	Clamps grid of V2A to —35 volts.
CR2	Clamps cathode of V2A to +10 volts.
CR3	Clamps cathode of V2A to —30 volts.
R1	Parasitic suppressor.
R2	Cathode load for V1A.
R3	Plate load resistor for V1B.
R4	Part of voltage divider biasing network (with R6).
R5	Parasitic suppressor.
R6	Part of voltage divider biasing network (with R4).
R7	Part of voltage divider (with R8).
R8	Part of voltage divider (with R7).
R9	Parasitic suppressor.
R10	Current limiting resistor, protects CR2.
R11	Part of V2A cathode load (with R12) and voltage divider for CR1 bias.
R12	Part of V2A cathode load (with R11) and voltage divider for CR1 bias.
V1A	Input cathode follower.
V1B	Grounded grid amplifier.
V2A	Output cathode follower.

grounded grid amplifier V1B rise to +2 volts. With —4 volts on the grid of V1B and +2 volts on the cathode, V1B is cut off. The voltage divider formed by resistors R3, R8, and R7 across a 550-volt potential sets the VIB plate potential at +200 volts. The divider formed by resistors R8 and R7 between +200 volts and —300 volts would produce a potential of +31 volts at the grid of output cathode follower V2A were it not for the following: the cathode of V2A is clamped to +10 volts by diode CR2; a potential more positive than +10 volts at the grid of V2A causes grid current to flow; the grid, therefore, cannot become more positive than +10 volts.

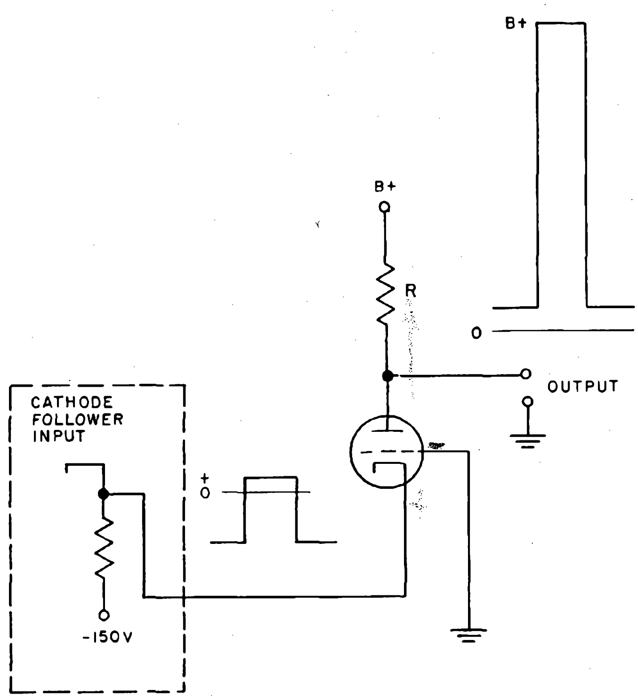


Figure 3–9. Grounded Grid Amplifier, Simplified Schematic Diagram

In addition to re-establishing levels, the level setters also improve the transition (rise and fall) time. Compensating capacitor C2 speeds up the rise and fall of the levels applied to the grid of V2A. Refer to table 3–3 for the function of detail parts not discussed.

2.2.3 Detailed Operation, Model B Level Setter

Figure 3–11 is a schematic diagram of the $_B$LA. Table 3–4 is the associated list of detail parts and their functions. If the model B schematic is compared with the model A (fig. 3–10), certain circuit variations are noted. Cathode voltage divider resistor R4 and speedup capacitor C2 have been added to the cathode of V1A, while R5 has been reduced in value. The cathode of V1B is tied to the junction of resistors R4 and R5. The values of voltage divider biasing resistors R8 and R10 have been interchanged, increasing the V1B bias from —4 to —10.4 volts. Bypass capacitor C3 has increased in value, and resistor R12 has decreased.

The variations noted in the $_B$LA increase the speed of rise and fall times slightly over the $_A$LA. This gain in speed, however, results in a more limited input level requirement than that in the $_A$LA. Refer to table 3–4 for the function of detail parts not discussed.

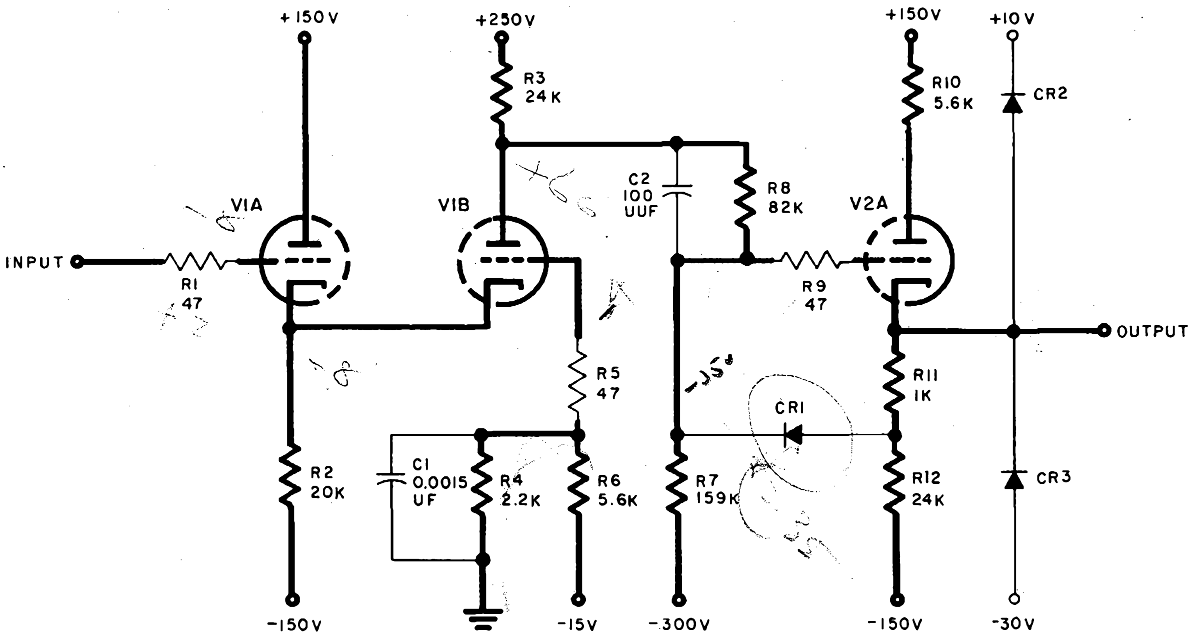


Figure 3–10. D-C Level Setter, Model A, Schematic Diagram

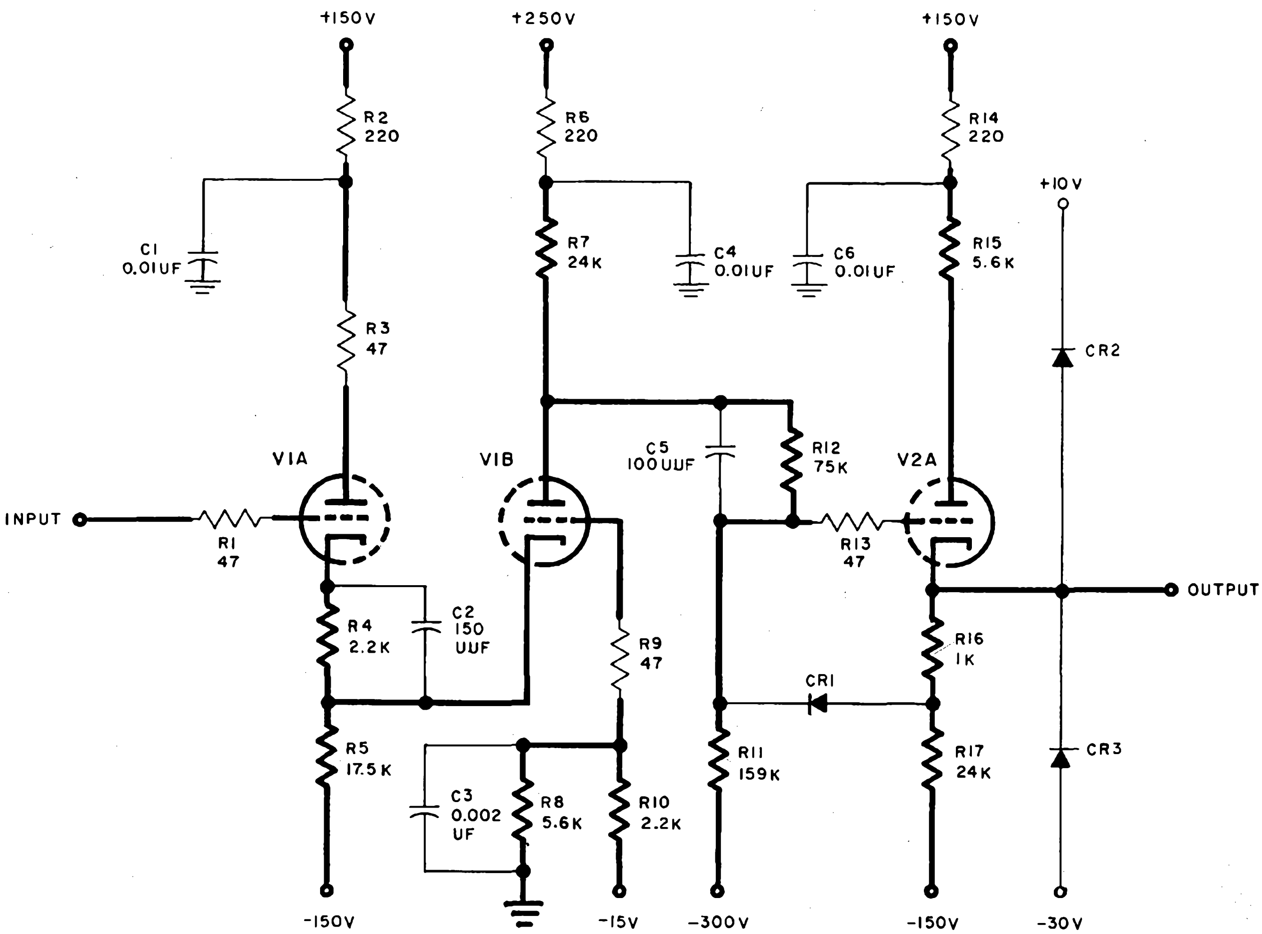


Figure 3–11. D-C Level Setter, Model B, Schematic Diagram

TABLE 3—4. D-C LEVEL SETTER, MODEL B, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Part of decoupling network (with R2)
C2	Speeds rise and fall time.
C3	Bypass capacitor.
C4	Part of decoupling network (with R6).
C5	Speeds rise and fall time.
C6	Part of decoupling network (with R14).
CR1	Clamps grid of V2A to —35 volts.
CR2	Clamps cathode of V2A to +10 volts.
CR3	Clamps cathode of V2A to —30 volts.
R1	Parasitic suppressor.
R2	Part of decoupling network (with C1).
R3	Parasitic suppressor.
R4	Part of V1A cathode load (with R5).
R5	Part of V1A cathode load (with R4).
R6	Part of decoupling network (with C4).
R7	Plate load resistor for V1B.
R8	Part of voltage divider (with R10).
R9	Parasitic suppressor.
R10	Part of voltage divider (with R8).
R11	Part of voltage divider (with R12).
R12	Part of voltage divider (with R11).
R13	Parasitic suppressor.
R14	Part of decoupling network (with C6).
R15	Current limiting resistor, protects CR2.
R16	Part of V2A cathode load (with R17) and voltage divider for CR1 bias.
R17	Part of V2A cathode load (with R17) and voltage divider for CR1 bias.
VIA	Input cathode follower.
VIB	Grounded grid amplifier.
V2A	Output cathode follower.

CHAPTER 3

PULSE AMPLIFIERS, MODELS A, B, AND C

3.1 DEFINITION AND DESCRIPTION

The pulse amplifiers (PA's) are nonlogic circuits and are represented in complete logic schematics by the logic block symbols in table 3–5. Pulse amplifiers are employed to increase the load-driving capabilities (to amplify power) of a standard pulse. Three models of this circuit are employed to cover the range of loads that must be driven and are used separately or in combination, depending upon the specific load to be driven. Table 3–5 lists the three models and gives their logic block symbols and load-driving capabilities.

The differences between the models are in the point of connection of the suppressor grid and the value of plate voltage applied. In the $_A$PA, the suppressor is tied to +10 volts. This connection limits the maximum value of current through the pentode. Current-carrying capacity is increased in the $_B$PA by connecting the suppressor grid to the plate of the pentode and operating the tube as a tetrode-connected pentode. In the $_C$PA, a tetrode-connected pentode is employed, and the plate supply voltage is either +250 volts or +150 volts. Although the plate supply voltage is reduced by 100 volts, the tetrode connection of the $_C$PA provides sufficient current to drive loads below the capabilities of $_A$PA. When greater output is required, a +250-volt plate return is employed. One other major difference between the $_C$PA and the others ($_A$PA and $_B$PA) is in the termination requirements. The $_A$PA and the $_B$PA drive constant loads. The terminating resistor satisfies the minimum load requirements for each load the circuit drives and will be different for each load. The $_C$PA can satisfy termination requirements for a varying load (no load to maximum load in any one application) while using only one value of terminating resistor. Thus, the three PA circuits are a versatile group, capable of driving a wide range of loads. Refer to the discussion of the register drivers in Chapter 4 for further modifications of this basic circuit which have increased the load carrying capacity to 34 load units.

Just as each model of the pulse amplifier is used to meet a specific range of load requirements, each model has variations (types) which are designed to meet specific input requirements for a given loading. These type-distinguishing features are detailed in the input circuits in figures 3–12, 3–13, and 3–14, and are discussed in 3.3.

3.2 PRINCIPLES OF OPERATION

3.2.1 Basic Considerations

The basic parts of the pulse amplifier are a pentode vacuum tube and a transformer. The pentode serves a power-amplifying function. The transformer provides the proper phase relationship at the output and, at the same time, serves an impedance matching function. This is accomplished by so connecting the transformer that a negative pulse at the plate of the pentode produces a positive pulse at the output. The transformer turns ratio of 4 to 1 provides an impedance stepdown of 16 to 1.

$$\frac{\text{output impedance}}{\text{input impedance}} = \left(\frac{\text{turns output}}{\text{turns input}}\right)^2$$

3.2.2 Detailed Operation

Figure 3–12 is a schematic diagram of the $_A$PA. Table 3–6 is the associated list of detail parts and their functions. A standard pulse applied to the input of the $_A$PA is coupled to the control grid of pentode V1 through capacitor C1. This capacitor allows signals at the input to pass to the grid while blocking the —15-volt d-c bias at the grid from the input circuit. The standard pulse overcomes the negative bias, which has held the grid of V1 considerably past cutoff, and tube V1 conducts. The resultant pulse of current produced in the plate circuit of V1 is transformer-coupled to the output through T1. This transformer, with a 4-to-1 turns

TABLE 3–5. PULSE AMPLIFIER, LOGIC BLOCK SYMBOLS AND LOAD-DRIVING CAPABILITIES

NAME	LOGIC BLOCK SYMBOL	LOAD DRIVING CAPABILITIES
Pulse amplifier, model A	→ $_A$PA →	Constant light load (2 to 8 units of load)
Pulse amplifier, model B	→ $_B$PA →	Constant heavy load (5 to 11 units of load)
Pulse amplifier, model C	→ $_C$PA →	Varying light load (0 to 3 units of load)

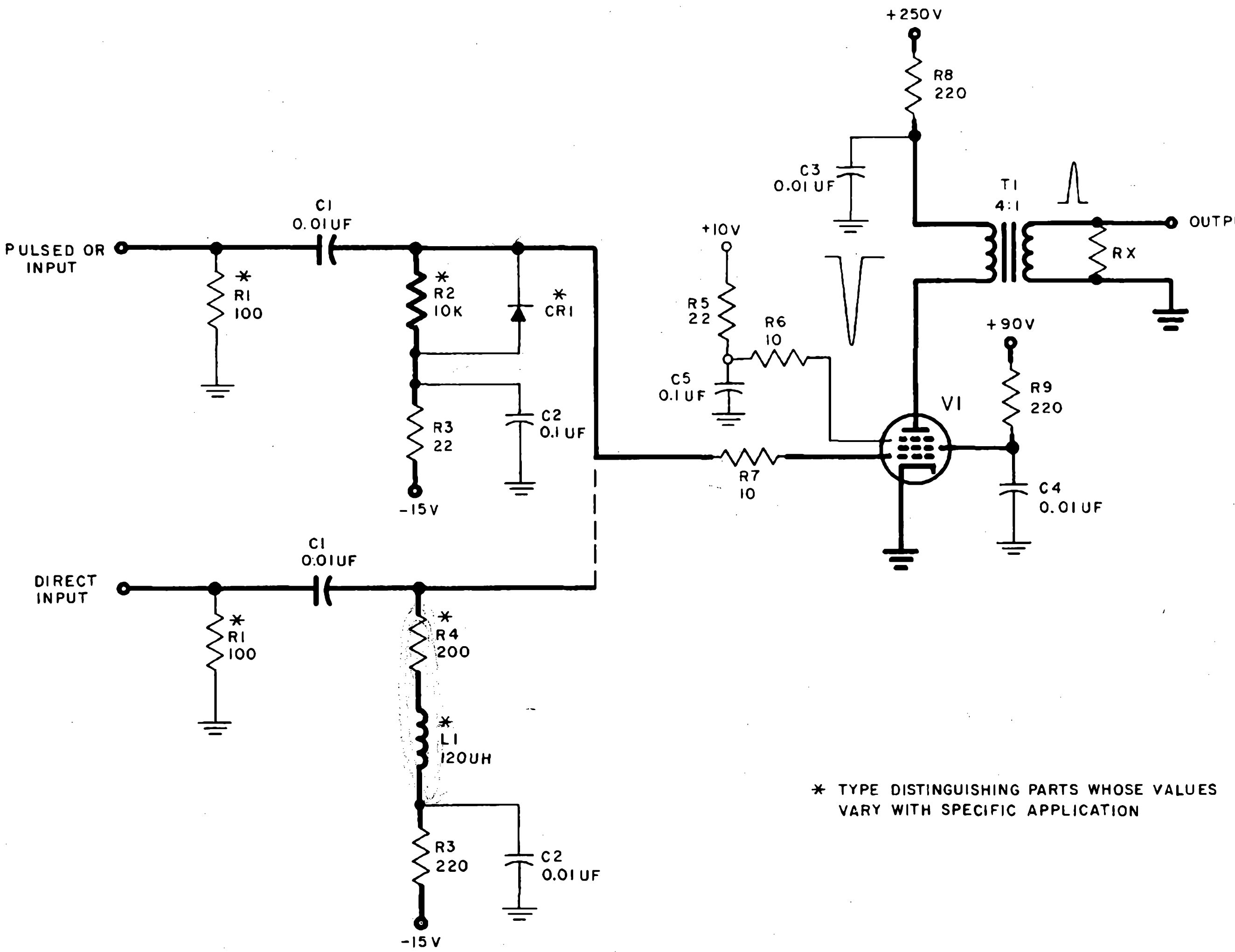


Figure 3—12. Pulse Amplifier, Model A, Schematic Diagram

ratio, steps down the voltage at the secondary (output) to $\frac{1}{4}$ of that appearing at the primary. The output current, in turn, is 4 times that appearing in the primary. Transformer T1 is connected to produce a positive pulse at the secondary (output) as a result of a current pulse in the primary. Thus a standard pulse applied to the input of PA appears as a standard pulse at the output. The $_A$PA, a nonlogic circuit, amplifies the power of the input pulse but does not otherwise change the standard pulse characteristics.

The pulse amplifier may be used to drive delay lines. For this application, the screen grid is returned to +90 volts, and the suppressor grid is returned to +90 volts through a 470-ohm resistor.

3.3 INPUT CIRCUIT VARIATIONS

Figures 3—12, 3—13, and 3—14 illustrate the input circuit variations for each model. Tables 3—7 and 3—8 are the associated lists of detail parts and their functions for figures 3—13 and 3—14, respectively. A comparison of the figures reveals the close similarity between the type-distinguishing parts for each model. Therefore, only the input circuits to the $_A$PA will be discussed.

The input circuits are classified in two groups: the pulsed OR and the direct. Consider the network used with the pulsed OR input, and note that this network has the same configuration in each schematic. The parallel combination of R2 and CR1 serves two functions: resistor R2 provides a high-resistance load for the input pulse, and CR1 provides a low-resistance discharge path for capacitor C1, preventing bias buildup on the control grid. The series connection of R4 and L1 used with the direct input type $_A$PA ensures the return of the control grid to —15 volts shortly after the standard pulse at the input returns to 0. Inductor L1 presents a high impedance to a rapidly changing voltage, ensuring an undistorted coupling of the input pulse to the grid. Thus the high impedance to pulses and the low impedance to dc of L1 ensure a rapid response of the control grid to input pulses and quick recovery to the control grid bias level to prepare the circuit for the next pulse.

TABLE 3—6. PULSE AMPLIFIER, MODEL A, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Input coupling capacitor.
C2	Part of decoupling network (with R3).
C3	Part of decoupling network (with R8).
C4	Part of decoupling network (with R9).
C5	Part of decoupling network (with R5).
CR1	Provides low-impedance discharge path for C1, preventing bias buildup.
L1	Peaking coil for input pulse.
R1	Input coaxial cable termination.
R2	Grid d-c return.
R3	Part of decoupling network (with C2).
R4	Damping resistor for inductor L1.
R5	Part of decoupling network (with C5).
R6	Parasitic suppressor.
R7	Parasitic suppressor.
R8	Part of decoupling network (with C3).
R9	Part of decoupling network (with C4).
Rx	Terminating resistor.
T1	Output transformer.
V1	Power amplifier electron tube.

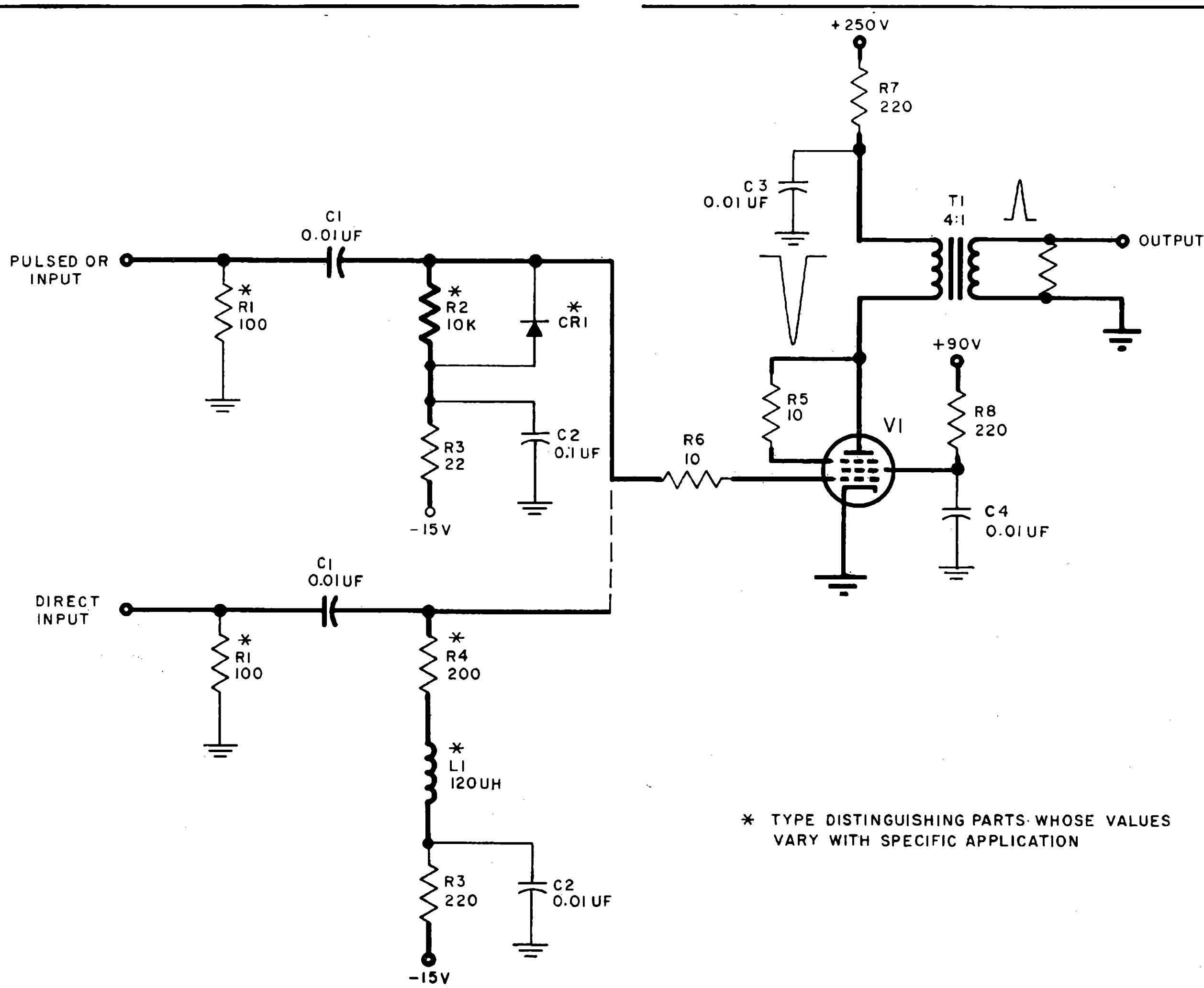


Figure 3—13. Pulse Amplifier, Model B, Schematic Diagram

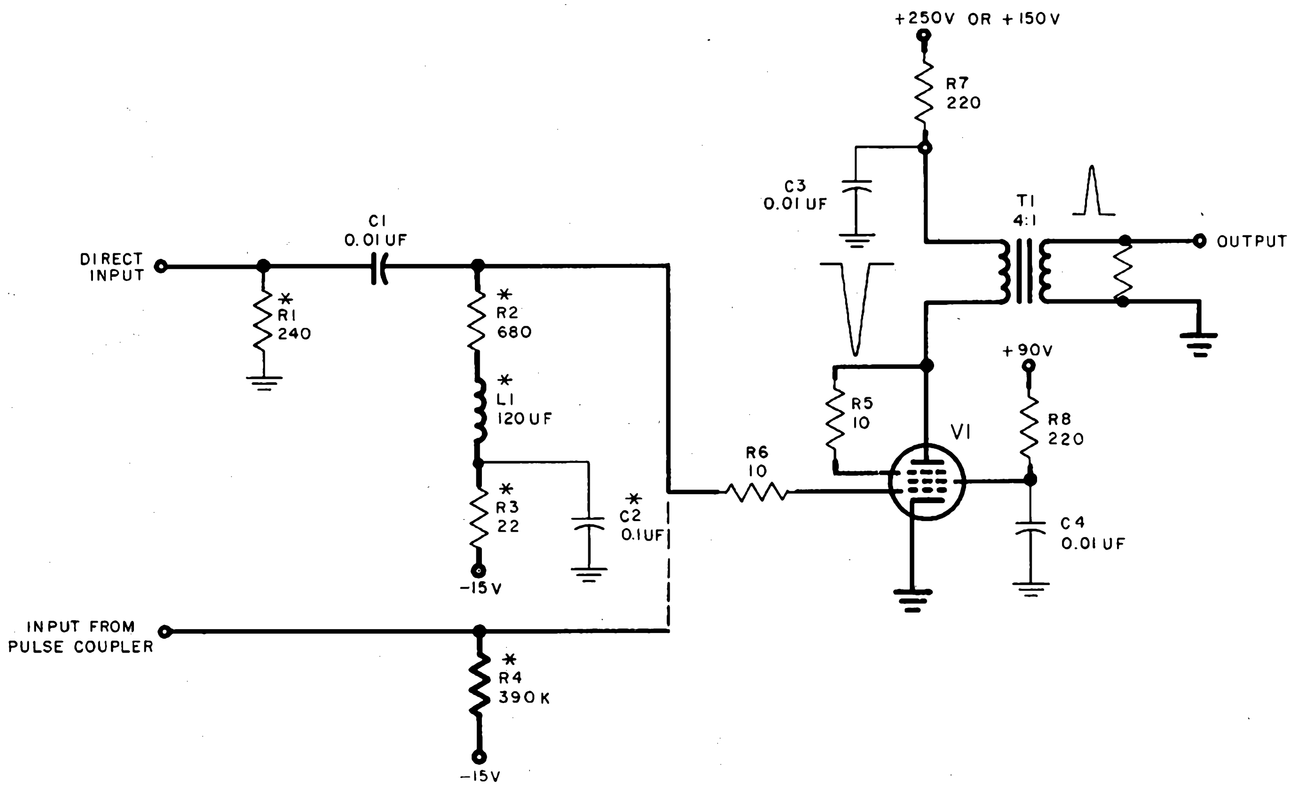


Figure 3–14. Pulse Amplifier, Model C, Schematic Diagram

TABLE 3–7. PULSE AMPLIFIER, MODEL B, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Input coupling capacitor.
C2	Part of decoupling network.
C3	Part of decoupling network.
C4	Part of decoupling network.
CR1	Provides low-impedance discharge path for C1, preventing bias buildup.
L1	Peaking coil for input pulse.
R1	Input coaxial cable termination.
R2	Grid return.
R3	Part of decoupling network (with C2).
R4	Damping resistor for inductor L1.
R5	Parasitic suppressor.
R6	Parasitic suppressor.
R7	Part of decoupling network (with C3).
R8	Part of decoupling network (with C4).
Rx	Terminating resistor.
T1	Output transformer.
V1	Power amplifier electron tube.

TABLE 3–8. PULSE AMPLIFIER, MODEL C, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Input cooling capacitor.
C2	Decoupling network (with R3).
C3	Decoupling network (with R7).
C4	Decoupling network (with R8).
L1	Peaking inductor for input pulse.
R1	Input coaxial cable termination.
R2	Damping resistor for inductor L1.
R3	Decoupling network (with C2).
R4	Grid return.
R5	Parasitic suppressor.
R6	Parasitic suppressor.
R7	Decoupling network (with C3).
R8	Decoupling network (with C4).
Rx	Terminating resistor.
V1	Power amplifier electron tube.

Resistor R1 connected across the input is not properly a part of the pulse amplifier circuit. It terminates coaxial lines connected between the driver and the pulse amplifier. The requirement for a close physical proximity to the pulse amplifier dictates its inclusion in the pulse amplifier assembly. Refer to tables 3–6, 3–7, and 3–8 for the function of detail parts not discussed.

CHAPTER 4

REGISTER DRIVERS, MODELS A AND B

4.1 DEFINITION AND DESCRIPTION

The register drivers ($_{X}$RD) are nonlogic circuits used to increase the load-driving capabilities (to amplify power) to a standard pulse. Table 3–9 lists the models by name with their logic block symbols and load-driving capabilities. The register drivers are essentially model B pulse amplifiers (see Ch. 3) with extended load-driving capabilities. There are two models: the $_{A}$RD is a $_{B}$PA with a transformer input circuit; the $_{B}$RD is a parallel input combination of two $_{B}$PA's with a single transformer feeding the inputs.

4.2 PRINCIPLES OF OPERATION

4.2.1 Basic Considerations

Figure 3–15 is a circuit schematic for both models of the register driver. Table 3–10 is the associated list of detail parts and their functions. As indicated, the $_{A}$RD is converted into a $_{B}$RD by connecting two identical pentode circuits to the output terminal of input transformer T1. The $_{B}$RD connection is shown by the dashed line. As with the pulse amplifier, a standard pulse input produces a standard pulse output. Transformer T1 is connected to produce a positive pulse output three times the amplitude of a standard pulse input. As a result, a standard pulse impressed on the primary appears as a positive potential at the control grid of V1. Tube V1 produces a pulse of current, and transformer T2 delivers a standard output. With proper termination, this standard pulse has much greater drive capabilities (power). Thus the register driver, a nonlogic circuit, power-amplifies standard pulses.

4.2.2 Detailed Operation

The input of the $_{A}$RD (see fig. 3–15) is fed a standard pulse. Transformer T1 amplifies this input three times and, in addition, provides a low-impedance d-c path for the grid bias of —30 volts and isolates the driving (preceding) circuit from the d-c grid bias voltage source. The —30-volt bias maintains the control grid of V1 far below cutoff. This prevents undesirable positive noise pulses, generated in the associated circuit by ringing and mismatch, from driving V1 into conduction.

The other detail parts in the input circuit serve a matching function and minimize effects of ringing in the secondary winding of T1. The parallel combination of resistor R1 and inductor L1 compensates for the mismatch under two conditions of loading in the secondary circuit. Because of ringing, a standard pulse applied to T1 tends to appear as a positive pulse with a large negative overshoot. During the positive pulse, V1 is driven past the point of initial grid conduction. The load across the secondary winding, during this period of grid conduction, is the series combination of resistor R4 and the grid to cathode resistance of V1. During the negative overshoot, current flows in the opposite direction through a load consisting of the forward resistance of CR1 and R3. Inductor L1 and resistor R1 supplement these loads to provide optimum termination for the coaxial input line feeding the primary of T1. The series combination of diode CR1 and resistor R3 limits the magnitude of the negative overshoot to a value approximately equal to the voltage drop across R3. If CR1 were used alone, the negative overshoot would be further limited, but the recovery time of the diode (return of grid to —30 volts) might be slower than the repetition rate of the pulses. Since the diode recovery is a function of the current through it, the addition of R3 speeds up the process by limiting the magnitude of current during diode conduction.

The positive pulse of voltage appearing at the secondary of T1 overcomes the —30-volt bias and causes grid current to flow. Grid-limiting resistor R4 prevents this current from becoming excessive. The grid of V1 is

TABLE 3–9. REGISTER DRIVERS, LOGIC BLOCK SYMBOLS AND LOAD-DRIVING CAPABILITIES

NAME	LOGIC BLOCK	LOAD-DRIVING CAPABILITIES
Register driver, model A	→ $_{A}$RD →	1–17 flip-flops or gate tubes with suitable termination resistor.
Register driver, Model B	→ $_{B}$RD →	17–34 flip-flops or gate tubes with suitable termination resistor.

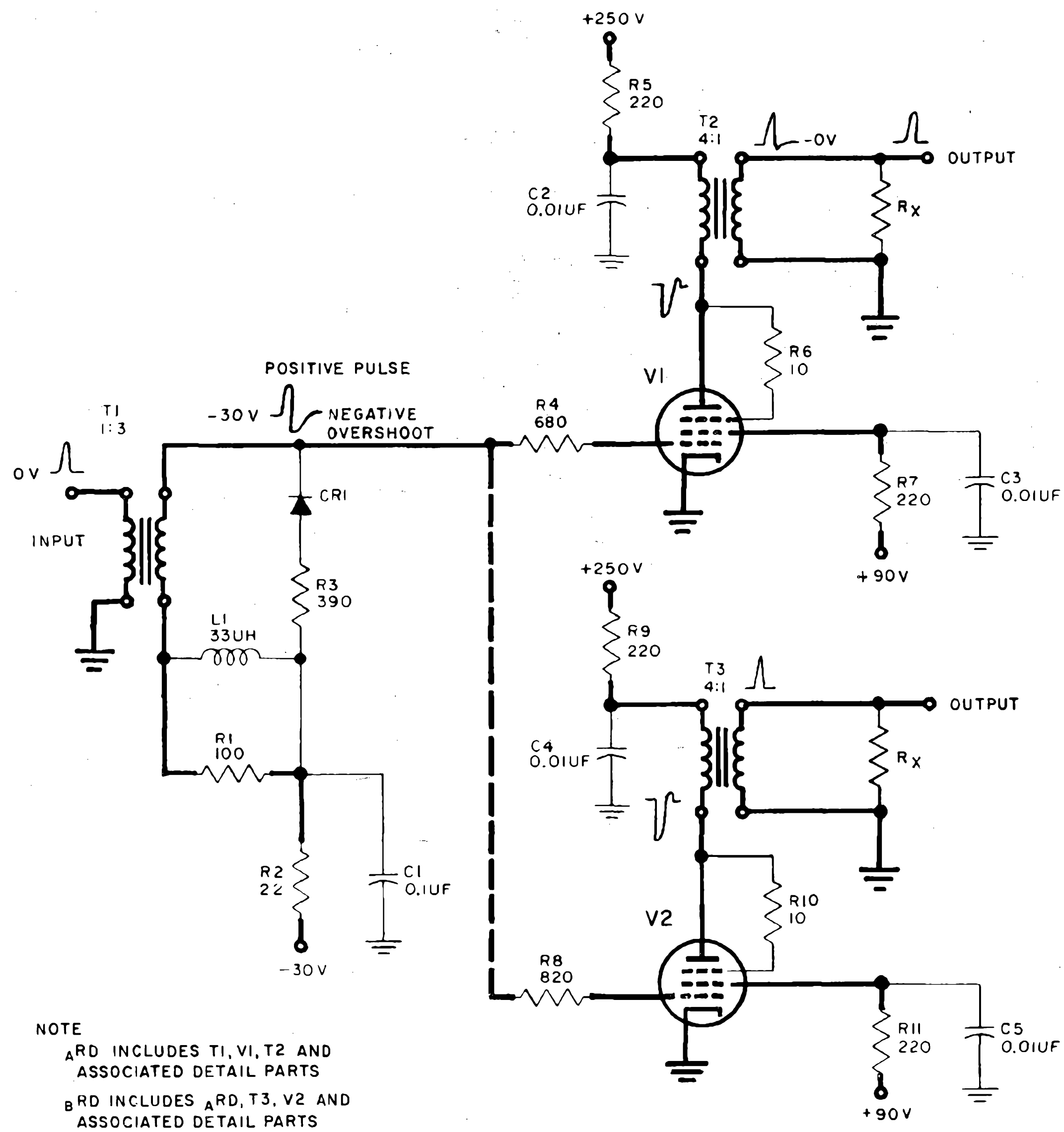


Figure 3–15. Register Driver, Models A and B, Schematic Diagram

TABLE 3–10. REGISTER DRIVERS, MODELS A AND B, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	USED ON MODEL	FUNCTION
C1	AB	Forms decoupling network for V1 and V2 grid bias return (with R2).
C2	AB	Forms decoupling network for V1 plate return (with R5).
C3	AB	Forms decoupling network for V1 screen grid return (with R7).
C4	AB	
C5	AB	Forms decoupling network for V2 screen grid return (with R11).
CR1	AB	Damps negative overshoot.
L1	AB	Forms a matching network for terminating coaxial line input (with R1).
R1	AB	Forms a matching network for terminating coaxial line input (with L1).

TABLE 3—10. REGISTER DRIVERS, MODELS A AND B, FUNCTION OF DETAIL PARTS (Cont'd)

REFERENCE SYMBOL	USED ON MODEL	FUNCTION
R2	AB	Forms decoupling network for V1 and V2 grid bias return (with C1).
R3	AB	Speeds up recovery of CR1.
R4	AB	Grid current limiting resistor.
R5	AB	Forms decoupling network for V1 plate return (with C2).
R6	AB	Parasitic suppressor.
R7	AB	Forms decoupling network for V1 screen return (with C3).
R8	B	V2 grid limiting resistor.
R9	B	Forms decoupling network for V2 plate return (with C4).
R10	B	Parasitic suppressor.
R11	B	Forms decoupling network for screen grid return (with C5).
RX	AB	Load-compensating resistor (variable value).
T1	AB	Input transformer amplifies input pulse in voltage and matches grid circuit to input circuit.
T2	AB	V1 output transformer impedance-matching and pulse-forming.
T3	B	V2 output transformer impedance-matching and pulse-forming.
V1	A	Pentode vacuum tube.
V2	B	Pentode vacuum tube.

maintained at a reduced positive potential during this time, producing a pulse of current in the plate circuit of V1, which is converted into a standard pulse by transformer T2. This output transformer, in addition to pulse-forming, matches the low impedance of the load to the relatively high impedance of the plate of pentode V1. The value of Rx is a variable and depends on the load driven by the output transformer. Its selection enables a large variation in loads to appear relatively the same.

The $_B$RD (fig. 3—15) consists of the basic input circuit of the $_A$RD except for the addition of pentode V2 and associated detail parts in parallel with V1. The output circuit of the $_B$RD is identical with two $_A$RD's enabling the driving of twice the load of an $_A$RD (split).

Although the function of the $_A$RD is comparable with that of the $_B$PA, certain marked differences exist. The $_A$RD has much greater drive capabilities. This is accomplished by increased grid drive. To accommodate this increased drive and to limit noise, the grid bias is increased to —30 volts as compared with the —15-volt bias on the $_B$PA.

Refer to table 3—10 for the function of detail parts not discussed.

CHAPTER 5

THYRATRON RELAY DRIVERS, MODELS A AND B

5.1 DEFINITION AND DESCRIPTION

The thyratron relay drivers (RYD's) identified by the logic block symbols in table 3–11, are nonlogic circuits. They are used to provide the current necessary to energize duo-relays, print and punch magnets, and wire contact relays. The thyratron relay drivers are essentially current switches which are triggered (made to pass current) by a positive shift in standard level from —30 volts to +10 volts.

There are two models of the thyratron relay driver, A and B. Model A performs its function when one positive level shift is applied to its input. Model B performs its function with the application of a positive level shift, after a second input is conditioned with a positive level. Thus, when the logic requires that a specific relay be energized on every occurrence of a positive level shift, the $_{A}$RYD circuit is used between the source of the standard level shift and the specific relay. When the logic requires that a specific relay or magnet be energized each time a positive level shift occurs some time after a conditioning level, the $_{B}$RYD circuit is used. In this application, the $_{B}$RYD includes the function of a gate circuit (Ch. 9). These examples of one application for each circuit point out the specific difference between the two models: the $_{A}$RYD is controlled by one input; the $_{B}$RYD is controlled by two inputs.

In addition, each model on the thyratron relay driver occurs as one of two types: cathode-loaded ($_{A}$RYD, circuit 1, and $_{B}$RYD, circuit 1) and plate-loaded ($_{A}$RYD, circuit 2, and $_{B}$RYD, circuit 2). This designation, according to type, specifies the location of the relay or magnet in the thyratron circuit.

Table 3–11 lists the models of the thyratron relay drivers, giving their names, logic block symbols, and functional description.

5.2 PRINCIPLES OF OPERATION

5.2.1 Basic Principles and Definitions

This paragraph presents a review of thyratron characteristics and defines the terms used to describe these characteristics, as an aid toward understanding the detailed circuit operation. Two basic considerations are involved in the operation of a thyratron circuit: the start of current and the extinction of current through the thyratron. For this reason, the RYD circuits are functionally divisible into the basic thyratron circuit and circuit refinements. The basic thyratron circuit consists of the thyratron and those detail parts that control the operation of the thyratron. The circuit refinements include those detail parts that serve a protective, isolating, and reliability function. The $_{A}$RYD and $_{B}$RYD schematic diagrams (figs. 3–16 and 3–17) indicate this distinction between the basic circuit and its refinements by the difference in line weight. The heavy lines are reserved for basic circuit elements. Table 3–12 is the associated list of detail parts and their functions for figures 3–16 and 3–17.

The thyratron used in the $_{A}$RYD and $_{B}$RYD is a gas-filled (Xenon) tetrode, containing a plate, cathode, control grid, and shield grid. The shield grid serves the function of a second control or input grid. The

TABLE 3–11. THYRATRON RELAY DRIVERS, LOGIC BLOCK SYMBOL AND FUNCTIONAL DESCRIPTION

NAME	LOGIC BLOCK SYMBOL	FUNCTIONAL DESCRIPTION
Thyratron relay driver, model A	$_{A}$RYD	A current switch which permits passage of current through a relay or magnet coil when triggered by a positive level shift from —30 volts to +10 volts.
Thyratron relay driver, model B	$_{B}$RYD	A current switch which permits passage of current through a relay or magnet each time a level shift from —30 volts to +10 volts is applied to one input, while the other input is conditioned with a +10-volt level.

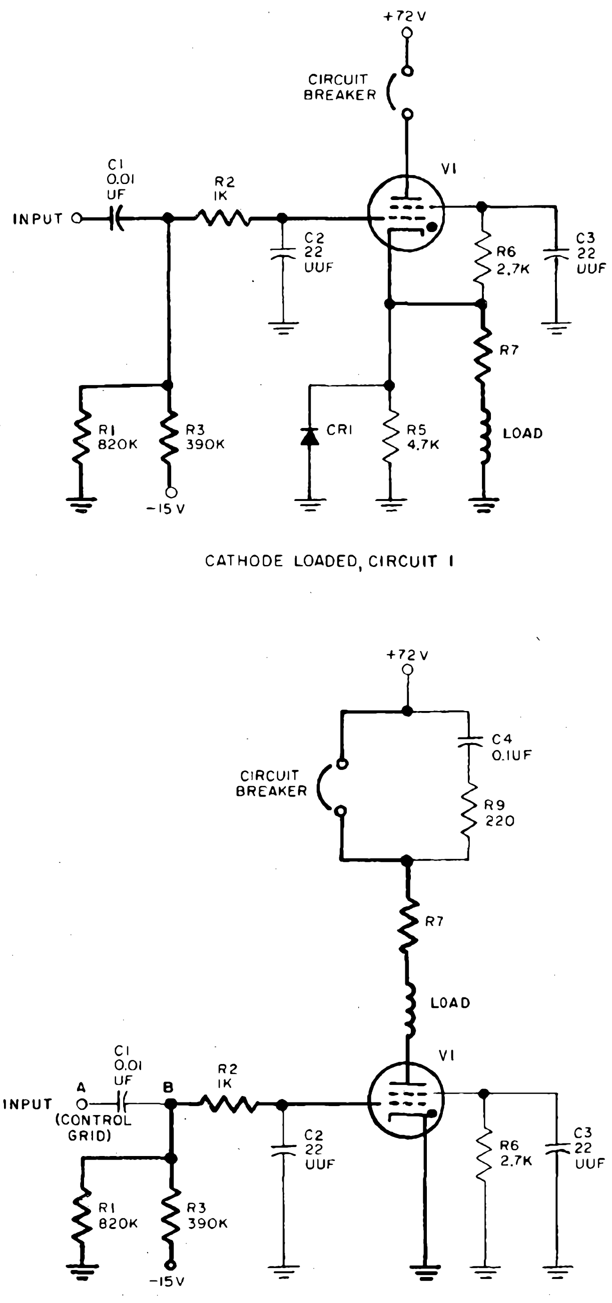


Figure 3-16. Thyratron Relay Driver, Model A, Schematic Diagram

other three elements are similar in function to their counterparts in a vacuum tube, except that the control grid loses control of plate current through the thyratron once conduction is started.

The two states of operation of the thyratron conducting and nonconducting are termed ionized and deionized, respectively. Ionization occurs when the potential between the anode and the cathode in a gas-filled thyratron is large enough to cause electrons to leave the cathode with sufficient energy to convert a gas molecule into an ion on impact. Such a potential between anode and cathode is termed the ionizing potential. Ionization occurs in a thyratron whenever the anode voltage is equal to, or greater than, the ionizing potential, and the control grid voltage is equal to, or greater than, a specified value termed the critical grid voltage. Once the thyratron is ionized, positive ions form a sheath around the control grid and cause this grid to lose control of current through the thyratron. The magnitude of the current, then depends on the load in the anode or cathode circuit of the thyratron. The thyratron may be deionized (made nonconducting) only by reducing the ionizing potential below a value termed the extinction voltage.

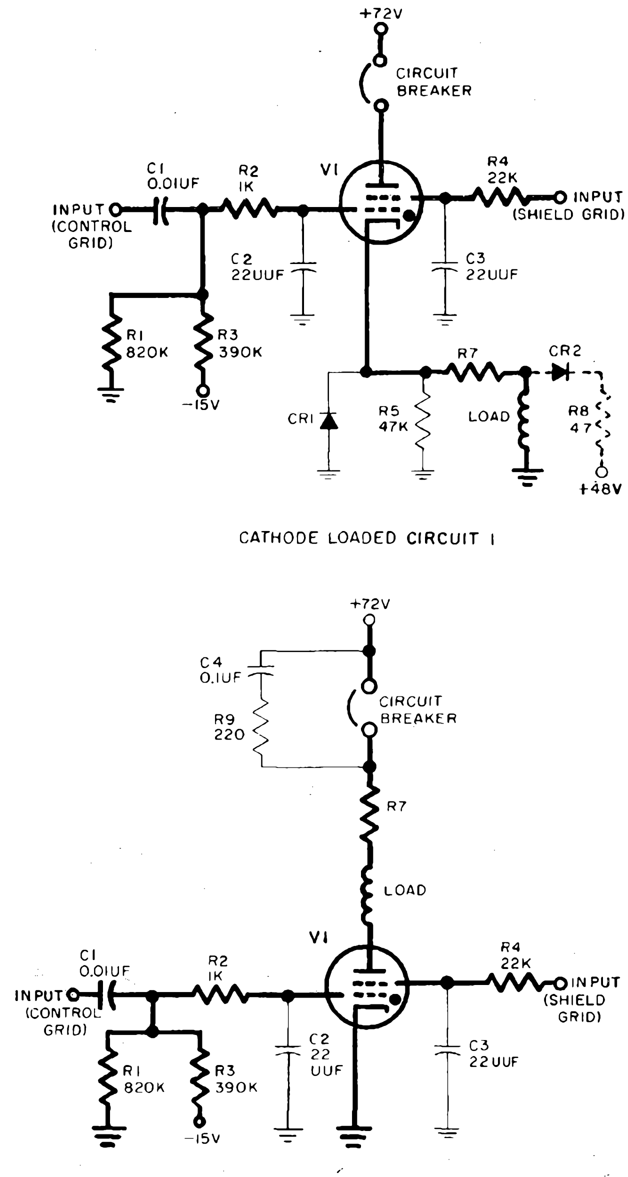


Figure 3-17. Thyratron Relay Driver, Model B, Schematic Diagram

TABLE 3–12. THYRATRON RELAY DRIVERS, MODELS A AND B, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	USED ON	FUNCTION
C1	A, B	Input coupling capacitor.
C2	A, B	Neutralizes control grid-plate interelectrode capacitance.
C3	A, B	Neutralizes shield grid-plate interelectrode capacitance.
C4	A, B	Arc-suppressor network in plate-loaded circuit (with R9).
CR1	A, B	Clamps cathode at ground in cathode-loaded circuits during negative excursion.
CR2	B	Limits positive rise of cathode in cathode-loaded circuits.
R1	A, B	Control grid, voltage divider (with R3).
R2	A, B	Limits control grid current.
R3	A, B	Control grid, voltage divider (with R1).
R4	B	Limits shield grid current.
R5	A, B	Reduces cathode circuit impedance to ensure ionization in cathode-loaded circuit.
R6	A	Limits shield grid current.
R7	A, B	Limits current through relay or magnet coil.
R8	B	Limits current through CR2.
R9	A, B	Arc-suppressor network in plate-loaded circuit (with C4).
V1	A, B	Current switch.
Circuit Breaker	A, B	Opens plate circuit to deionize VI.

In its application in the $_A$RYD and $_B$RYD circuits, the thyratron is ionized by an appropriate rise in control grid voltage (well above critical grid voltage) and deionized by opening a circuit breaker (manually or automatically) in the anode circuit, reducing anode to cathode voltage well below extinction voltage.

5.2.2 Detailed Operation, Model A

Figures 3–16 contains the two circuits of the $_A$RYD. Consider circuit 2, and assume that the circuit breaker is closed and that the input is at the —30-volt standard level. The anode-to-cathode voltage is well above the ionizing potential, and the control grid is biased at —10 volts by the voltage divider consisting of resistors R1 and R3 between —15 volts and ground. This voltage is below the critical grid voltage for the given ionizing potential. A standard level rise of 40 volts from —30 volts to +10 volts at the input, point A, raises the control grid above the critical grid voltage.

Capacitor C1 will start to discharge through resistor R3, bringing point B down towards the bias voltage. The time constant of C1 and R3 is large (approximately 400 milliseconds) in comparison with the time it takes the tube to ionize (approximately 0.5 microsecond). Therefore, the thyratron will ionize before the grid voltage can fall appreciably. As soon as the thyratron ionizes, grid current brings point B rapidly down to cathode potential (ground level). A shift in standard level to —30 volts at point A will be coupled to point B by C1, lowering point B from ground to —40 volts. Since V1 is ionized, however, this fall in voltage at the control grid will not affect current through the tube, and C1 will discharge, raising point B to —10 volts.

Current through V1 passes through the relay or magnet coil in the plate circuit, energizing the relay or magnet. The circuit breaker then opens. With less than extinction voltage across the tube, V1 will deionize. The time required to deionize V1 is approximately 150 microseconds. Whether the circuit breaker is manually operated or automatically operated, the time between the opening and the closing of the circuit breaker will always be greater than the time required for deionization. Thus, when the anode voltage is reapplied to the anode, the control grid, now at less than critical grid voltage, resumes control of the V1, and the circuit is ready for the next positive rise in standard level at point A.

Circuit 1 in figure 3–16 operates in the same manner. The location of the load in the cathode circuit requires special circuitry that is protective and ensures reliable performance. These are discussed in 5.3.

5.2.3 Detailed Operation, Model B

Both circuits of the $_{B}$RYD operate in the same manner. However, in comparing figures 3–16 and 3–17, it will be noted that the shield grids in figure 3–16 are at ground potential and that the shield grids in figure 3–17 are input terminals at standard level potential. In the $_{B}$RYD, prior to ionization, both grids are at the —30-volt standard level. It is a property of the thyratron that a positive voltage rise on the control grid cannot initiate ionization if the shield grid is maintained at a negative level with respect to the cathode. A positive level must be impressed on the shield grid before a positive shift in level on the control grid will ionize V1. This circuit performs its function, then, whenever a positive rise in level is applied to the input after a positive level shift has conditioned the shield grid. Once ionization takes place, a change in voltage at either input grid has no effect on current through V1.

5.3 CIRCUIT REFINEMENTS

The circuit refinements which ensure reliable performance are dictated in part by the location of the load-coil and in part by interelectrode capacity in V1. With the load in the cathode circuit (circuit 1, figs. 3–16 and 3–17), the coil presents a high impedance to (opposes) current. Resistor R5, connected across the coil and R7, decreases the impedance of the cathode circuit to a point where sufficient current will flow to ensure ionization with each occurrence of positive rise in level at the control grid. If R5 were removed, the cathode voltage would initially rise, reducing the anode-to-cathode potential to less than the ionizing potential. Unless the input level remained at the +10-volt level longer than it takes for the cathode potential to fall and restore the ionizing potential, the thyratron could not ionize, and the $_{A}$RYD would not perform its function. Thus R5 ensures ionization by lowering cathode impedance.

Diode CR1 maintains the cathode at ground level in the presence of negative signals. If the cathode were to fall below ground level when the tube is in its quiescent state, the control grid bias would be raised above critical grid voltage, and the thyratron would ionize. A —10-volt pulse, for example, would reduce control grid bias to 0 and fire the thyratron. The negative pulses, generated by collapsing fields in relay and magnet coils, can be coupled into nonenergized circuits through interconnecting cables. Diode CR1 prevents the adverse effects of these pulses when they occur. In addition, the coils in the circuits proper induce these negative pulse voltages each time current through the coil is stopped. Such pulses can carry the cathode below ground sufficiently to maintain ionization between grid and cathode until the circuit breaker recloses. In such a case, the thyratron would not deionize. Diode CR1 also prevents this.

In figure 3–17, whenever circuit 1 is used to drive a print or punch magnet, an additional network (shown in dashed line) is used to eliminate positive transient pulses which would raise the cathode above 48 volts. Such a rise would prevent the ionization of the gas in the thyratron for reasons already stated.

Capacitors C2 and C1 also ensure reliable performance. Each time the circuit breaker closes, the surge voltage appearing at the thyratron anode is coupled to the grids of the thyratron by the inherent capacitance between the tube elements. Capacitors C2 and C3 (relatively much larger than these inherent capacities) drain off the charge on the grids as fast as it tends to accumulate and thus prevent the grid or grids from rising above critical grid voltage. Thus C2 and C3 prevent a misfiring of the thyratron due to the effects of interelectrode capacitance each time the circuit breaker closes.

Resistors R6 and R9 and capacitor C4 are protective circuit elements. Resistor R6 limits shield grid current and protects the shield grid from being burned out. If it were removed, the life of the thyratron would be greatly shortened by the destruction of the shield grid. Parts C4 and R9 form an arc-suppressing network. They prevent the occurrence of an arc at the circuit breaker terminals each time the circuit breaker is opened. This protective circuit is used only in the plate-loaded thyratron relay driver. The same property of the coil to generate self-induced voltages with each initiation and interruption of current, which made the use of R5, CR1, CR2, and R8 necessary in the cathode-loaded circuit, makes the arc-suppressor network necessary in the plate-loaded circuit.

Resistor R7 is a protective part which limits the magnitude of current through the coil and thyratron.

Refer to table 3–12 for the function of detail parts not discussed.

CHAPTER 6

VACUUM-TUBE RELAY DRIVER, MODEL B

6.1 DEFINITION AND DESCRIPTION

The logic block symbol for the model B vacuum-tube relay driver ($_{B}$VRD) circuit is shown in figure 3–18. This is a nonlogic circuit and is used to energize a sensitive relay each time a positive standard level (+10 volts) is applied to its input terminal (left input). The input and output levels shown on the right side of the logic block symbol indicate inputs and outputs of the relay which is a part of the $_{B}$VRD. Figure 3–18 shows the relation of these levels and the state of the relay being driven. An input level is applied to the movable arm or armature of the relay. The state of the relay (energized or de-energized) will determine at which output this level will appear. Thus, although two outputs are shown in the logic block symbol, they occur one at a time. The function of the $_{B}$VRD can now be stated more completely as follows: the $_{B}$VRD is a nonlogic circuit which applies a nonstandard level to one of two outputs. A standard down level produces a nonstandard level at output 1; a standard up level produces a nonstandard level at output 2.

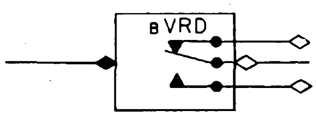


Figure 3–18. Vacuum-Tube Relay Driver, Model B, Logic Block Symbol

6.2 PRINCIPLES OF OPERATION

Figure 3–19 is a schematic diagram of the $_{B}$VRD. Table 3–13 is the associated list of detail parts and their functions. The circuit consists of a triode, a relay, and the circuit elements required to provide decoupling and plate current limiting and to satisfy input requirements.

Triode V1 has two states of operation in this circuit, conducting and nonconducting. When the standard level input to the gird is +10 volts, V1 conducts. When the standard level input to the control grid is −30 volts, V1 is cut off. Assume the input level is at −30 volts, with capacitor C1 charged negatively to this voltage. In this state, a level is being applied to channel 1 through relay K1. A shift of input level from −30 volts to +10 volts does not immediately appear at the grid

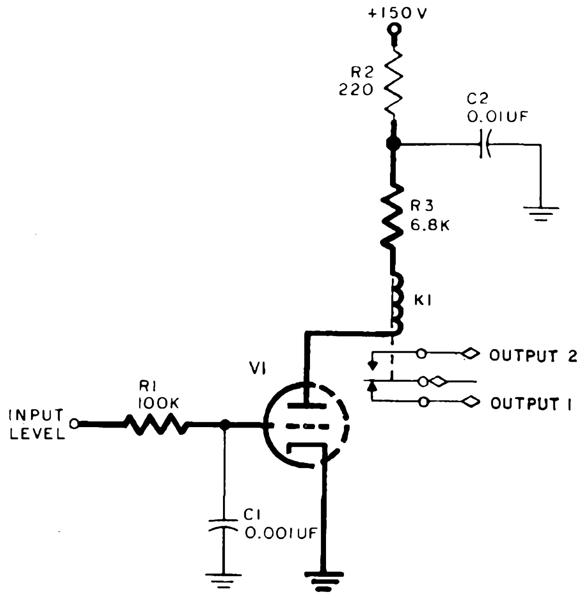


Figure 3–19. Vacuum-Tube Relay Driver, Model B, Schematic Diagram

TABLE 3–13. VACUUM-TUBE RELAY DRIVER, MODEL B, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Slows down rise and fall times of input to prevent chatter in relay K1 (with R1).
C2	Decoupling network (with R2).
K1	Plate load for V1 and used to switch a non-standard level into one of two channels.
R1	Grid-limiting resistor; slows down input rise and fall times preventing chatter in relay K1 (with C1).
R2	Decoupling network (with C2).
R3	Plate load (with K1) and limits plate current through K1.
V1	Controls current through sensitive relay K1.

of V1. The negative charge on C1 maintains the grid at —30 volts. The value of R1 is chosen to translate the rapid shift at the input (0.5 usec) into a slower and more gradual rise of voltage (100 usec) at the grid. Capacitor C1 discharges toward the +10-volt input level through R1. Plate current starts when the point of grid cutoff voltage is passed and increases as the grid voltage continues to rise. Grid current flows when the grid becomes more positive than the cathode. The grid-limiting action of R1 maintains the grid at ground level (cathode potential), and V1 assumes its alternate state of conduction. In this state, plate current energizes relay K1, and a level is switched to channel 2. Note that, with the grid at ground level, C1 is completely discharged. A rapid shift of voltage at the input to the —30-volt standard level again appears as a gradual change at the grid as a result of the slow charging time of C1 through R1. The gradual fall in grid voltage causes a decrease in plate current until cutoff voltage is reached. At this point, the tube becomes nonconducting, and the relay reverts to its former state. Capacitor C1 continues to charge through R1 to the —30-volt level.

Refer to table 3—13 for the function detail parts not discussed.

CHAPTER 7

DIODE AND CIRCUITS

7.1 DEFINITION AND DESCRIPTION

Figure 3—20 is a logic block symbol of a diode AND circuit.

A diode AND circuit is a logic circuit which develops a positive level output, provided all inputs are positive levels. If any input is a negative level, the AND circuit may have several inputs.

The crystal diode is an essential part of the diode AND circuit. It is therefore important to become acquainted with the mechanical and electrical characteristics of the crystal diode to better understand the theory of operation of the diode AND circuit.

The crystal diode is 0.75 inch in length and 0.25 inch in diameter. It has two pigtails, one attached to the anode and one to the cathode. To guard against the harmful effects of humidity, it is hermetically sealed. (See figs. 3—21 and 3—22.)

The crystal diode has a unidirectional electrical characteristic utilized in the AND circuit. When the anode of a diode is positive with respect to its cathode, the diode will conduct. When the anode of a diode is negative with respect to its cathode, the diode will not conduct.

When a diode is conducting, its forward resistance is 50 ohms (see fig. 3—23).

When a diode is cut off, its backward resistance is approximately 500,000 ohms (see fig. 3—24).

This property of high resistance for one polarity and low resistance for the opposite polarity is employed in AND circuitry.

7.2 PRINCIPLES OF OPERATION

7.2.1 Basic Operation

Figure 3—25 is a simplified schematic diagram of a diode AND circuit. With —30 volts applied to the cathode of CR1, the diode conducts. Because of the low forward resistance of a crystal diode, the voltage drop in the circuit will occur across resistor R_{AND}. The voltage at point C is then —30 volts. With +10 volts applied to the cathode of CR2 and —30 volts on its anode, CR2 is cut off. Point C remains at —30 volts. The high backward resistance of crystal diode CR2 isolates one input circuit (point B) from the output circuit (point C). If both crystal diodes CR1 and CR2 have +10 volts applied to their cathodes, both will conduct, and the potential at point C will be +10 volts.

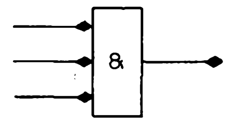


Figure 3—20. Diode AND Circuit, Logic Block Symbol

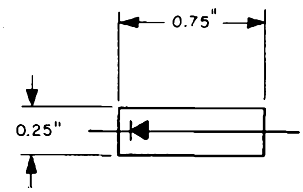


Figure 3—21. Crystal Diode, Physical Dimensions

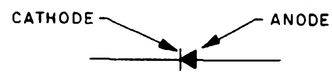


Figure 3—22. Crystal Diode, Electrical Symbol

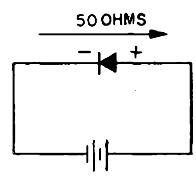


Figure 3—23. Forward Resistance of Crystal Diode, Schematic Diagram

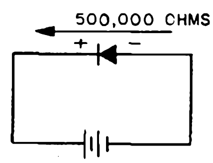


Figure 3—24. Backward Resistance of Crystal Diode, Schematic Diagram

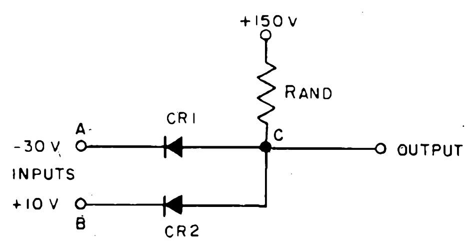


Figure 3—25. Two-way AND Circuit, Simplified Circuit Diagram

It can be seen that, to make point C positive, inputs A and B must be positive and that, to make point C negative, either one or both of the inputs must be negative. Figure 3–26 is a schematic diagram of a diode AND circuit.

Crystal diode CR3 is a protective feature of the circuit. It clamps point C at +10 volts, limiting the positive level at point C to +10 volts. This prevents the grid of a vacuum tube in a following stage from being driven so far positive that destruction of the tube might result.

7.2.2 Detailed Operation

The effect of load capacitance on the circuit may be seen in the output waveshape (Eo in fig. 3–27). The leading (left-hand) edge does not rise vertically. The reason for this is shown in figure 3–27. Capacity C represents the capacitance of the output circuit load and stray wiring capacitance. If both inputs are at —30 volts, electrons will flow through the low forward resistance of the diodes to the positive power supply. The outputs will be —30 volts. If both inputs are raised to +10 volts, the diodes will stop conducting, since C will hold the anodes at —30 volts until C can charge through R_{AND} toward +150 volts; C charges to +10 volts. The time constant of RC will determine the rate at which the voltage waveform (Eo) will rise. When one of the inputs returns to —30 volts, C will discharge through the low forward resistance of the diode. Since the forward resistance is low (about 50 ohms), the fall time will be negligible. The comparatively long rise time limits the applications of the diode AND circuit.

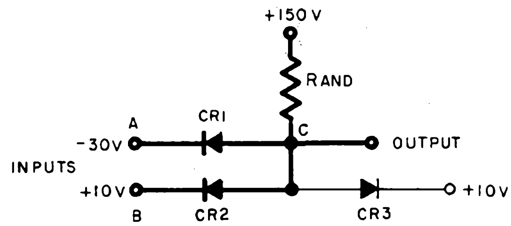


Figure 3–26. Two-Way AND Circuit, Schematic Diagram

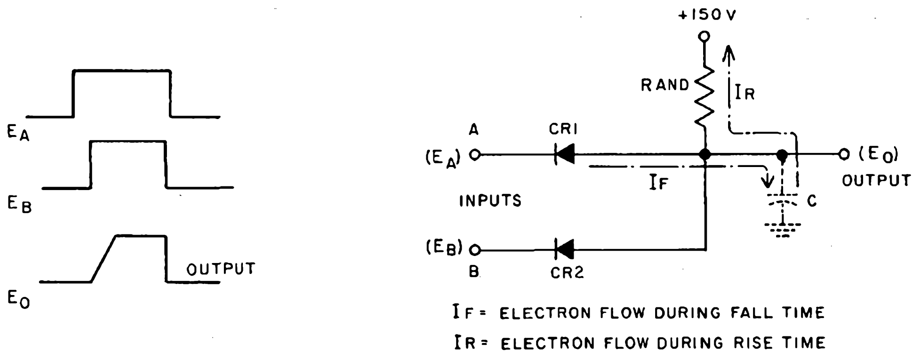
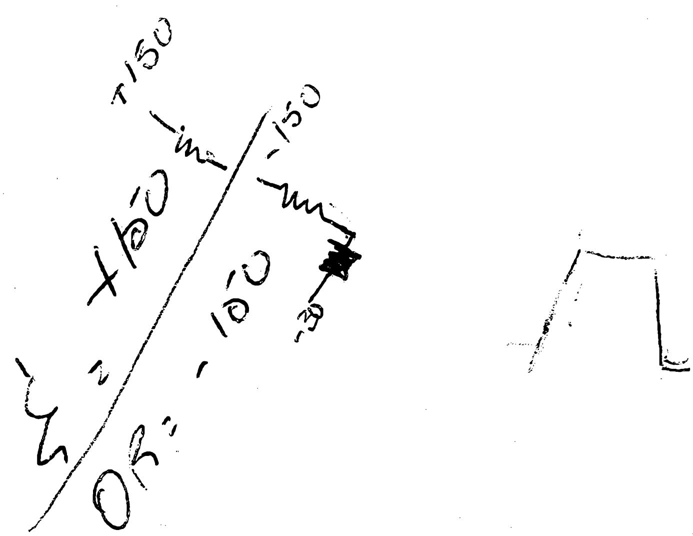


Figure 3–27. AND Circuit, Effect of Load Capacitance, Schematic Diagram and Waveforms



CHAPTER 8
DIODE OR CIRCUITS

8.1 DEFINITION AND DESCRIPTION

Figure 3—28 is a logic block symbol of a diode OR circuit.

A diode OR circuit is a logic circuit which develops a negative level output, provided that all inputs are negative levels. If any input is a positive level, the OR circuit develops a positive level output. This type of circuit may have several inputs. For information concerning the crystal diode, an essential part of the diode OR circuit, see 7.1.

8.2 PRINCIPLES OF OPERATION

8.2.1 Detailed Operation of Diode OR Circuit

Figure 3—29 is a schematic diagram of a diode OR circuit. With +10 volts applied to the anode of CR_1, the diode conducts. Because of the low forward resistance of the crystal diode, the voltage drop in the circuit will be across resistor R_{OR}. The voltage at point C is then +10 volts. With +10 volts applied to the cathode of CR^2 and —30 volts on its anode, CR_2 is cut off. Point C remains at +10 volts. The high backward resistance of crystal CR^2 isolates one input circuit (point B) from the output circuit (point C).

If both crystal diodes CR^1 and CR^2 have —30 volts applied to their anodes, both will conduct, and the potentional at point C will be —30 volts. It can be seen that, to make point C negative, A and B must be negative and, to make point C positive, either one or both of the inputs (A and B) must be positive. Crystal diode CR_3 is a —30-volt clamp.

If all the OR circuit inputs are fed from AND circuits, there is nothing to prevent the output from going extremely negative should the +150-volt supply fail. A protection diode, clamping the circuit to —30 volts, is connected to the outputs of all OR circuits of this category.

The effect of load capacitance on the circuit may be seen in the output waveshapes of figure 3—30. The effect is the same as in the AND circuit, except that the trailing (right-hand) edge is affected. For a discussion of this, see 7.2.2.

8.2.2 Detailed Operation of Pulsed OR Circuit

The fast rise time of the OR circuit permits a pulse input. This is not possible with the AND circuit because

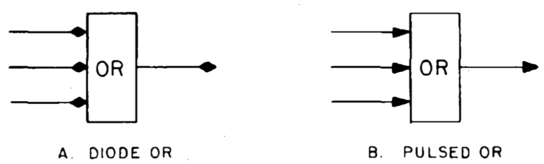


Figure 3—28. Diode OR Circuit, Logic Block Symbols

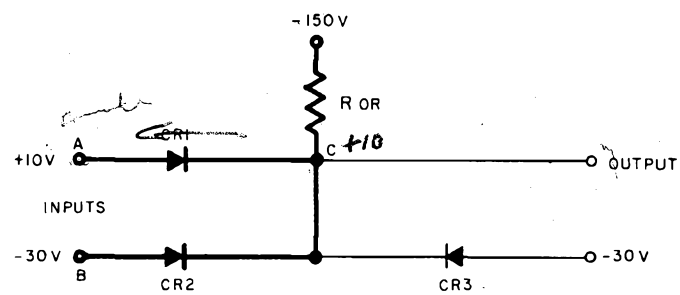


Figure 3—29. Two-Way OR Circuit, Schematic Diagram

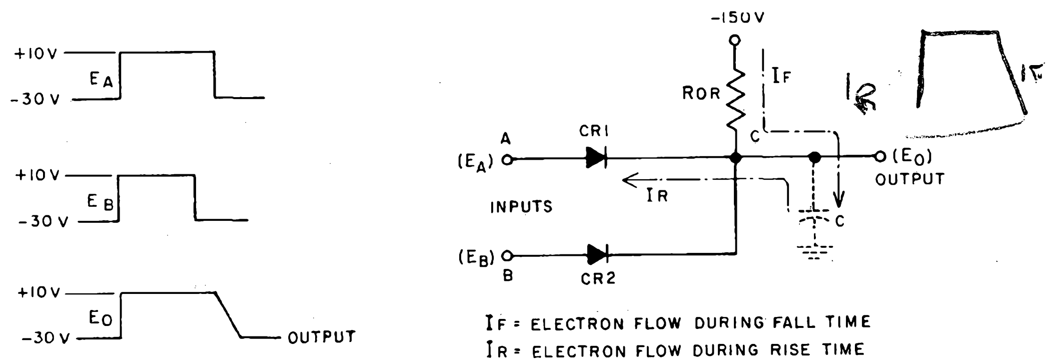


Figure 3—30. Effect of Load Capacitance in OR Circuit

load capacitance gives the circuit a slow rise time. Figure 3–31 shows a pulsed OR circuit. In order for this circuit to function with pulse inputs, the fall time must be speeded up. This is accomplished by replacing resistor R_{OR} with an inductor, L. Resistor R_L is used to prevent oscillation between L and C (stray capacitance). Resistor R_L is of low ohmic value.

It can be seen that any positive pulse applied to either input will appear at the output. The cathodes of the diodes are grounded through inductor L and resistor R_L. When a positive pulse appears at the input, the diode involved will conduct, and the pulse will appear at the output.

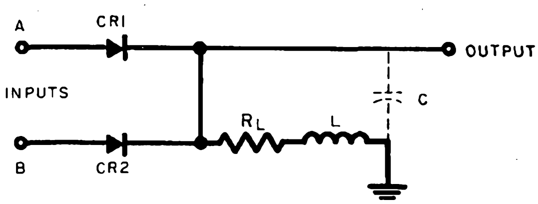


Figure 3–31. Pulsed OR Circuit, Schematic Diagram

8.2.3 Operation of $_Y$OR Operation

When the output from a pulsed OR is applied to a pulse transformer, the $_Y$OR circuit shown in figure 3–32 is employed.

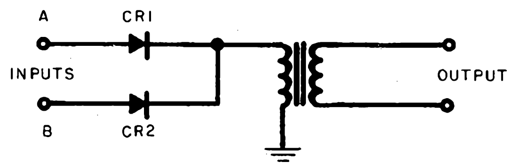


Figure 3–32. $_Y$OR Circuit, Schematic Diagram

CHAPTER 9
GATE TUBE, MODEL A

9.1 DEFINITION AND DESCRIPTION

The model A gate ($_A$GT) is a logic coincidence circuit. Figure 3–33 is the logic block symbol. A standard pulse applied to the input of the $_A$GT will appear at the output only when the $_A$GT is conditioned by a positive standard level.

9.2 PRINCIPLES OF OPERATION

9.2.1 Basic Operation

Figure 3–34 is a schematic diagram of the $_A$GT. Table 3–14 is the associated list of detail parts and their functions. The $_A$GT consists of a pentode vacuum tube, an output transformer, and associated circuitry. A standard pulse input is applied to the control grid of pentode V1, and a standard level is applied to its suppressor grid. Pentode V1 is biased past cutoff by a fixed −15 volts applied to the control grid.

The $_A$GT has two states: conditioned and nonconditioned (see fig. 3–35). In the nonconditioned state, a −30-volt level is applied to the suppressor grid (input B). In this state, although a standard pulse is applied to input A, overcoming the −15-volt bias, no current will flow through V1 because the −30-volt level is sufficient to hold this pentode at cutoff.

The $_A$GT is conditioned by the application of a +10-volt level of the suppressor grid of V1. In this state, the application of a standard pulse at input A overcomes the −15-volt grid bias, and the pentode conducts, producing a standard pulse at the output.

9.2.2 Detailed Operation

The standard pulse source is coupled to the control grid through capacitor C1 (see fig. 3–34). This capacitor blocks the −15-volt bias from the pulse source. For direct pulse inputs, inductor L1 presents a high impedance to the high-frequency pulse and a low impedance to the d-c discharge path of C1. This provides the proper loading to the input pulse while preventing bias buildup on C1. The standard level source is coupled directly to the suppressor grid. When coincidence occurs, the tube conducts. The resulting pulse of current in the plate circuit of V1 is transformer-coupled by T1, producing a standard pulse at the output. Transformer T1 also matches the high impedance of the plate to the low impedance of the load.

Decoupling networks are provided where the $_A$GT is connected to common power supplies. These networks isolate the gate from other circuits powered from the same supplies. Resistors R5 and R6 are parasitic suppressors.

Capacitor C2 is used when the $_A$GT is fed from a flip-flop. Pentode V1 conducts heavily for a brief pe-

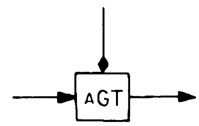
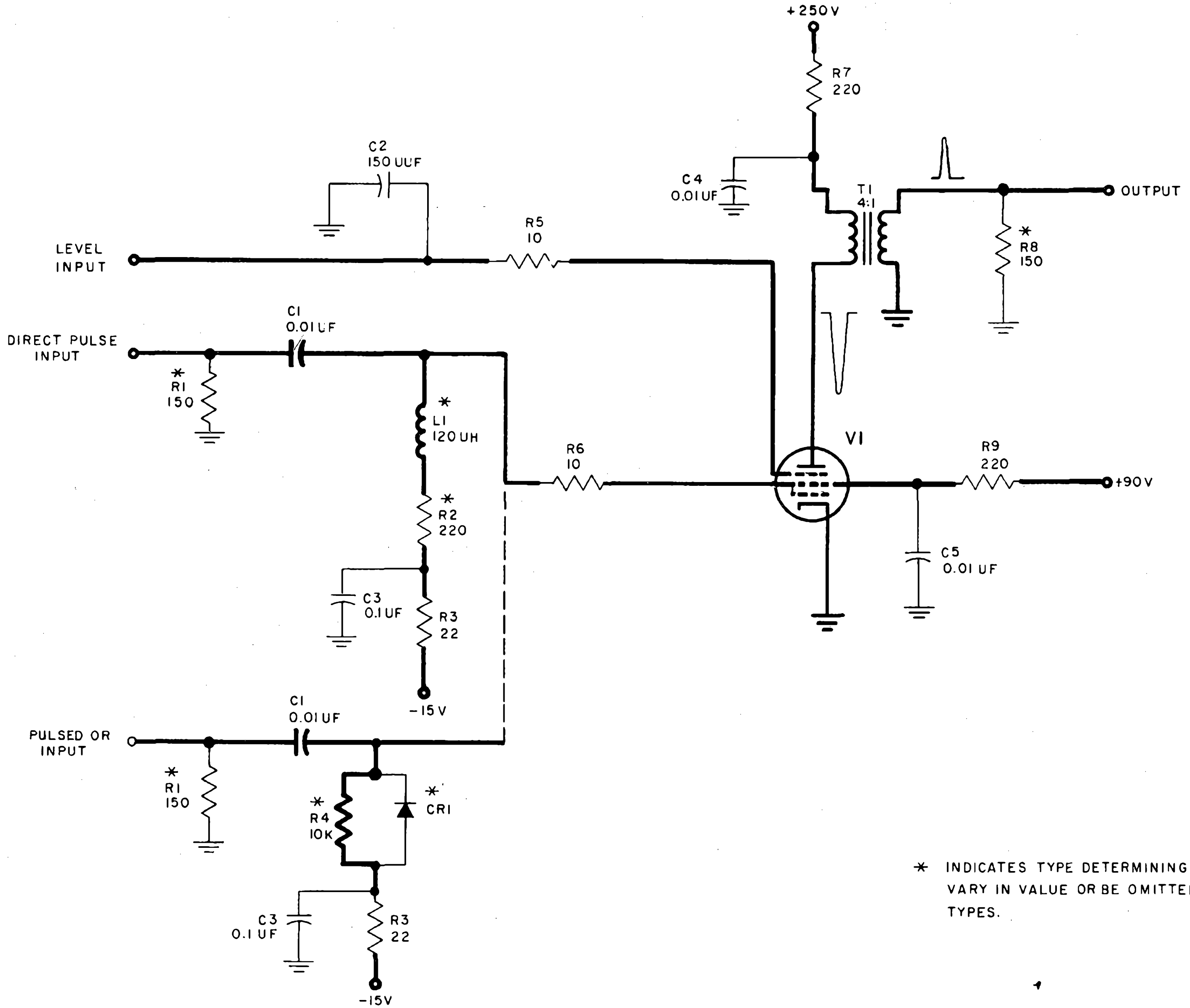


Figure 3–33. Gate Tube, Model A, Logic Block Symbol

TABLE 3–14. GATE TUBE, MODEL A, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Input coupling capacitor.
C2	Suppressor grid bypass capacitor.
C3	Part of decoupling network (with R3).
C4	Part of decoupling network (with R7).
C5	Part of decoupling network (with R9).
CR1	Provides low impedance discharge path for C1, preventing bias buildup.
L1	Peaking coil for input pulse.
R1	Input coaxial cable termination.
R2	Damping resistor for inductor L1.
R3	Part of decoupling network (with C3).
R4	Grid d-c return.
R5	Parasitic suppressor.
R6	Parasitic suppressor.
R7	Part of decoupling network (with C4).
R8	Terminating resistor.
R9	Part of decoupling network (with C5).
T1	Output transformer.
V1	Gate electron tube.



* INDICATES TYPE DETERMINING COMPONENTS. THESE MAY VARY IN VALUE OR BE OMITTED FROM CIRCUIT IN DIFFERENT TYPES.

Figure 3-34. Gate Tube, Model A, Schematic Diagram riod. The suppressor grid draws current during this time. Capacitor C2 smooths out these current surges, establishing a more desirable loading effect on the conditioning flip-flop. Resistor R1 is the terminating resistor for a coaxial cable input; R8 is the terminating resistor for the transformer.

Resistor R4 and diode CR1 are employed in the grid circuit for pulsed OR inputs. Resistor R4 provides a high-resistance load to the pulse, and crystal diode CR1 provides a low-resistance discharge path for capacitor C1. When input A is pulsed, the control grid draws current. A negative charge accumulates on capacitor C1. If this capacitor has not discharged by the time the next pulse arrives, a residual charge will add to the —15-volt bias. Succeeding pulses will then develop a bias buildup which will cause circuit failure. Refer to table 3—14 for the function of detail parts not discussed.

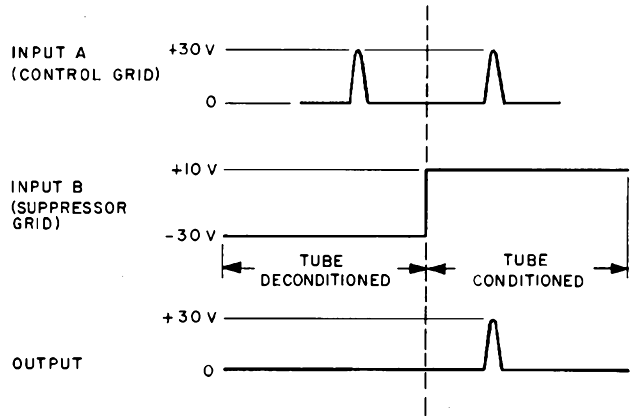


Figure 3—35. Gate Tube, Model A, Input-Output Relationship

CHAPTER 10

D-C INVERTER

10.1 DEFINITION AND DESCRIPTION

The model A d-c inverter ($_{A}$I), shown in logic symbol form in figure 3–36, is a logic circuit. The $_{A}$I

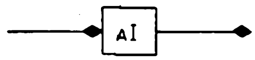


Figure 3–36. D-C Inverter, Model A, Logic Block Symbol

produces a —30-volt level when the input level is positive and a +10-volt level when the input level is negative. The $_{A}$I is the only inverter model and is used when logic requires a level reversal.

10.2 PRINCIPLES OF OPERATION

10.2.1 Basic Operation

Figure 3–37 is a simplified block diagram of the $_{A}$ I. The circuit consists of an overdriven amplifier (driven to grid-limiting or cutoff) and a cathode follower whose output is clamped at levels of +10 and —30 volts.

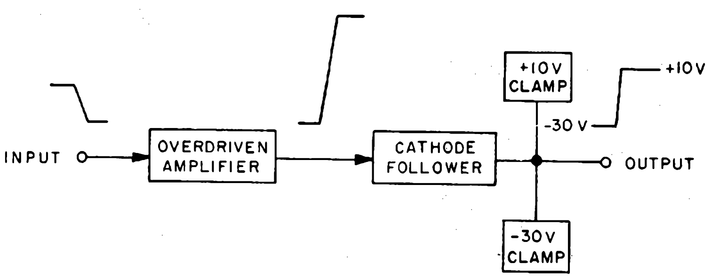


Figure 3–37. D-C Inverter, Simplified Block Diagram

A positive level between 0 and +12 volts applied to the overdriven amplifier input is amplified and inverted and fed to the cathode follower, whose output circuit clamps the inverted level of —30 volts. Similarly, a negative level between —8 and —30 volts applied to the overdriven amplifier is amplified, inverted, and clamped at +10 volts at the cathode follower output.

TABLE 3–15. D-C INVERTER, MODEL A, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Resistor R1 bypass; speeds rise time of input level (and fall time of output level).
C2	Part of decoupling network (with R3).
C3	Resistor R5 bypass; speeds rise and fall time.
C4	Part of decoupling network (with R8).
CR1	Clamps V1B grid at —35 volts.
CR2	Clamps V1B cathode at +10 volts.
CR3	Clamps V1B cathode at —30 volts.
R1	Grid-limiting resistor.
R2	Parasitic suppressor.
R3	Part of decoupling network (with C2).
R4	Plate load resistor for V1A.
R5	Part of voltage divider network (with R6).
R6	Part of voltage divider network (with R5).
R7	Parasitic suppressor.
R8	Part of decoupling network (with C4).
R9	Diode CR2 current-limiting resistor.
R10	Part of cathode load resistor and of voltage divider for CR1 bias (with R11).
R11	Part of cathode load resistor and of voltage divider for CR1 bias (with R10).
V1A	Overdriven amplifier.
V1B	Cathode follower.

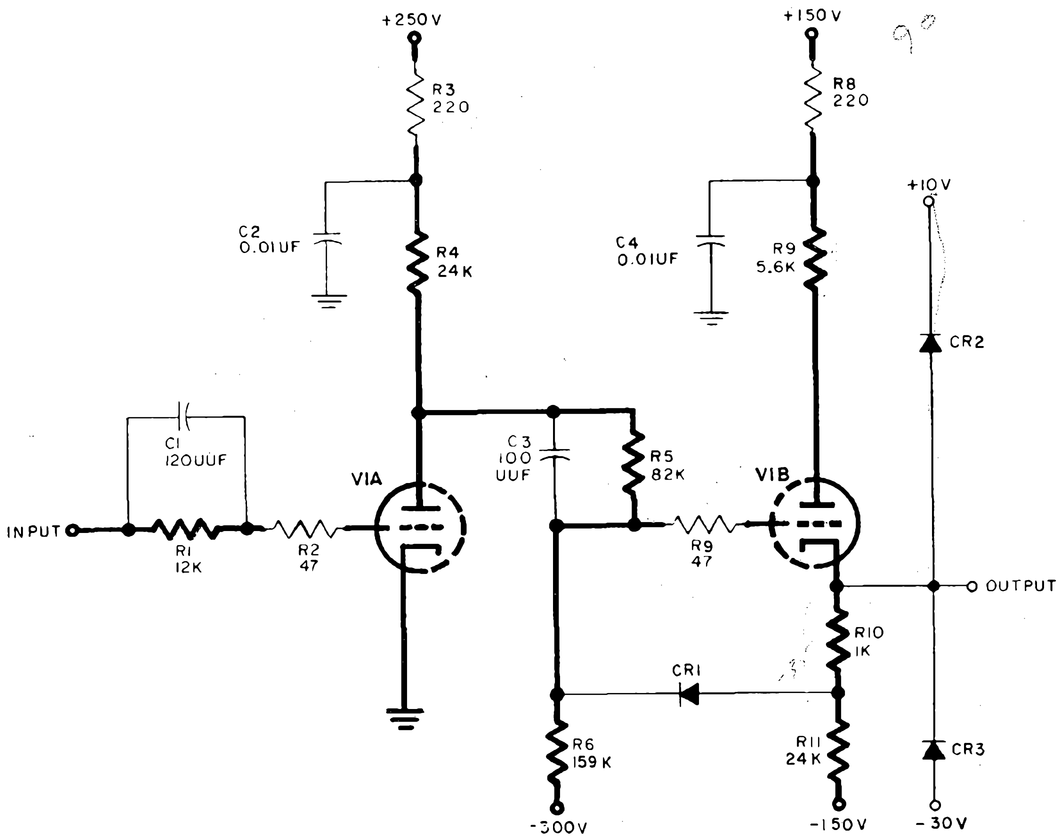


Figure 3–38. D-C Inverter, Model A, Schematic Diagram

10.2.2 Detailed Operation

Figure 3–38 is a circuit schematic of the $_A$I. Table 3–15 is the associated list of detail parts and their functions. When a —8-volt level is applied to V1A, this tube is cut off. With no plate current flow, the plate potential of V1A would rise to +250 volts. However, the voltage divider formed by resistors R4, R5, and R6 holds the plate at +200 volts when V1A is cut off. With a +200-volt potential at the plate of V1A, there is a 500-volt potential across the voltage divider formed by resistors R5 and R6. The voltage drop across R5 would place the grid of V1B at +31 volts. The grid of V1B, however, does not become more positive than +10 volts because diode CR2 clamps the cathode of V1B at +10 volts. A more positive potential at the input of V1B results in grid current flow through R5, keeping the grid from becoming more positive in potential than +10 volts.

A positive potential of +2 volts applied to the grid of V1A results in its plate current's reducing the plate potential to +66 volts. The potential across the voltage divider formed by resistors R5 and R6 is now 366 volts. The voltage drop across R5 would place the grid of cathode follower V1B at —58 volts. The grid, however, never becomes more negative than —35 volts because diode CR3 clamps the cathode of V1B at —30 volts. Cathode resistors R10 and R11 form a voltage divider between potentials of —30 and —150 volts. The anode of CR1 is at —35 volts, preventing the grid from becoming more negative than this potential.

A positive input level becomes a —30-volt output level, and a negative input level becomes a +10-volt output level. Refer to table 3–15 for the function of detail parts not discussed.

CHAPTER 11

FLIP-FLOPS

11.1 DEFINITION AND DESCRIPTION

Because of circuit complexity, the flip-flops and their associated models will be discussed in the manner that follows. The logic block function will be presented, followed by a tabulation of logic symbols and fundamental circuit characteristics of each model. This, in turn, will be followed by discussions of the flip-flop block diagram and basic circuit. The remainder of the text will discuss the significant features of each flip-flop circuit.

The flip-flop are logic circuits capable of storing a binary digit. The model A flip-flop ($_A$FF) produces d-c output levels only when the input is a standard pulse. The $_B$FF and $_C$FF produce standard d-c output levels when the input is either a standard pulse or a negative d-c level shift. Table 3–16 depicts the logic block symbols for the three flip-flop models and indicates generally the speed and drive characteristics of each. As indicated, the $_B$FF and $_C$FF operate with either standard pulses or standard level inputs.

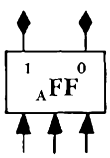
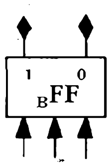
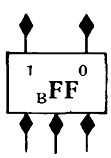
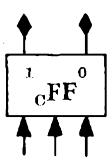
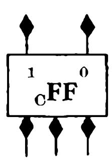
11.2 PRINCIPLES OF OPERATION

11.2.1 Basic Operation

Figure 3–39 is a simplified block diagram of a flip-flop. It consists of two amplifiers, designated A and B. The output of each amplifier feeds the input of the other. Circuits of this type are called multivibrators. The flip-flop itself is a form of multivibrator having two stable states and, for this reason, is called a bistable multivibrator.

By definition, the output of amplifier B (see fig. 3–39) is the set or 1 output of the flip-flop, and the output of amplifier A is the clear or 0 output. When the set output is up (+10-volt level), the clear output is down (—30-volt level), and the flip-flop is in the set state. Conversely, the flip-flop is in the clear state when

TABLE 3–16. FLIP-FLOPS, LOGIC BLOCK SYMBOLS AND CHARACTERISTICS

FLIP-FLOP MODEL	LOGIC BLOCK SYMBOL		CHARACTERISTICS	
	PULSE INPUT	LEVEL INPUT	SPEED	DRIVE
A			High speed	Can drive load directly
B			Low speed	Cannot drive load directly
C			Low speed (lower than BFF)	Can drive load directly

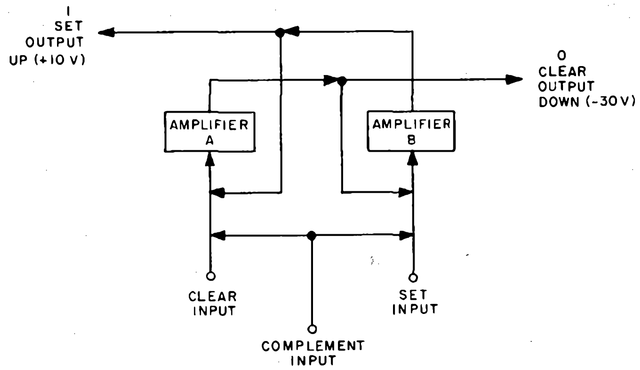


Figure 3—39. Flip-Flop, Block Diagram

the clear output is up and the set output is down. The flip-flop is always in one of these two states.

Applying an appropriate signal to the clear input ensures that the clear output will be up. Likewise, the set output is up when an appropriate signal is applied to the set input. By applying signals to both inputs simultaneously, the state of the flip-flop is changed. This process is known as complementing.

Figure 3—40 is a simplified schematic diagram of a flip-flop. Before circuit operation is discussed, the following should be noted:

a. Resistors R3, R1, and R2 are equal to resistors R4, R5, and R6, respectively.
b. An increase in plate current through plate load resistor R3 lowers the plate potential of V1. Conversely, a decrease in plate current raises the V1 plate potential. The same is true of V2 and associated plate load resistor R4.
c. The voltage divider formed by resistors R4, R1, and R2 between B+ and B— serves several functions. When V1 is conducting and V2 is cut off, the voltage divider provides a proper up level at the set output and, at the same time, keeps the grid of V1 sufficiently positive to ensure full conduction. When V2 is conducting and V1 is cut off, the divider provides sufficient bias to keep V1 cut off and provides a proper down level at the set output. The voltage divider formed by R3, R5, and R6 between B+ and B— serves the same function at the opposite side of the flip-flop.

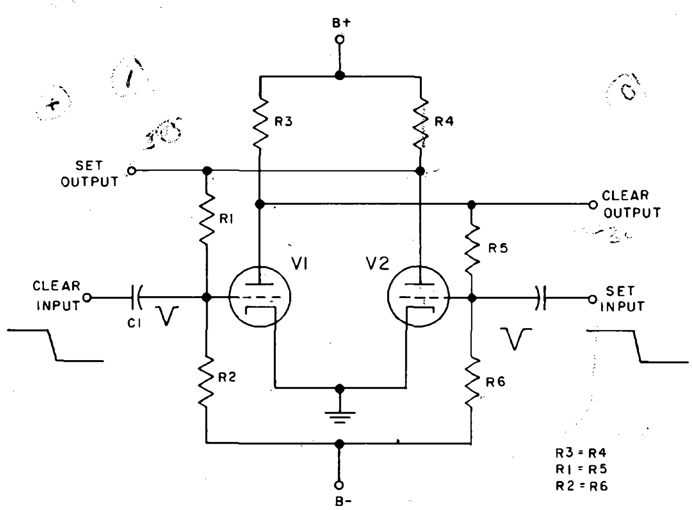


Figure 3—40. Flip-Flop, Simplified Schematic Diagram

With the flip-flop in its set state, V1 is conducting and V2 is cut off. A negative-going level applied to the clear input is changed to a negative pulse (fig. 3—40) by the combination of coupling capacitor C1 and resistor R2. This negative pulse at the grid of V1 decreases the plate current, which, in turn, increases the plate potential of V1. The voltage divider formed by resistors R5 and R6 between the plate of V1 and B— presents a positive rise of voltage at the grid of V2. This increases the plate current through V2 and, in turn, reduces its plate potential. The voltage divider formed by resistors R1 and R2 between the plate of V2 and B— presents a negative fall in voltage at the grid of V1. This further decreases plate current through V1. The resultant rise of voltage at the V1 plate leads to the increase of V2 plate current, causing a further drop in its plate potential. This action is cumulative and continues until V1 is cut off and V2 is conducting fully. Since V1 and V2 amplify the potential changes appearing at their respective grids, regeneration results and the process of changing state is very rapid. The flip-flop is now in a clear state, with an up level at the clear output and a down level at the set output. Figure 3—41 depicts the flip-flop output levels being changed from a set to a clear state.

When a negative-going level is applied to the set input, V2 is cut off and V1 conducts fully, changing the flip-flop to a set state. The action is similar to those in the previous discussions.

The detailed operation of the flip-flop circuits is explained in the following manner. The $_{B}$FF is described first, followed by the $_{C}$FF and $_{A}$FF, in that order. The $_{B}$FF description includes a brief discussion of function and operating characteristics. This is followed by a brief description of circuit operation based on the previous discussion of basic circuit operation. (Because of circuit symmetry, this description deals mainly with components for one-half of the flip-flop.) The components that serve speedup, stabilization, protective, and type-distinguishing functions are explained.

The $_{C}$FF and $_{A}$FF are explained in a manner similar to that for the $_{B}$FF. However, the $_{C}$FF circuit is discussed mainly with reference to change from the $_{B}$FF, and the $_A$FF circuit is discussed with reference to change from the $_B$FF and $_C$FF.

A tabulated list of parts and their circuit function is included in the discussion of each flip-flop model.

11.2.2 Detailed Operation of Low-Speed, Model B Flip-Flop

The low-speed $_B$FF produces standard d-c level outputs for either a standard pulse or negative-going level shift input, depending upon the configuration of the input circuits.

The $_B$FF operates at a maximum pulse repetition frequency of 500 kc (400 kc for complement input).

Figure 3—42 is a schematic diagram of the $_B$FF. Table 3—17 is the associated list of detail parts and their functions. In the set state of the $_B$FF, V1A is conducting, and V1B is cut off. A negative pulse at the grid of V1A reverses this state, and, as a result, V1A is cut off and V1B conducts. (The flip-flop action leading to this result is the same as that discussed in the basic flip-flop circuit.) At this time, the clear output is at +10 volts (up), and the set output is at —30 volts (down). These output voltages are obtained from voltage dividers similar to those in the basic flip-flop circuit.

The set output is maintained at a —30-volt potential by a combination of two voltage dividers. One voltage divider, in the plate circuit of V1B, is formed by resistors R11 and R10 between +90 volts and ground potential. The other divider consists of inductor L2 and resistors R3 and R5. The effect of L2 on the voltage divider is negligible (except during transitions) because of its low d-c resistance. A similar combination of voltage dividers keeps the clear output at +10 volts. When a negative pulse at the grid of V1B changes the state of the $_B$FF, the set output returns to +10 volts, and the clear output returns to —30 volts. These levels are set by the respective voltage dividers when V1A conducts and V1B is cut off.

In order to speed up rises and falls (transitions), capacitor C2 is connected across resistor R3. This capacitor couples the grid of V1A to the plate of V1B (for high frequencies) and, in this way, serves as a speedup device. Capacitor C6 across resistor R13 serves the same function in the grid circuit of V1B. Inductors L1 and L2 are peaking coils and speed up rises and falls (transitions) at the plates of V1A and V1B, respectively. As indicated in figure 3—42, levels are applied directly to the set and clear inputs. Standard pulses are applied through a special network, consisting of input diodes, transformer, and damping diode, to these inputs.

With V1A conducting and V1B cut off, a negative shift applied to the clear input is changed to a peaked negative pulse by the differentiating network composed of capacitor C1 and resistor R1. (This negative pulse is similar to the one depicted in figure 3—40.) Crystal diode CR4 passes this negative pulse to the grid of V1A, causing a reduction in plate current. This diode prevents positive voltages from reaching the grid, thereby isolating this grid from the cathode of V1A and V1B and permitting V1A to be cut off.

A standard pulse is applied to either crystal diode CR1 or CR2 at the clear input. These diodes, together with pulse transformer T1, form a pulsed $_Y$OR circuit similar to that discussed in Chapter 10, except that the secondary connections of T1 are interchanged to invert the positive input. The resultant negative pulse is unaffected by C1 and R1. This pulse is fed to the grid of V1A through diode CR4, causing a reduction in plate current.

Diode CR3 provides a low resistance (forward resistance) to a positive pulse and, in this way, damps the positive overshoot.

Circuits feeding pulses to input diodes CR1 and CR2 at the primary of T1 are isolated from each other by these diodes. An input diode is added to the pulse input circuit for each additional source feeding the $_B$FF.

The $_B$FF is complemented when the set and clear inputs are pulsed simultaneously, producing a change of state each time the complement input is pulsed.

Load current drawn from either output of the $_B$FF would upset the associated divider, causing the output

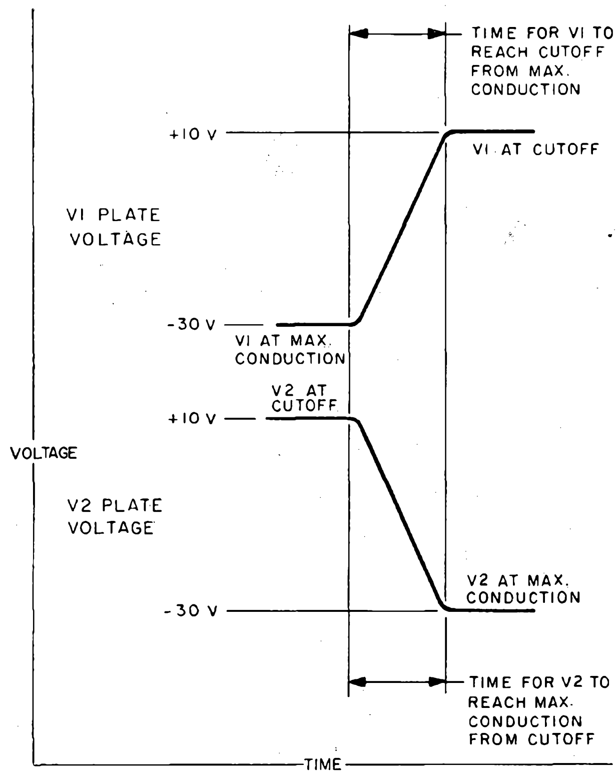


Figure 3—41. Flip-Flop Output Levels When Changing from a Set to a Clear State

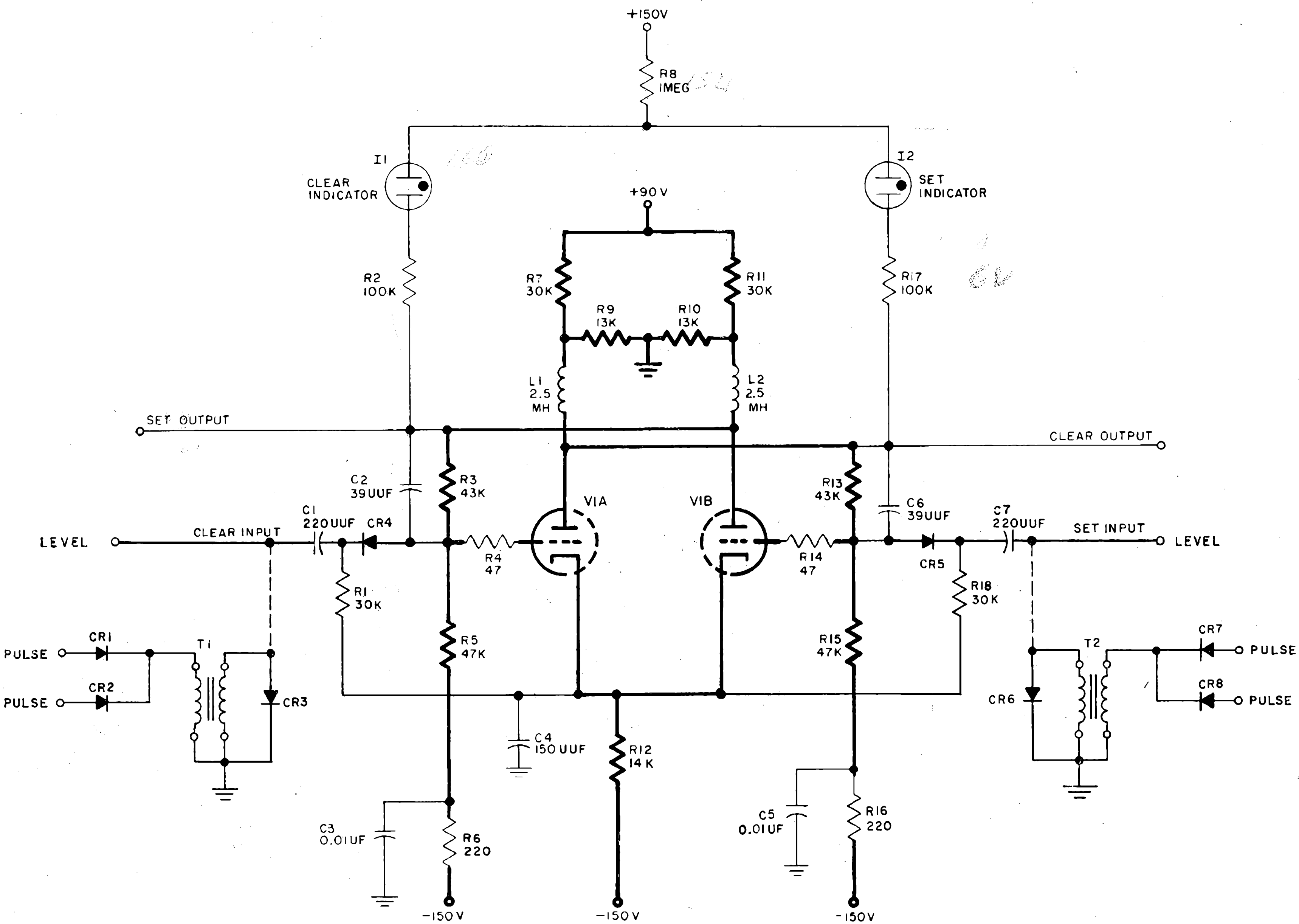


Figure 3—42. Flip-Flop, Model B, Schematic Diagram

TABLE 3–17. FLIP-FLOP, MODEL B, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION	REFERENCE SYMBOL	FUNCTION
C1	Part of differentiating network (with R1).	R1	Part of differentiating network (with C1).
C2	Speedup capacitor, improves rise and fall time.	R2	Isolates set output from I1.
C3	Part of decoupling network (with R6).	R3	Part of voltage divider (with R5).
C4	Ground return (ac).	R4	Parasitic suppressor.
C5	Part of decoupling network (with R16).	R5	Part of voltage divider (with R3).
C6	Speedup capacitor, improves rise and fall time.	R6	Part of decoupling network (with C3).
C7	Part of differentiating network (with R18).	R7	Part of voltage divider (with R9).
CR1	Pulsed OR input diode.	R8	Limits current through I1 and I2.
CR2	Pulsed OR input diode.	R9	Part of voltage divider (with R7).
CR3	Clips positive overshoot.	R10	Part of voltage divider (with R11).
CR4	Isolates grid of V1A from V1A and V1B cathodes.	R11	Part of voltage divider (with R10).
CR5	Isolates grid of V1B from V1A and V1B cathodes.	R12	Cathode resistor for V1A and V1B.
CR6	Clips positive overshoot.	R13	Part of voltage divider (with R15).
CR7	Pulsed OR input diode.	R14	Parasitic suppressor.
CR8	Pulsed OR input diode.	R15	Part of voltage divider (with R13).
I1	Indicates clear state.	R16	Part of decoupling network (with C5).
I2	Indicates set state.	R17	Isolates clear output from I2.
L1	Peaking coil, improves rise and fall time.	R18	Part of differentiating network (with C7).
L2	Peaking coil, improves rise and fall time.	T1	Input transformer.
		T2	Input transformer.
		V1A	Flip-flop triode.
		V1B	Flip-flop triode.

levels which are dependent upon the voltage dividers to vary from their nominal values. For this reason, the $_B$FF must be isolated from its load by a cathode follower.

There are two neon indicators, I1 and I2. Indicator I1 glows when the set output is down, indicating a clear state; I2 glows when the clear output is down, indicating a set state. These indicators are located at appropriate positions on the computer. Resistors R2 and R17 isolate each indicator circuit from its respective output. Refer to table 3–17 for the function of detail parts not discussed.

11.2.3 Detailed Operation of Low-Speed, Model C Flip-Flop

Figure 3–43 is a schematic diagram of the $_C$FF, which operates with a maximum pulse repetition frequency of 200 kc. Table 3–18 is the associated list of detail parts and their functions. The $_C$FF is slower than the $_B$FF; however, it can drive a load directly.

The set output is clamped at +10 volts by CR4 and at —30 volts by CR5. The clear output is clamped at +10 volts by CR7 and at —30 volts by CR8. The voltage divider associated with V1A consists of resistors

R11, R12, R17, and R18 between potentials of +90 and −300 volts. The $_C$FF does not employ peaking coils in its plate circuits as does the $_B$FF. The RC network formed by capacitor C3 and resistor R9 ensures circuit stability with the aging of VA and V1B. This is accomplished by the development of a positive bias on the grids of V1A and V1B. Such a bias enables each flip-flop triode to function properly after cathode emission has decreased because of aging. The input circuits for pulses and levels are similar to those discussed with the $_B$FF. The values of C1 and R1 vary to meet input requirements. Complementing is accomplished in the same manner as in the $_B$FF. Refer to table 3–18 for the functions of detail parts not discussed.

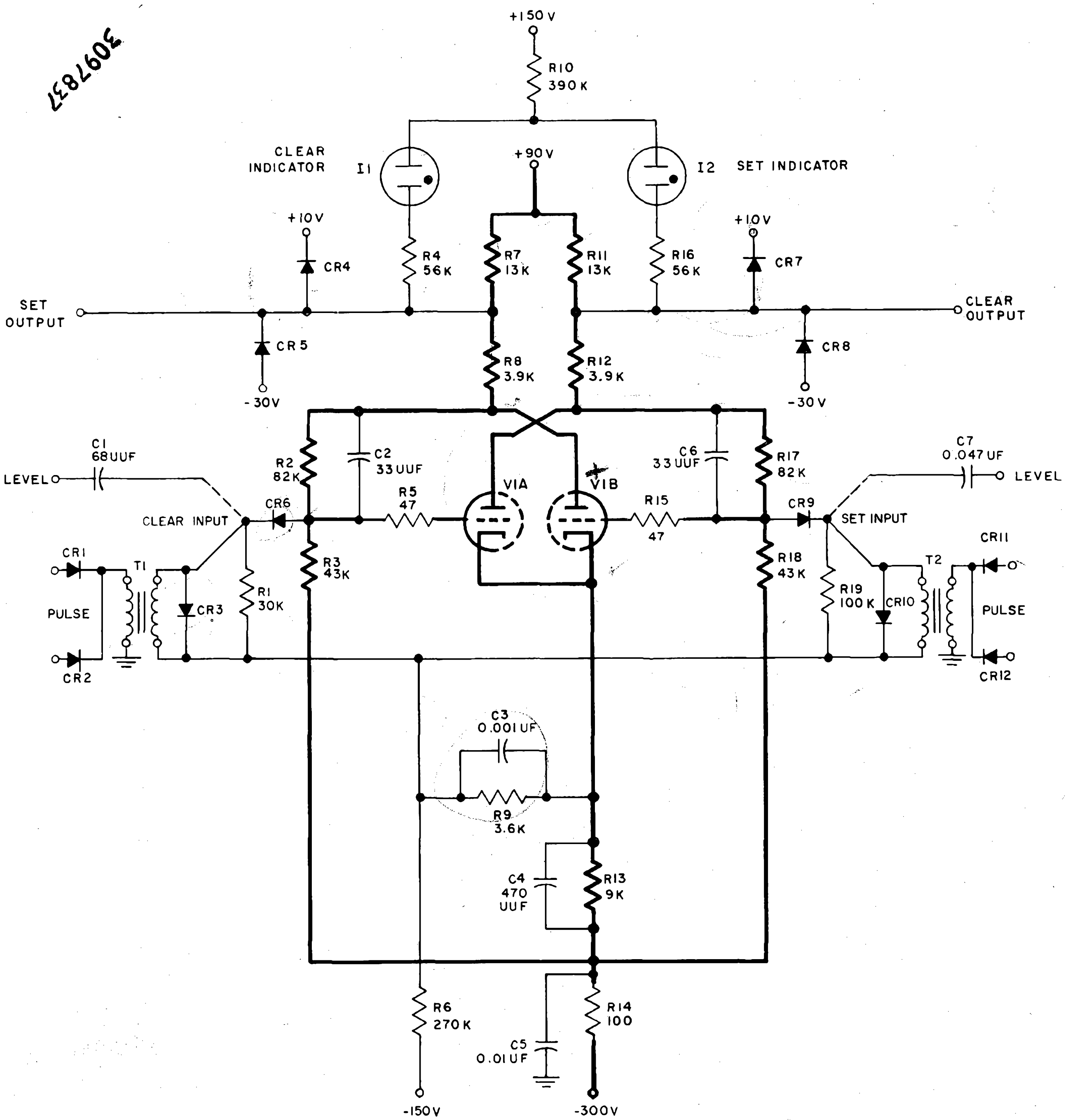


Figure 3–43. Flip-Flop, Model C, Schematic Diagram

11.2.4 Detailed Operation of High-Speed, Model A Flip-Flop

The high-speed $_A$FF, shown in figure 3–44, operates with a maximum pulse repetition frequency of 2 megacycles. Table 3–19 is the associated list of detail parts and their functions. The input signal to the $_A$FF is a standard pulse. The use of cathode follower output circuits enables the $_A$FF to drive a load directly. Cathode follower V2A isolates the plate circuit of V2B from the grid circuit of V1B. Cathode follower V1A isolates the plate of V1B from the grid circuit of V2B. This permits faster flip-flop action.

TABLE 3–18. FLIP-FLOP, MODEL C, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Part of differentiating network (with R1).
C2	Speedup capacitor, improves rise and fall time.
C3	Ensures circuit stability (with R9).
C4	Cathode bypass capacitor.
C5	Part of decoupling network (with R14).
C6	Speedup capacitor, improves rise and fall time.
C7	Part of differentiating network (with R19).
CR1	Pulsed OR input diode.
CR2	Pulsed OR input diode.
CR3	Clips positive overshoot.
CR4	+10-volt clamp (set output).
CR5	—30-volt clamp (set output).
CR6	Isolates grid of V1A.
CR7	+10-volt clamp (clear output).
CR8	—30-volt clamp (clear output).
CR9	Isolates grid of V1B.
CR10	Clips positive overshoot.
CR11	Pulsed OR input diode.
CR12	Pulsed OR input diode.
I1	Indicates clear state.
I2	Indicates set state.
R1	Part of differentiating network (with C1).
R2	Part of voltage divider (with R3, R7, and R8).
R3	Part of voltage divider (with R2, R7, and R8).
R4	Isolates set output from I1.
R5	Parasitic suppressor.
R6	Part of voltage divider (with R9 and R13).
R7	Part of voltage divider (with R2, R3, and R8).
R8	Part of voltage divider (with R2, R3, and R7).
R9	Part of voltage divider (with R6) ensures circuit stability (with C3).
R10	Limits current through I1 and I2.
R11	Part of voltage divider (with R12, R17, and R18).
R12	Part of voltage divider (with R11, R17, and R18).
R13	Cathode resistor for V1A and V1B.
R14	Part of decoupling network (with C5).
R15	Parasitic suppressor.
R16	Isolates clear output from I2.
R17	Part of voltage divider (with R11, R12, and R18).
R18	Part of voltage divider (with R11, R12, and R17).
R19	Part of differentiating network (with C7).
T1	Input transformer.
T2	Input transformer.
V1A	Flip-flop triode.
V1B	Flip-flop triode.

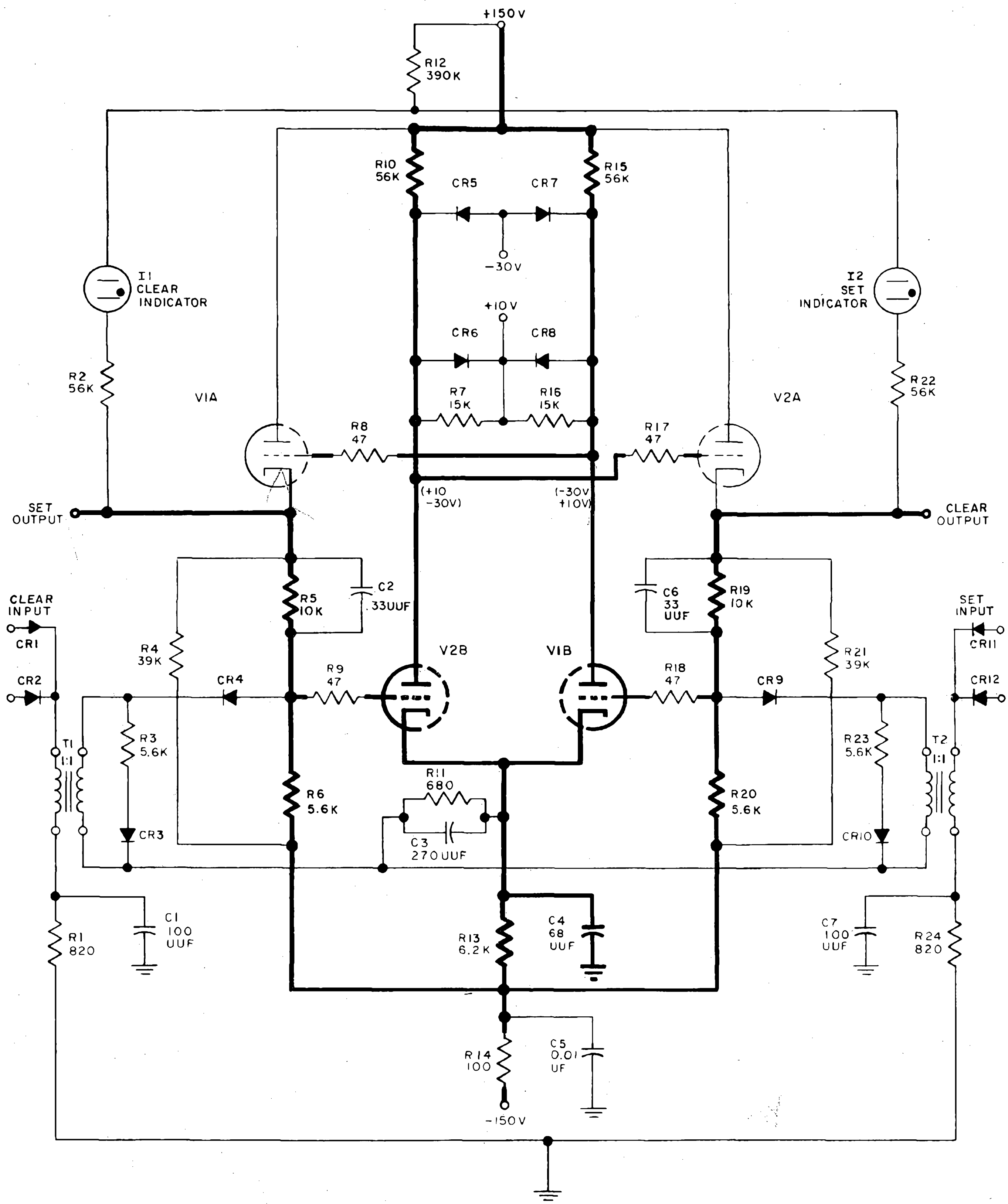


Figure 3—44. Flip-Flop, Model A, Schematic Diagram

TABLE 3–19. FLIP-FLOP, MODEL A, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Part of input diode biasing network (with R1).
C2	Speedup capacitor, improves rise and fall time.
C3	Ensures circuit stability (with R11).
C4	Cathode bypass capacitor.
C5	Part of decoupling network (with R14).
C6	Speedup capacitor, improves rise and fall time.
C7	Part of input diode biasing network (with R24)
CR1	Pulsed OR input diode.
CR2	Pulsed OR input diode.
CR3	Clips positive overshoot.
CR4	Isolates grid of V2B.
CR5	—30-volt clamp (clear output).
CR6	+10-volt clamp (clear output).
CR7	—30-volt clamp (set output).
CR8	+10-volt clamp (set output).
CR9	Isolates grid of V1B.
CR10	Clips positive overshoot.
CR11	Pulsed OR input diode.
CR12	Pulsed OR input diode.
I1	Indicates clear state.
I2	Indicates set state.
R1	Part of input diode biasing network (with C1).
R2	Isolates set output from I1.
R3	Current-limiting for CR3.
R4	Part of cathode load for V1A with R5 and R6.
R5	Part of voltage divider (with R6).
R6	Part of voltage divider (with R5).
R7	Protection against failure of CR6.
R8	Parasitic suppressor.
R9	Parasitic suppressor.
R10	Plate load resistor for V2B.
R11	Ensures circuit stability (with C3).
R12	Limits current through I1 and I2.
R13	Cathode resistor for V1B and V2B.
R14	Part of decoupling network (with C5).
R15	Plate load resistor for V1B.
R16	Protection against failure of CR8.
R17	Parasitic suppressor.
R18	Parasitic suppressor.
R19	Part of voltage divider (with R20).
R20	Part of voltage divider (with R19).
R21	Part of cathode load for V2A with R19 and R20.
R22	Isolates clear output from I2.
R23	Current limiting for CR10.
T1	Input transformer.
T2	Input transformer.
V1A	Isolating cathode follower (plate of V1B from grid of V2B)
V1B	Flip-flop triode.
V2A	Isolating cathode follower (plate of V2B from grid of V1B).
V2B	Flip-flop triode.

The plate supply voltage for the $_A$FF is greater than that used on the $_B$FF and $_C$FF.

In order to minimize wiring capacitance which would slow down the $_A$FF, each of the twin triodes contains an amplifier and associated cathode follower in the same envelope.

The network consisting of resistor R1 and capacitor C1 connected to the return of the primary of T1 prohibits noise pulses from affecting the $_A$FF. Resistor R3, in series with diode CR3 across the secondary of T1, limits the current through CR3. Resistor R7 across diode CR6 (+10-volt clamp) prevents a large positive potential from being applied to the grid of V2A should CR6 open. The $_A$FF may have numerous diode inputs accompanying diodes CR1 and CR2.

Refer to table 3–19 for function of detail parts not discussed.

CHAPTER 12

SINGLE-SHOT MULTIVIBRATORS

12.1 DEFINITION AND DESCRIPTION

The single-shot multivibrator ($_X$SS) is a logic circuit which generates a level of predetermined duration when a standard pulse is applied to its input. Figure 3—45 depicts the logic block symbol of each multivibrator model with its associated outputs.

12.2 PRINCIPLES OF OPERATION

12.2.1 Basic Operation

The SS has one stable state; in this it differs from the flip-flop multivibrator, which has two stable states.

Figure 3—46 is a block diagram of an SS consisting of amplifiers A and B. Normally, amplifier B is conducting and amplifier A is cut off. This is the stable state of the SS.

An appropriate signal applied to the input will cause amplifier B to cut off and amplifier A to conduct. This change of state is maintained, for a predetermined period of time, by the RC network. The SS then returns to its stable state. The output level of the SS is down in its stable state and up in its nonstable state.

Figure 3—47 is a simplified diagram of the single-shot multivibrator. Initially, V2 conducts because its cathode is at B— and its grid is at ground potential. Because of the conduction of V2, resistors R3 and R4 between the plate of V2 and B— apply a potential to

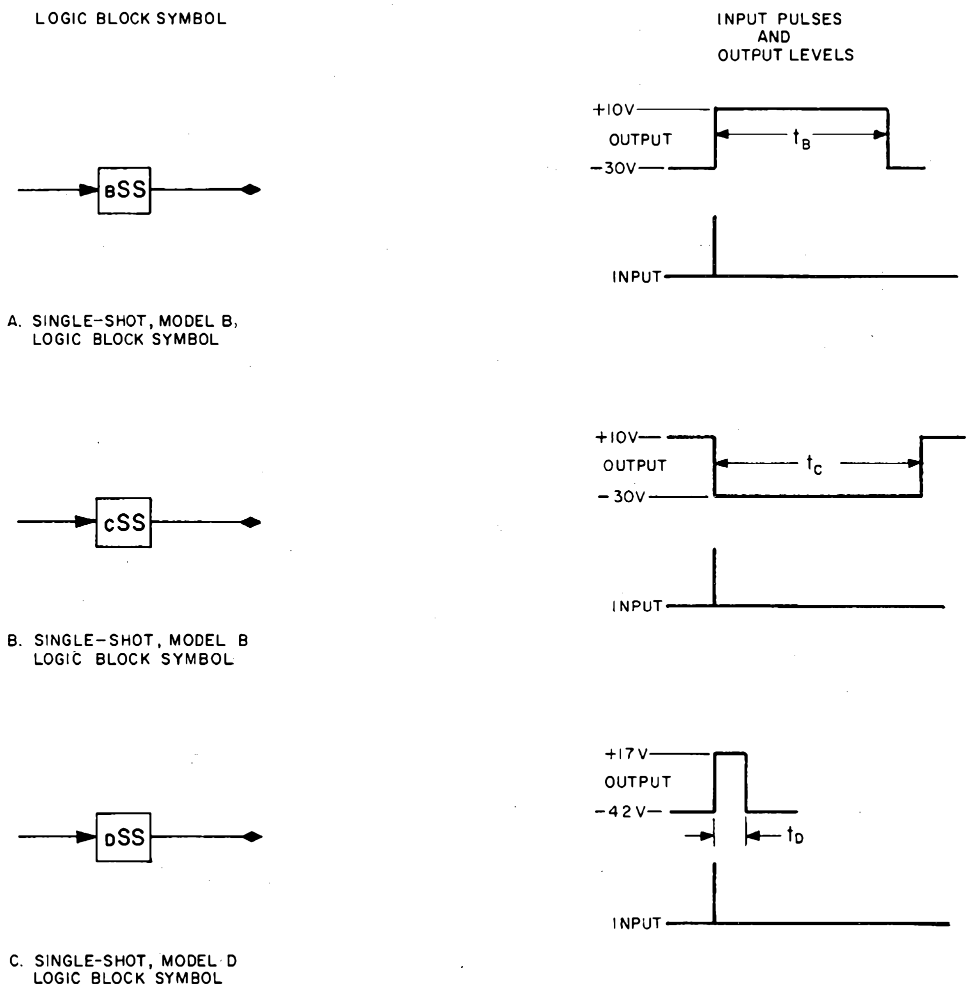


Figure 3—45. Single-Shot, Logic Block Symbols and Output Waveforms

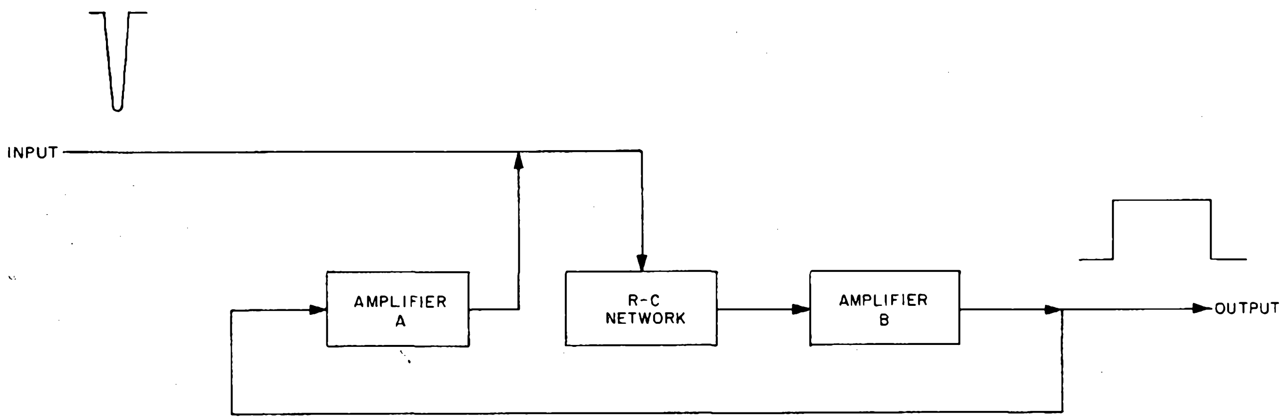


Figure 3–46. Single-Shot, Simplified Block Diagram

the grid of V1 sufficiently negative to maintain V1 at cutoff. With V1 cut off and V2 conducting, capacitor C1 charges to (B+) – (B–) through the cathode to grid circuit of V2.

A negative pulse applied at the input is coupled by capacitor C1 to the grid of V2, reducing the plate current through R6.

The reduction in voltage drop across R6 results in a rise of potential at the plate of V2. This rise is coupled to the grid of V1 through the voltage divider consisting of resistors R3 and R4. Tube V1 conducts, and its plate voltage falls. This negative shift in potential at the plate of V1 adds to the negative pulse input and is coupled by C1 to the grid of V2. The plate voltage of V2 rises, and this action continues in a regenerative manner until V2 is cut off. At this time, the plate potential of V2 is at maximum, the plate potential of V1 is at minimum, and the grid potential of V2 is below B–. As was previously indicated, the initial charge across C1 is B+ – B–, with the potential at the grid of V2 at B– and the potential at the plate of V1 at B+. When the plate of V1 falls, the grid potential of V2 falls a like amount (fig. 3–48). This is accomplished by the coupling action of capacitor C1 (the charge across a capacitor cannot change instantaneously). At the instant V2 is cut off, a positive level shift occurs, and the level is maintained until V2 resumes conduction. Tube V2 will remain cut off until the charge on C1 leaks off

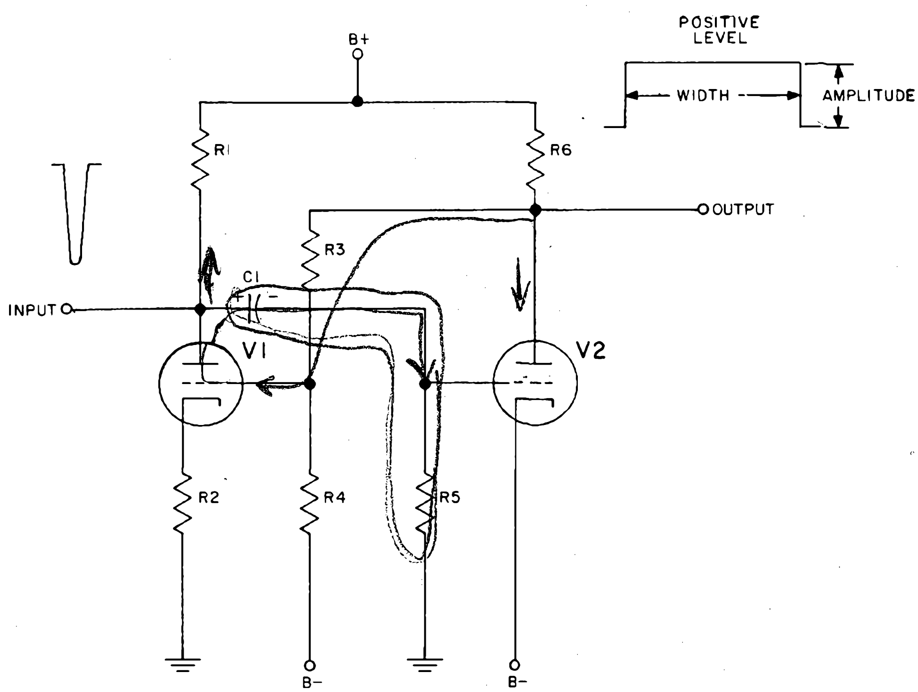


Figure 3–47. Single-Shot, Simplified Schematic Diagram

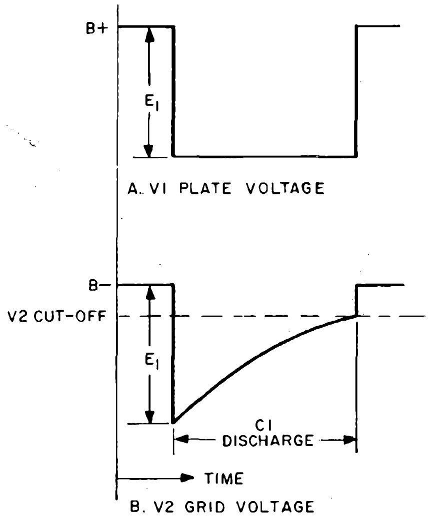


Figure 3–48. V1 Plate Voltage and V2 Grid Voltage

through R5. As the charge on C1 is decreased, the grid of V2 approaches B— and reaches the point where V2 conducts. Current through V2 causes a fall in voltage at the plate of V2. This fall is coupled to the grid of V1 through resistors R3 and R4. The plate of V1 rises, and regenerative action returns the SS to its stable state (V1 cut off and V2 conducting). In the stable state, the grid and cathode of V2 are at B—, and the plate potential of V2 is reduced to its minimum value; hence, the output level falls (fig. 3–47). The width of the output waveform (the time required for capacitor C1 to discharge sufficiently to enable V2 to conduct) is determined by the capacity of C1 and the resistance of R5. The duration of the up level output is predetermined by, and directly proportional to, the product of C1 and R5: an increase of either C1 or R5 increases the time; a decrease of either C1 or R5 decreases the time.

Figure 3–49 depicts the grid and plate voltage waveforms of C2 for varying values of C1 and R5. From this figure, it can be seen that the width of the positive level output is dependent upon values of C1 and R5.

12.2.2 Detailed Operation, Single-Shot, Model B

Figure 3–50 is a composite schematic diagram of the $_B$SS. Table 3–20 is the associated list of detail parts and their functions. The $_B$SS produces a +10-volt (up) level for a predetermined duration when a standard pulse is applied to its input. The range of duration of the up level is from 1 to 100,000 microseconds and is determined by the values of C1 and R8. Two input circuits are employed to cover the range. The high-speed input circuit is used for the range of 1 to 4 microseconds. The low-speed input circuit is used for the range of 4 to 100,000 microseconds. Cathode follower V2A increases the load-driving capabilities of the $_B$SS.

The stable state of $_B$SS is determined by the considerations that follow. Tube V1B conducts because its grid is returned to ground and its cathode is at —150 volts. With V1B conducting, the junction of plate load

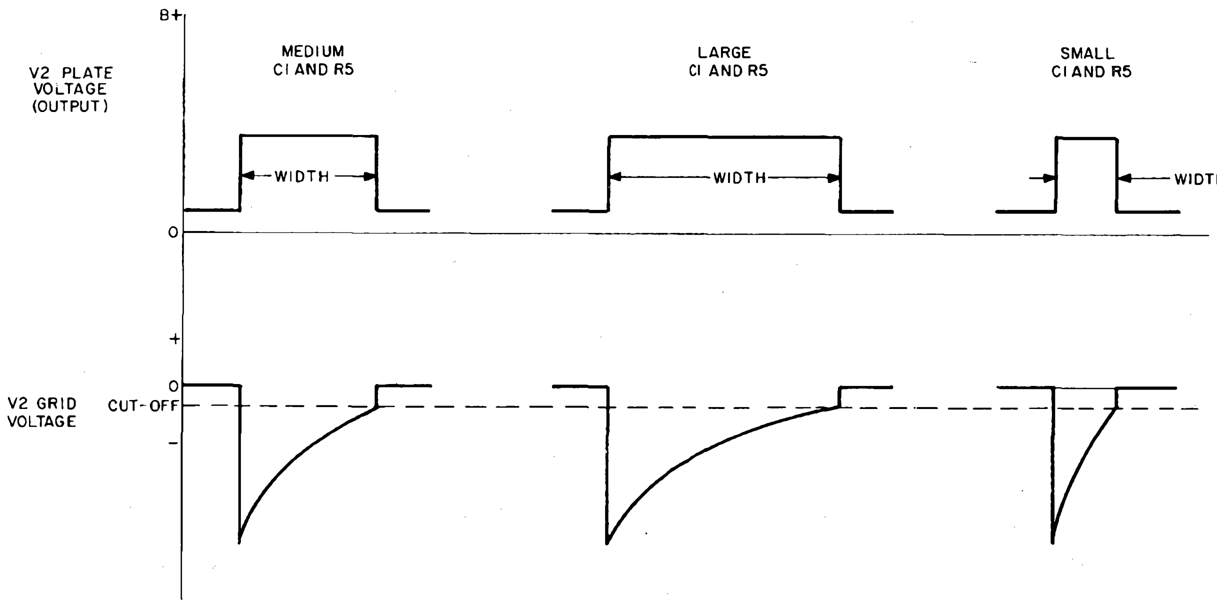


Figure 3–49. Plate and Grid Voltages of V2 for Varying Values of C1 and R5

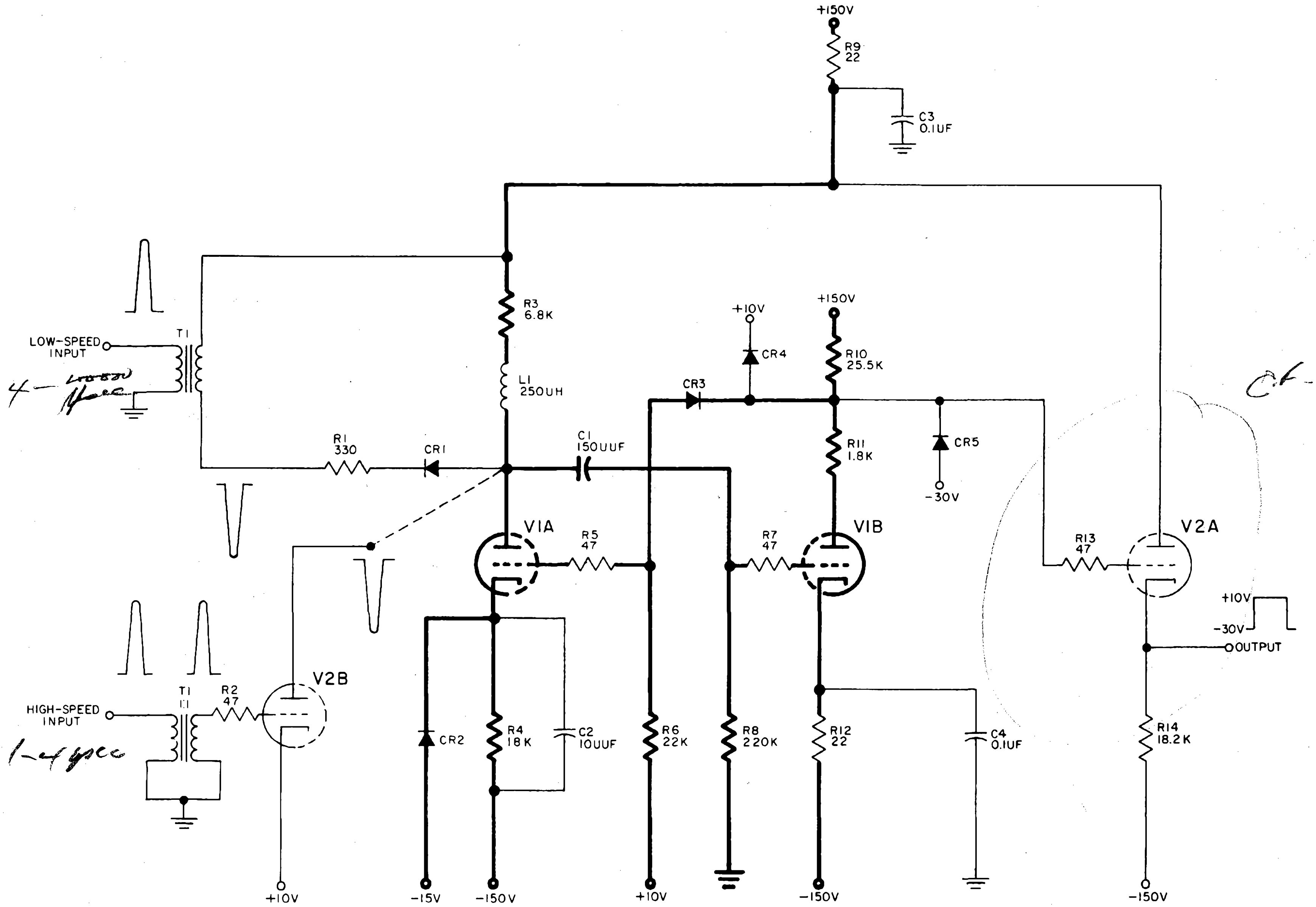


Figure 3—50. Single-Shot, Model B, Schematic Diagram

resistors R10 and R11 is maintained at —30 volts by diode CR5. Diode CR3, in series with R6, conducts, maintaining the grid of V1A at —30 volts. Diode CR2, in series with R4 between/—15 volts and —150 volts, conducts, maintaining the cathode of V1A at —15 volts. This —15-volt bias (—15 volts at the cathode and —30 volts at the grid) is sufficient to hold V1A cut off. The plate potential of V1A is at the plate supply potential, +150 volts. Consider the path between +150 volts and —150 volts, consisting of R9, R3, L1, C1, and R7 and the grid and cathode of V1B. With V1A cut off and V1B conducting, capacitor C1 charges to 300 volts [+150 volts – (—150 volts)] = 300 volts through this path. Since the grid of cathode follower V2A, connected to the junction of resistors R10 and R11, is clamped at —30 volts, the output at the cathode of V2A is a —30-volt level.

Therefore, in the stable state of the $_{B}$SS, capacitor C1 is charged to 300 volts, V1A is cut off, V1B conducts, and V2A produces an output of —30 volts.

When a standard pulse is applied to the primary of input transformer T1, a negative pulse appears at the plate of V1A. Capacitor C1 couples this negative pulse to the grid of V1B, reducing current through V1B. The resultant rise of plate voltage initiates the regenerative action discussed in 12.2.1. The $_{B}$SS assumes its unstable state (V1A conducting and V1B cut off). With V1B cut off, CR4 conducts, and the junction of plate load resistors is clamped at +10 volts, maintaining the grids of V1A and V2A at +10 volts. As a result, the output of V2A rises and is held at +10 volts, and the plate of V1A falls and is held at a voltage below +150 volts by the voltage drop across R3. Initially, the unstable state of the $_{B}$SS is characterized by the following conditions: V1A conducts, V1B is cut off, the output of V2A is at +10 volts, and capacitor C1 is charged to 300 volts. This unstable state is maintained until the charge on capacitor C1 is discharged through R8 sufficiently to raise the grid of V1B above cutoff. As soon as V1B conducts, regenerative action is initiated, and the $_{B}$SS returns to its stable state.

The low-speed input circuit, consisting of T1, R1, and CR1, is used when the required single-shot output width (delay) is between 4 and 100,000 microseconds. For this application, the value of C1 varies between 68 micromicrofarads and 0.5 microfarad, and R6 varies between 220K and 700K. The specific values are determined by the delay required.

A standard pulse applied to the primary of T1 appears as a negative pulse across the secondary. Diode CR1 passes this negative pulse to the plate of V1A. This diode serves to isolate the plate circuit of V1A from the input. Resistor R1 prohibits noise pulses from triggering the SS when a large value of capacitance is used for C1.

TABLE 3–20. SINGLE-SHOT MULTIVIBRATOR, MODEL B, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Determines duration of unstable state (with R8).
C2	Cathode bypass capacitor for V1A.
C3	Part of decoupling network (with R9).
C4	Part of decoupling network (with R12).
CR1	Isolates plate circuit of V1A from input.
CR2	Clamps cathode of V1A at —15 volts.
CR3	Coupling diode between plate circuit of V1B and grid of V1A.
CR4	Clamps V1B output at +10 volts.
CR5	Clamps V1B output —30 volts
L1	Part of plate load for V1A and V2B, peaking coil.
R1	Prohibits noise pulses.
R2	Parasitic suppressor.
R3	Part of plate load for V1A and V2B (with L1).
R4	Cathode resistor for V1A.
R5	Parasitic suppressor.
R6	Grid return for V1A.
R7	Parasitic suppressor.
R8	Determines duration of unstable state (with C1).
R9	Part of decoupling network (with C3).
R10	Part of plate load for V1B (with R11).
R11	Part of plate load for V1B (with R10).
R12	Part of decoupling network (with C4).
R13	Parasitic suppressor.
R14	Cathode load for V2A.
T1	Input transformer.
V1A	Single-shot triode.
V1B	Single-shot triode.
V2A	Cathode follower triode.
V2B	Plate-pullover triode.

When the output is delayed between 1 and 4 microseconds, the input circuit employing V2B is connected to the plate of V1B, and the other input circuit is removed. The value of C1 is then either 22 or 33 micromicrofarads, and R6 varies between 220K and 420K.

A standard pulse at the primary of T1 is peaked and applied to the grid of V2B. Plate load resistor R3 and inductor L1 provide the plate load for plate pullover tube V2B as well as for V1A. The plate current of V2B flows through R3 and L1, and an amplified inverted (negative) pulse appears at the plate of V1A. Because of this amplification, the output from V2A rises faster. (Rise time becomes more significant when the level output is up for short durations.)

Inductor L1 in the plate circuit of V1A speeds rise time for both long and short delays. Refer to table 3—20 for the function of detail parts not discussed.

12.2.3 Detailed Operation, Single-Shot, Model C

Figure 3—51 is a schematic diagram of the $_{C}$SS. Table 3—21 is the associated list of detail parts and their functions. This circuit produces a —30-volt level for a duration of from 4 to 100,000 microseconds for each standard pulse input. The output then returns to a +10-volt level (stable state).

The $_{C}$SS circuit is essentially the same as the $_{B}$SS; however, a modified inverter, V2A, precedes cathode follower V1A to invert the level. The voltage divider formed by resistors R12 and R13 couples the plate of V2B to the grid of V2A. Capacitor C5 speeds transition time. For up levels wider than 10 microseconds, R1 is shorted. Refer to table 3—21 for the function of detail parts not discussed.

12.2.4 Detailed Operation, Single-Shot, Model D

Figure 3—52 is a schematic diagram of the $_{D}$SS. Table 3—22 is the associated list of detail parts and their functions. The output of the $_{D}$SS in its stable state is a —42-volt level. For each standard pulse applied to its input, the $_{D}$SS produces a +17-volt level of 2.2-microsecond duration.

The $_{D}$SS circuit is the same as the $_{B}$SS, utilizing a pullover tube input with the modifications that follow. The positive rise of output from V2B is clamped to +30.8 volts by diode CR3 during the 2.2 microseconds this tube is cut off, permitting the $_{D}$SS output to rise to +17 volts. This +30.8-volt bias is obtained from the junction of divider resistors R7 and R8 between +90 volts and ground. Capacitor C4 maintains the voltage across R8 constant. Because of the heavy load requirement, the $_{D}$SS output circuit consists of paralleled cath-

TABLE 3—21. SINGLE-SHOT MULTIVIBRATOR, MODEL C, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Determines duration of unstable state (with R7).
C2	Cathode bypass capacitor for V1B.
C3	Part of decoupling network (with R10).
C4	Part of decoupling network (with R11).
C5	Speeds rise and fall time.
CR1	Isolates plate circuit of V1B from input.
CR2	Clamps cathode of V1B at —15 volts.
CR3	Coupling diode between plate circuit of V2B and grid of V1B.
CR4	Clamps V2B at +10 volts.
CR5	Clamps V2B output at —30 volts.
CR6	Clamps V2A output at +10 volts.
CR7	Clamps V2A output at —30 volts.
L1	Part of plate load for V1B, peaking coil.
R1	Prohibits noise pulses.
R2	Part of plate load for V1B (with L1).
R3	Cathode resistor for V1B.
R4	Parasitic suppressor.
R5	Grid return for V1B.
R6	Parasitic suppressor.
R7	Determines duration of unstable state (with C1).
R8	Part of plate load for V2B (with R9).
R9	Part of plate load for V2B (with R8).
R10	Part of decoupling network (with C3).
R11	Part of decoupling network (with C4).
R12	Part of voltage divider (with R13).
R13	Part of voltage divider (with R12).
R14	Parasitic suppressor.
R15	Part of plate load for V2A (with R16).
R16	Part of plate load for V2A (with R15).
R17	Parasitic suppressor.
R18	Cathode load for V1A.
T1	Input transformer.
V1A	Cathode follower triode.
V1B	Single-shot triode.
V2A	Inverter triode.
V2B	Single-shot triode.

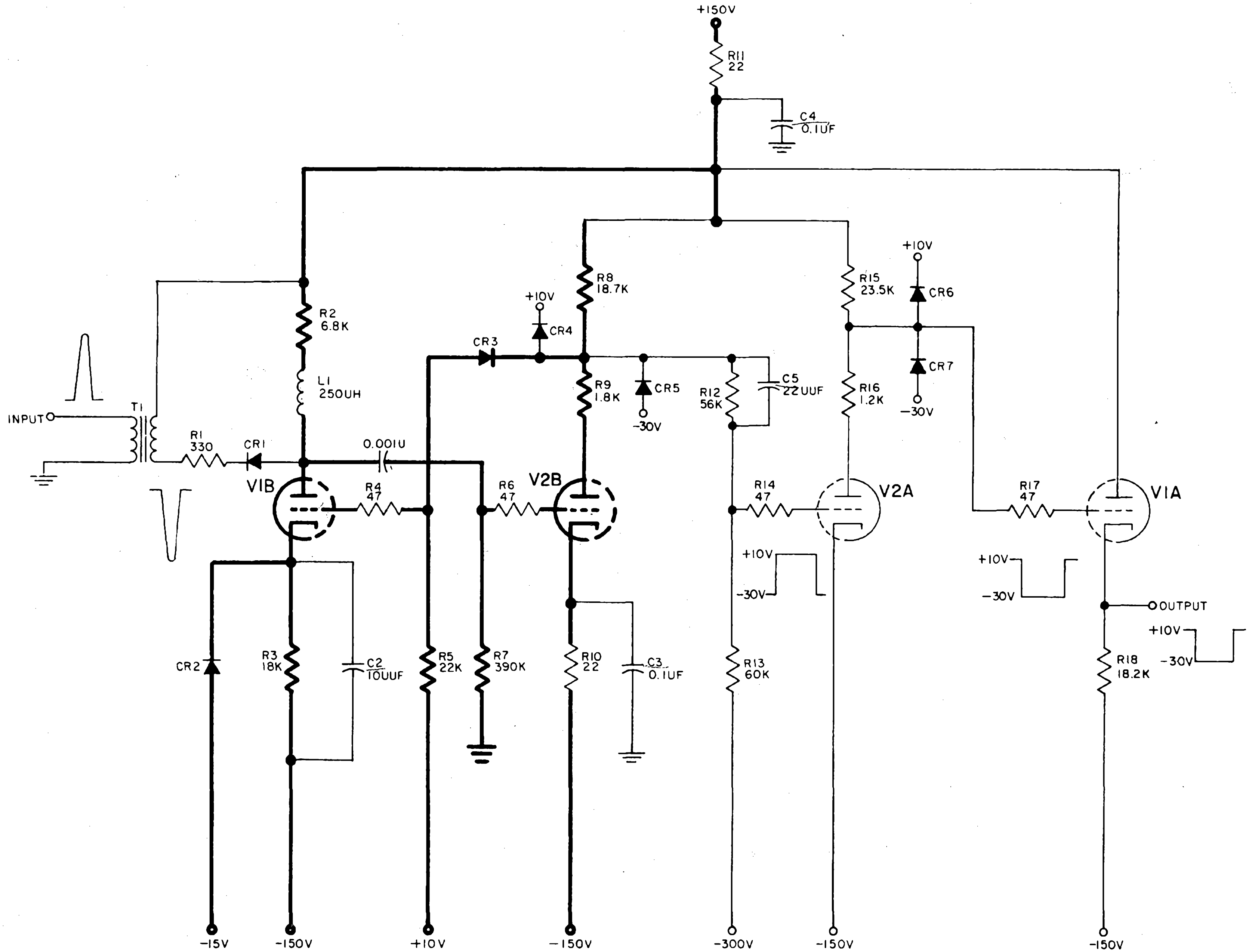


Figure 3–51. Single-Shot, Model C, Schematic Diagram

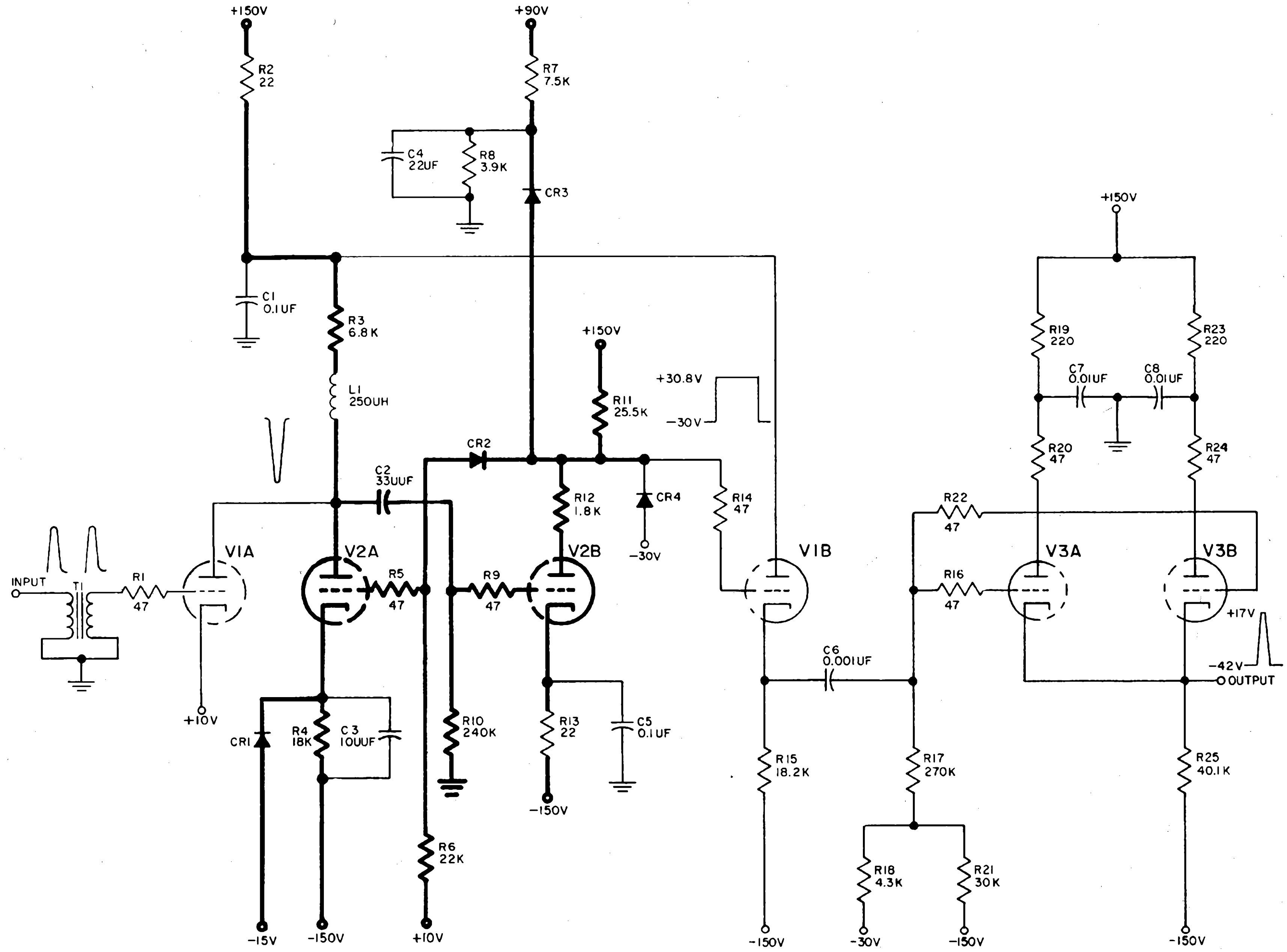


Figure 3–52. Single-Shot, Model D, Schematic Diagram

ode followers V3A and V3B. Capacitor C6 couples the output of cathode follower V1B to the grids of V3A and V3B. Grid return resistor R17 is common to V3A and V3B and is tied to the junction of the voltage divider composed of resistors R18 and R21. This divider develops a potential of —45 volts at the junction of R18 and R21, enabling the $_D$SS output to fall to —42 volts during the stable state.

When a standard pulse is applied to the input, the output pulse rises to +17 volts for 2.2 microseconds. (Refer to table 3—22 for the function of detail parts not discussed.)

TABLE 3—22. SINGLE-SHOT MULTIVIBRATOR, MODEL D, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Part of decoupling network (with R2).
C2	Determines duration of unstable state (with R10).
C3	Cathode bypass capacitor for V2A.
C4	Maintains voltage across R8 constant.
C5	Part of decoupling network (with R13).
C6	Couples cathode of V1B to grids of V3A and V3B.
C7	Part of decoupling network (with R19).
C8	Part of decoupling network (with R23).
CR1	Clamps cathode of V2A at —15 volts.
CR2	Coupling diode between plate circuit of V2B and grid of V2A.
CR3	Clamps V2B output at +30.8 volts.
CR4	Clamps V2B output at —30 volts.
L1	Part of plate load for V1A and V2A, peaking coil.
R1	Parasitic suppressor.
R2	Part of decoupling network (with C1).
R3	Part of plate load resistor for V1A and V2A (with L1).
R4	Cathode resistor for V2A.
R5	
R6	Grid return for V2A.
R7	Part of voltage divider (with R8).
R8	Part of voltage divider (with R7).
R9	Parasitic suppressor.
R10	Determines duration of unstable state (with C2).
R11	Part of plate load for V2B (with R12).
R12	Part of plate load for V2B (with R11).
R13	Part of decoupling network (with C5).
R14	Parasitic suppressor.
R15	Cathode load for V1B.
R16	Parasitic suppressor.
R17	Grid return resistor for V3A and V3B.
R18	Part of voltage divider (with R21).
R19	Part of decoupling network (with C7).
R20	Parasitic suppressor.
R21	Part of voltage divider (with R18).
R22	Parasitic suppressor.
R23	Part of decoupling network (with C8).
R24	Parasitic suppressor.
R25	Cathode load for V3A and V3B.
T1	Input transformer.
V1A	Plate-pullover triode.
V1B	Cathode follower triode.
V2A	Single-shot triode.
V2B	Single-shot triode.
V3A	Cathode follower triode.
V3B	Cathode follower triode.

CHAPTER 13

PULSE GENERATORS, MODELS A, B, C, D, AND E

13.1 DEFINITION AND DESCRIPTION

Pulse generators (PG's) are logic circuits which provide standard pulse outputs for appropriate inputs. Figure 3–53 is the logic block symbol of the several model groups. Pulse generators, models A, B, and C, are essentially the same circuit, the only difference being the means of input. Model A is actuated by hand-operated switching at a maximum repetition rate of 240 pulses per minute; model B, by a cam-operated switch at a maximum rate of 3,600 pulses per minute; model C, by a positive level shift at a maximum rate of 30,000 shifts per minute. The output of each is a standard pulse.

The model D input is a rapid shift in standard level from −30 volts to +10 volts. The output is a nonstandard pulse. The model E input is a standard level shift from +10 volts to —30 volts. The output is a standard pulse.

13.2 PRINCIPLES OF OPERATION

13.2.1 Basic Operation, Models A, B, and C

Models A, B, and C consist basically of an input circuit, a tetrode thyratron, and an output transformer. These pulse generators produce standard pulses whenever a switch is actuated in the input grid circuit or, as in model C, a positive shift in voltage is applied to the input.

13.2.2 Detailed Operation, Models A, B, and C

Figure 3–54 is a schematic diagram for the models A, B, and C pulse generators. Table 3–23 is the associated list of detail parts and their functions.

With application of power, tetrode thyratron V1 is biased below critical grid voltage by the —15 volts applied to the grid through resistor R3 and R5. Capacitor C1 charges to —150 volts through resistor R2. When discharge path P1 is completed, C1 discharges through resistor R1. The change in potential on the grid side of C1 is coupled to the control grid of thyratron V1

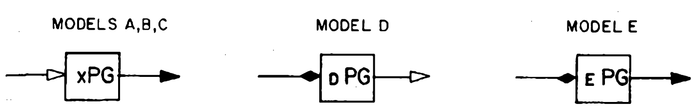


Figure 3—53. Pulse Generators, Logic Block Symbols

through capacitor C2. The potential at the juncture of capacitor C2 and resistor R2 was —150 volts. The potential at the juncture of capacitor C2 and R3 was —15 volts. The capacitor only passes the change in levels, —150 to 0 volts, not the level itself; therefore, the upward change of potential rises from −15 volts to + 135 volts.

This positive potential exceeds that required to ionize the thyratron, resulting in the flow of grid and plate current. The grid current flowing through limiting resistor R5 maintains the grid at cathode potential. Capacitor C3 discharges through the primary of transformer T1 and the thyratron V1 until the plate of V1 reaches extinction potential. Transformer T1 is connected so that a positive output pulse results. This transformer, together with C3 and R4, shapes the pulse. The value of terminating resistor R7 will vary with the value of output load.

13.2.3 Circuit Refinements, Models A, B, and C

While the thyratron is conducting, the shield grid draws current, and a representative pulse appears across current limiting resistor R8, for testing purposes.

The only difference between model B and model A is in the value of resistor R2. In model B, the value for resistor R2 is 0.2 megohm. The reduction in the resistance of R2 decreases the charging time for capacitor C1, permitting the circuit to be actuated at a higher repetition rate by a cam-operated switch.

Model C is triggered by a positive level shift at capacitor C2. Resistor R3 and capacitor C2 convert this positive level shift into a positive trigger at the grid side of C2. Capacitor C2 discharges through the now conducting grid and resistors R5 and R3. The trigger generating components, R1, C1, P1, and R2, are not used. A composite schematic diagram of models A, B, and C is shown in figure 3–54.

An optional arrangement in the form of a special switch (P2) is incorporated in the circuit as shown in figure 3–54. This switch eliminates the possibility of multiple output pulses caused by switch (P1) bounce. Removing the +250-volt plate supply before P1 is closed prevents capacitor C1 from charging during the bounce period and eliminates the possibility of accidental triggering of thyratron V1. Refer to table 3–23 for the function of detail parts not discussed.

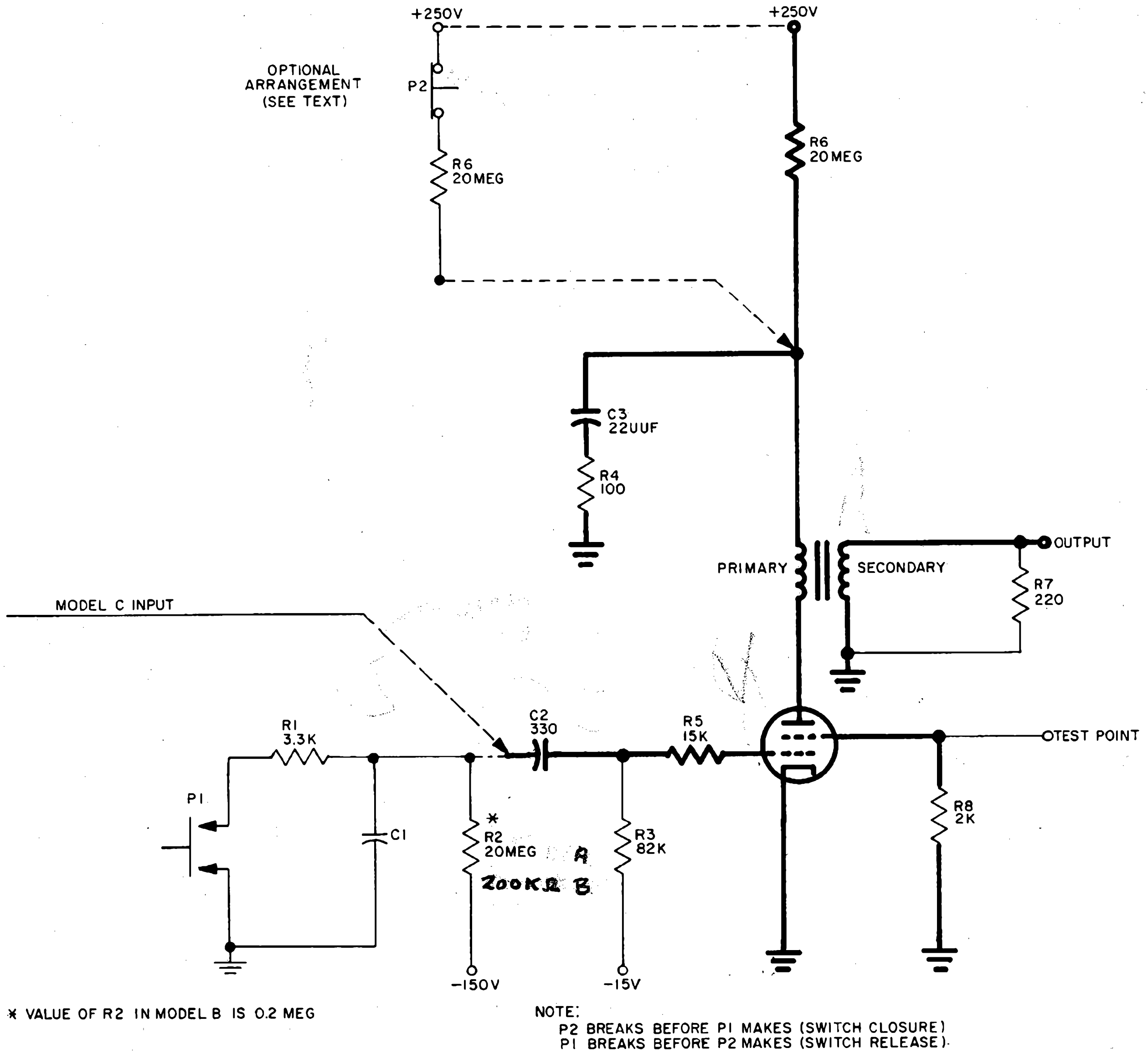


Figure 3—54. Pulse Generators, Models A, B, and C, Schematic Diagram

13.2.4 Basic Operation, Model D

This blocking-oscillator type pulse generator consists of a plate pullover triode, a tetrode-connected oscillator, and a pulse-shaping transformer. A shift from the down to the up level at the input is necessary to trigger the circuit. The output is a standard pulse.

13.2.5 Detailed Operation, Model D

A schematic diagram of the $_D$PG is shown in figure 3—55. Table 3—24 is the associated list of detail parts and their functions.

With the application of power to the pulse generator, both tubes are cut off. Tube V1 is maintained at cutoff by —15 volts applied to the grid through resistors R1 and R2. Tube V2 is cut off by —30 volts applied to the control grid through resistor R3 and the secondary of transformer T1. A positive level shift is applied to the grid of triode V1 through coupling capacitor C2, driving V1 into conduction. Plate current then flows through the primary of transformer T1, inducing a voltage in the secondary. The transformer is so connected that an increase of current in the primary causes the grid of pentode V2 to become positive, overcoming the —30-volt cutoff bias. With tube V2 conducting, additional current flows in the primary of transformer T1, increasing the positive voltage on the control grid of tube V2. Plate current increases until plate saturation is reached. Plate current is now constant, and the induced voltage on the secondary drops to 0 volt. The unopposed —30-volt bias cuts off tube V2, returning it to its original state. The resultant output pulse developed

TABLE 3–23. PULSE GENERATORS, MODELS A, B, AND C, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	USED ON	FUNCTION
C1	A & B	Part of trigger generating network (with P1, R1, and R2).
C2	A, B, & C	Grid coupling V1.
C3	A, B, & C	Supplies current to tetrode V1 and aids in pulse forming.
P1	A & B	Part of trigger generating network (with C1, R1, and R2).
P2	A & B	Spurious pulse prevention.
R1	A & B	Part of trigger generating network (with P1, R2, and C1).
R2	A & B	Part of trigger generating network (with C1, P1, and R1).
R3	A, B, & C	Part of pulse forming network (with C3 and T1).
R4	A, B, & C	Grid return.
R5	A, B, & C	Grid limiting.
R6	A, B, & C	Charging resistor for C3.
R7	A, B, & C	Terminating resistor.
R8	A, B, & C	Grid return for V2 (test point).
T1	A, B, & C	Impedance matching and pulse-shaping transformer.
V1	A, B, & C	Thyratron tetrode.

TABLE 3–24. PULSE GENERATOR, MODEL D, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Decoupling network (with R3).
C2	Grid coupling capacitor for V1.
C3	Decoupling network (with R2).
C4	Decoupling network (with R4).
C5	Decoupling network (with R8).
C6	Output coupling capacitor for V2.
CR1	Damping diode for positive overshoot.
CR2	Damping diode for positive overshoot.
R1	Grid return for V1.
R2	Decoupling network (with C3).

SYMBOL REFERENCE	FUNCTION
R3	Decoupling network (with C1).
R4	Decoupling network (with C4).
R5	Cathode load resistor.
R6	Parasitic suppressor.
R7	Current limiting resistor for CR1 and CR2.
R8	Decoupling network (with C5).
T1	Pulse forming and feedback to grid of V2.
V1	Plate pullover triode.
V2	Tetrode-connected pentode.

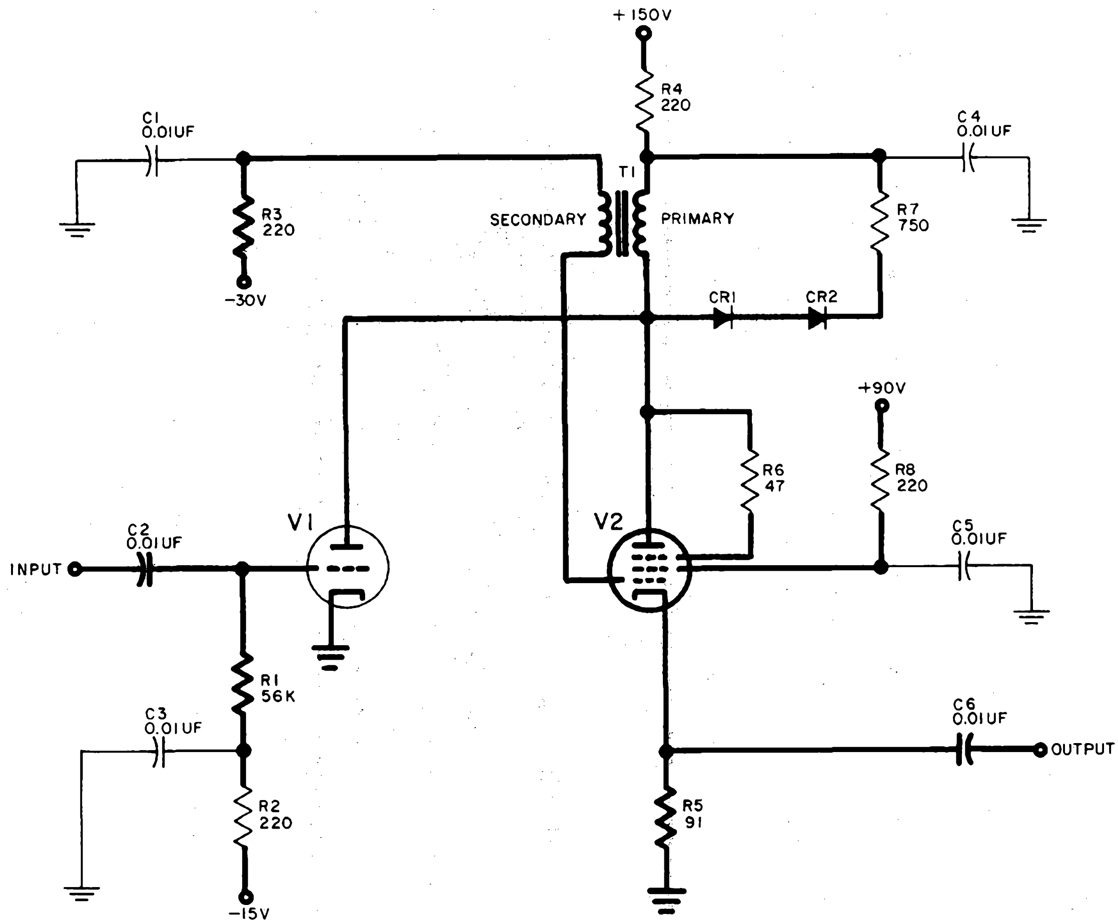


Figure 3—55. Pulse Generator, Model D, Schematic Diagram

across resistor R5 is coupled to a load through capacitor C6.

Diodes CR1 and CR2 and resistor R7 damp out oscillations of transformer T1. Resistor R2 and capacitor C3, capacitor C5 and resistor R8, capacitor C4 and resistor R4, and capacitor C1 and resistor R3 form decoupling networks.

Refer to table 3—24 for the function of detail parts not discussed.

13.2.6 Detailed Operation, Model E

The $_E$PG consists of a duo-triode tube, a pulse transformer, a pentode tube, and an output transformer.

A schematic diagram of the $_E$PG is shown in figure 3—56. Table 3—25 is the associated list of detail parts and their functions.

When power is first applied to the $_E$PG, triode V1A conducts and triode V1B is cut off. Triode V1B and pentode V2 are cut off by the —15 volts applied to the control grid of each tube. Triode V1A conducts as a result of the 10-volt level applied to the input of the $_E$PG. When the level at the grid input of the $_E$PG shifts to —30 volts, tube V1A is cut off. With plate

TABLE 3—25. PULSE GENERATOR, MODEL E, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Decoupling network (with R3).
C2	Grid coupling capacitor for V1B.
C3	Decoupling network (with R7).
C4	Grid coupling capacitor for V1A.
C5	Grid coupling capacitor for V1B.
C6	Decoupling network (with R9).
C7	Grid coupling capacitor for V2.
C8	Decoupling network (with R11).
C9	Decoupling network (with R12).
C10	Decoupling network (with R14).
CR1	Damping diode.
L1	Peaking coil.
R1	Input isolating and limiting.

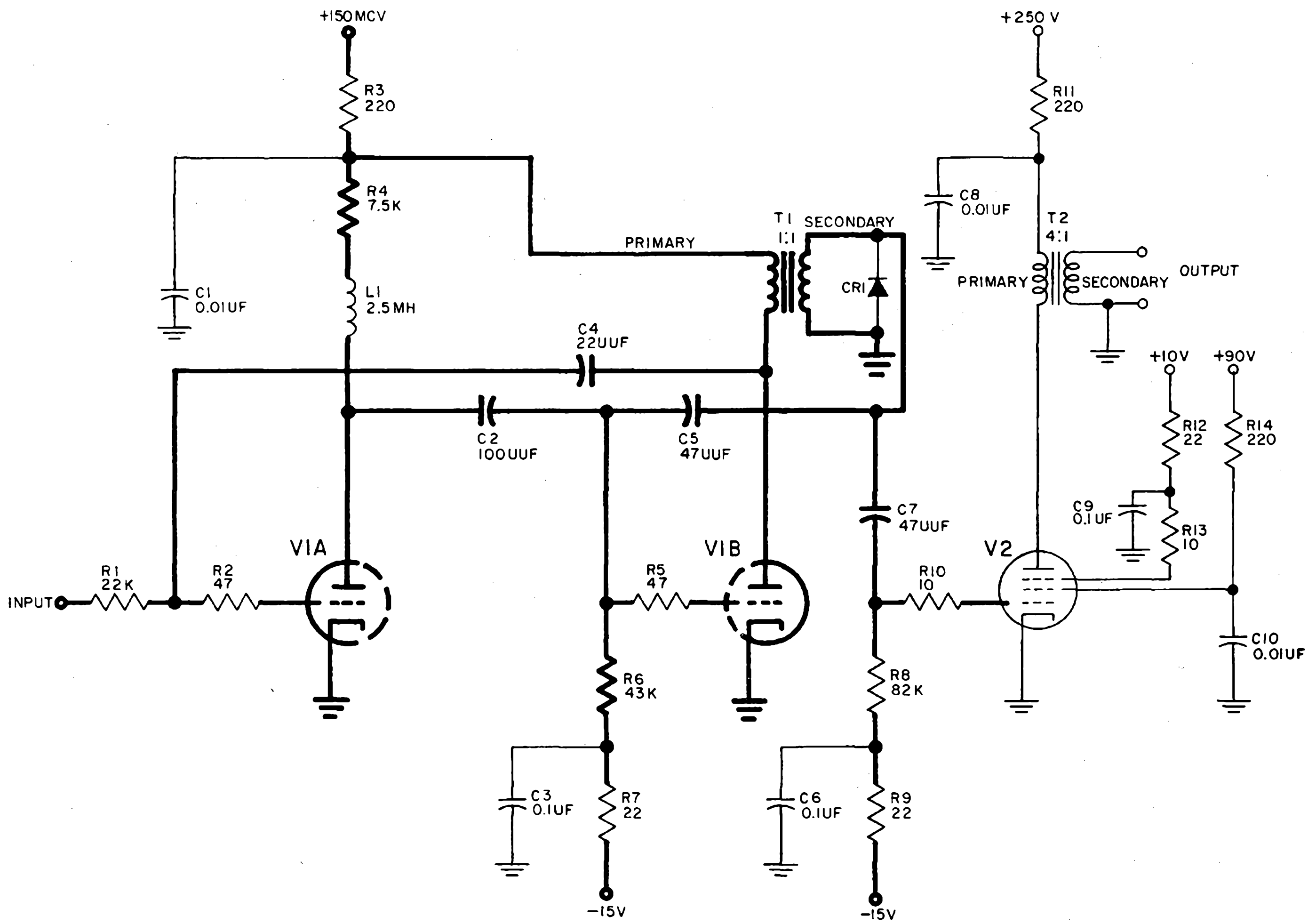


Figure 3–56. Pulse Generator, Model E, Schematic Diagram

TABLE 3–25. PULSE GENERATOR, MODEL E, FUNCTION OF DETAIL PARTS (cont'd)

REFERENCE SYMBOL	FUNCTION
R2	Parasitic suppressor.
R3	Decoupling network (with C1).
R4	Plate load V1A.
R5	Parasitic suppressor.
R6	Grid leak V1B.
R7	Decoupling network (with C8).
R8	Grid leak V2.
R9	Decoupling network (with C6).
R10	Parasitic suppressor.

REFERENCE SYMBOL	FUNCTION
R11	Decoupling network (with C8).
R12	Decoupling network (with C9).
R13	Parasitic suppressor.
R14	Decoupling network (with C10).
T1	Pulse forming.
T2	Transformer output coupling.
V1A	Plate pullover triode.
V1B	Blocking oscillator triode.
V2	Amplifier pentode.

current reduced to 0, the plate of triode V1A rises to +150 volts. The rise of plate voltage is coupled to the grid of triode V1B by capacitor C2, causing V1B to conduct. Increasing plate current through the primary of transformer T1 induces a potential on the secondary. This positive voltage coupled to the grid of V1B through capacitor C5 causes grid current to flow, charging capacitors C2 and C5.

The plate current through triode V1B increases until plate saturation is reached and then levels off. At this point, where the current through transformer T1 is constant, the voltage across the secondary drops to 0. The charges developed across capacitors C2 and C5, added to the —15-volt bias, holds triode V1B well past cutoff, blocking further operation of the $_E$PG, until this charge leaks off through resistor R6.

The positive shift in voltage that appears at the plate of V1B is coupled to the grid of V1A through capacitor C4. This results in a negative shift at the plate of V1A which, coupled to the grid of V1B, aids in bringing V1B to cutoff more rapidly.

The action just described maintains the $_E$PG in an insensitive state for several microseconds after cutoff of triode V1B is reached, eliminating the possibility of erroneous multiple pulse output.

The pulse at the secondary of transformer T1 is coupled to the grid of pentode V2 by capacitor C7. This pulse overcomes the —15-volt bias on the control grid of pentode V2, and the tube conducts. The resulting pulse of plate current through the primary of transformer T2 results in a standard pulse output. The 4-to-1 ratio of primary to secondary turns effects a 16-to-1 impedance match from the pentode V2 plate to the output. The transformer also shapes the output pulse.

A more detailed description of the amplifier section of this generator (V2) is found in Chapter 3. Refer to table 3—25 for the function of detail parts not discussed.

CHAPTER 14

DELAY UNIT GROUP

14.1 DEFINITION AND DESCRIPTION

Delay unit, model C ($_C$D), is a logic circuit consisting of a delay line and a delay line driver. Table 3–26 shows the logic block symbols for the delay unit and its component parts. The purpose of the delay unit is to delay information (a standard pulse) for a fixed length of time. The standard pulse is fed to the delay line by the delay line driver. It appears at the output of the delay line a fixed time after the initial pulse is applied to the input.

14.2 PRINCIPLES OF OPERATION

14.2.1 Detailed Operation of Delay Line

The delay line consists of a series of LC filter sections (see fig. 3–57). A standard pulse applied to the input of the delay line charges C1 in a finite period of time. The voltage developed across C1 causes current to flow through L1, charging C2. This process continues with L2 and C3, L3 and C4, and L4 and C5. Finally, C5 discharges through terminating resistor R1, producing a voltage pulse. This pulse will appear a fixed time after the standard pulse is applied to the input. The time difference between these pulses (the delay) is determined by the values of L and C and the number of LC sections. The nominal time difference of a delay unit is 0.5 microsecond. When a smaller delay is needed, the delay line may be tapped at one of the LC sections. For greater delays, lines are cascaded (connected in series).

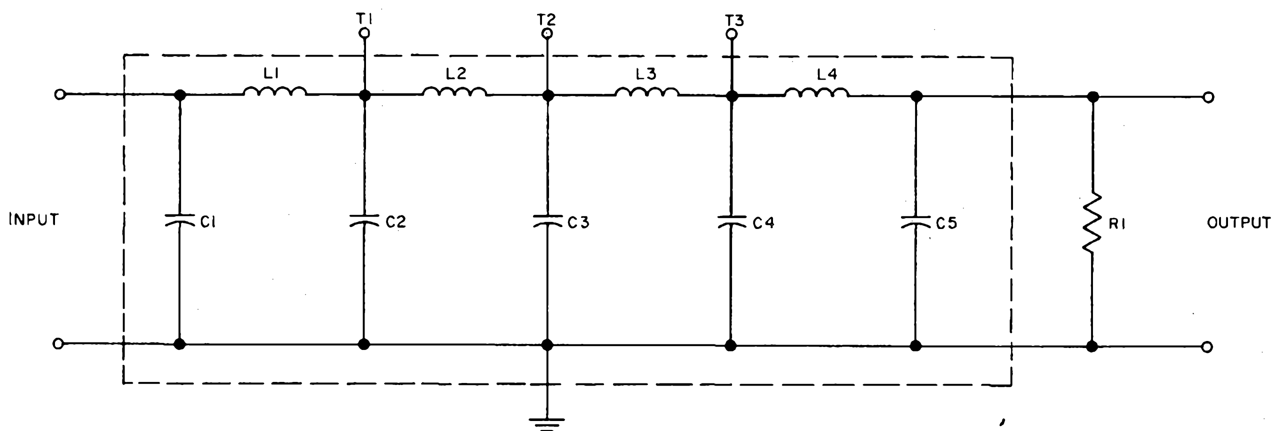


Figure 3–57. Typical Delay Line

TABLE 3–26. DELAY UNIT, LOGIC BLOCK SYMBOLS AND FUNCTIONS

NAME	LOGIC BLOCK SYMBOL	FUNCTION
Delay unit, model C ($_C$D)	→ $_C$D 0.5 usec →	Delays information for a fixed period of time. Composed of delay line and driver.
Delay line	→ 0.5 usec →	Provides necessary delay.
Delay driver, model A ($_A$DD)	→ $_A$DD →	Provides power amplification necessary to drive delay line.

14.2.2 Detailed Operation of Model A Delay Line Driver

Figure 3–58 is a schematic diagram of the model A delay line driver. Table 3–27 is the associated list of detail parts and their functions. Pulse power is required to drive the delay line because a 40-volt standard pulse is being fed to a 100-ohm load (the impedance of the delay line). The model A delay line driver provides this power. It is basically composed of an input transformer, a tetrode-connected pentode, and an output transformer. A standard pulse is applied to the input transformer. The output of the transformer is a positive pulse amplified by a factor of 3. This pulse is applied to the control grid of vacuum tube V1. Tube V1 is a tetrode-connected pentode; this arrangement provides more power output than a pentode. Bias considerably below cutoff is provided by a fixed −30 volts on the control grid. The pulse at the secondary of the input transformer overcomes this bias and causes V1 to conduct heavily. The resulting plate current flows through the primary of the output transformer. The negative-voltage pulse at the plate of V1 is inverted at the output of transformer T1, feeding a positive pulse to the delay line. Transformer T1 matches the high impedance of the plate of V1 to the low impedance of the delay line. It also steps down the voltage by a factor of 4, thereby increasing the current four times.

Decoupling networks are provided because the $_{A}$DD is connected to common service voltage lines. These networks isolate the $_{A}$DD from other circuits powered from the same supplies. Diode CR1 is a clamping diode for negative overshoots.

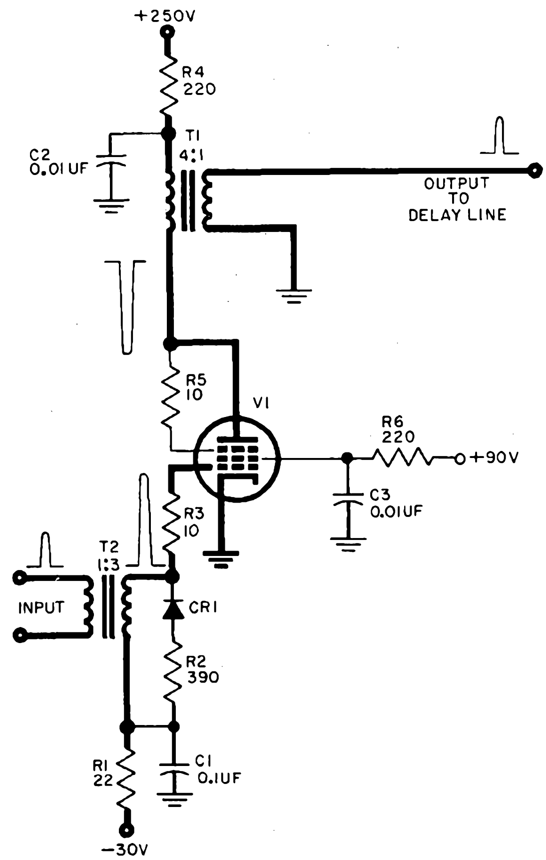


Figure 3–58. Delay Line Driver, Model A

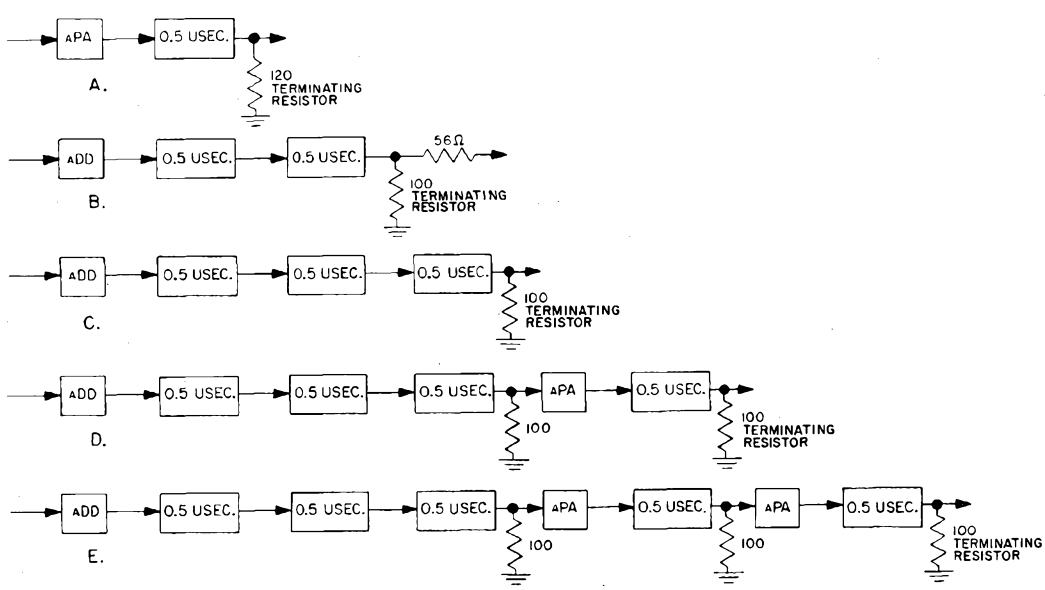


Figure 3–59. Typical Arrangements of Delay Units

When it is necessary to cascade delay lines for longer delays, the standard pulse is distorted beyond acceptable limits. To correct this condition, $_A$PA is used instead of an $_A$DD to drive each additional delay line. Arrangements of delay lines and driving sources are shown in figure 3–59. When tapped delay lines are used for delays shorter than 0.5 microsecond, series-limiting resistors are used to limit pulse amplitude. The values of these resistors depend on the load and on the position of the tap in the delay line. Refer to table 3–27 for the function of detail parts not discussed.

TABLE 3–27. DELAY LINE DRIVER, MODEL A, FUNCTION OF DETAIL PARTS

REFERENCE SYMBOL	FUNCTION
C1	Part of RC decoupling network (with R1).
C2	Part of RC decoupling network (with R4).
C3	Part of RC decoupling network (with R6).
R1	Part of RC decoupling network (with C1).
R2	Current-limiting resistor for CR1.
R3	Parasitic suppressor.
R4	Part of RC decoupling network (with C2).
R5	Parasitic suppressor.
R6	Part of RC decoupling network (with C3).
T1	Output transformer.
T2	Input transformer.
V1	Tetrode-connected pentode.

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