varying the position of the tap switch, the voltage across the secondary is changed. Since the voltage drop across the tube and the choke does not vary to any extent, any change in the secondary voltage will result in a change in the +150 volt line. 147 to 152 volts are acceptable.

After the +150 volt line is adjusted, the bias voltages may be adjusted in any order. The −100 volt line and the −250 volt line are both adjusted by means of potentiometers. Both potentiometers are accessible from the rear of the power supply chassis. The +65 volt supply is also adjusted by means of a potentiometer in the B chassis.

PRINCIPLE OF MULTIPLYING

Multiplication is performed in this machine by over-and-over addition of the multiplicand factor. The value of the multiplier digit determines the number of times that the multiplicand is to be added into the product counter. The order of the digit (i.e., units, tens, etc.) determines which positions of the product counter will receive the multiplicand factor and also during which column shift cycle the adding will take place. An example of multiplication by over-and-over addition is shown in Figure 58. Observe that no adding occurs in the 12th position of the product counter; this position is reserved for carry-overs. This method of multiplication is the simplest possible since only three counters are required. This method is not feasible for mechanical machines, because the time required to complete a problem is too great. However, electronic addition is so rapid that it permits use of this simple method. The time required by the electronic unit to complete a problem by this method corresponds to slightly over one-half a cycle point of mechanical movement of the card through the punch unit.

Observe that the column shifting is performed in the reverse order to that customarily done when multiplying by hand. The order of column shifting is immaterial, as the final result will be the same regardless of the order in which the multiplier factors are taken. In the 603 multiplier, column shifting is from the 6th multiplier position to the first simply because the earliest engineering model required it. When changes were made which no longer required reverse column shifting, it was felt that it was not feasible to make the necessary circuit changes to establish normal column shifting.

Note from Figure 58 that no addition occurs during column shift cycles in which the multiplier is 0. Mechanical machines usually have some arrangement to test for 0's so that all multiplier positions containing 0 may be skipped. This complicates the machine but saves time. Where time is not a factor, this unnecessary complication may be eliminated by completing all the column shift cycles regardless of the value of the multiplier digit. This is done in the 603 electronic computing unit; six column shift cycles are taken for every multiplication regardless of the value of the multiplier.

Also observe from Figure 58 that the multiplicand is added into the product counter as many times as the value of the multiplier digit by which multiplication is taking place. This means that during any given column shift cycle, the multiplicand may have to be added as many as 9 times. Again, to avoid unnecessary complications a fixed number of adding cycles are taken each column shift cycle regardless of the value of the multiplier digit. In the 603 computing circuits ten adding cycles are taken during each column shift cycle rather than nine for reasons explained later. This means that each multiplication consists of six groups of ten adding cycles, or a total of 60 adding cycles.

The computing section of the 603 multiplier is arranged so that a definite number of voltage pulses represent an adding cycle. For an analogy to a mechanical machine, one pulse may be considered as one cycle point of the basic adding cycle. The basic adding cycle consists of 16 pulses; 10 are reserved for adding, 4 for carrying, and the other

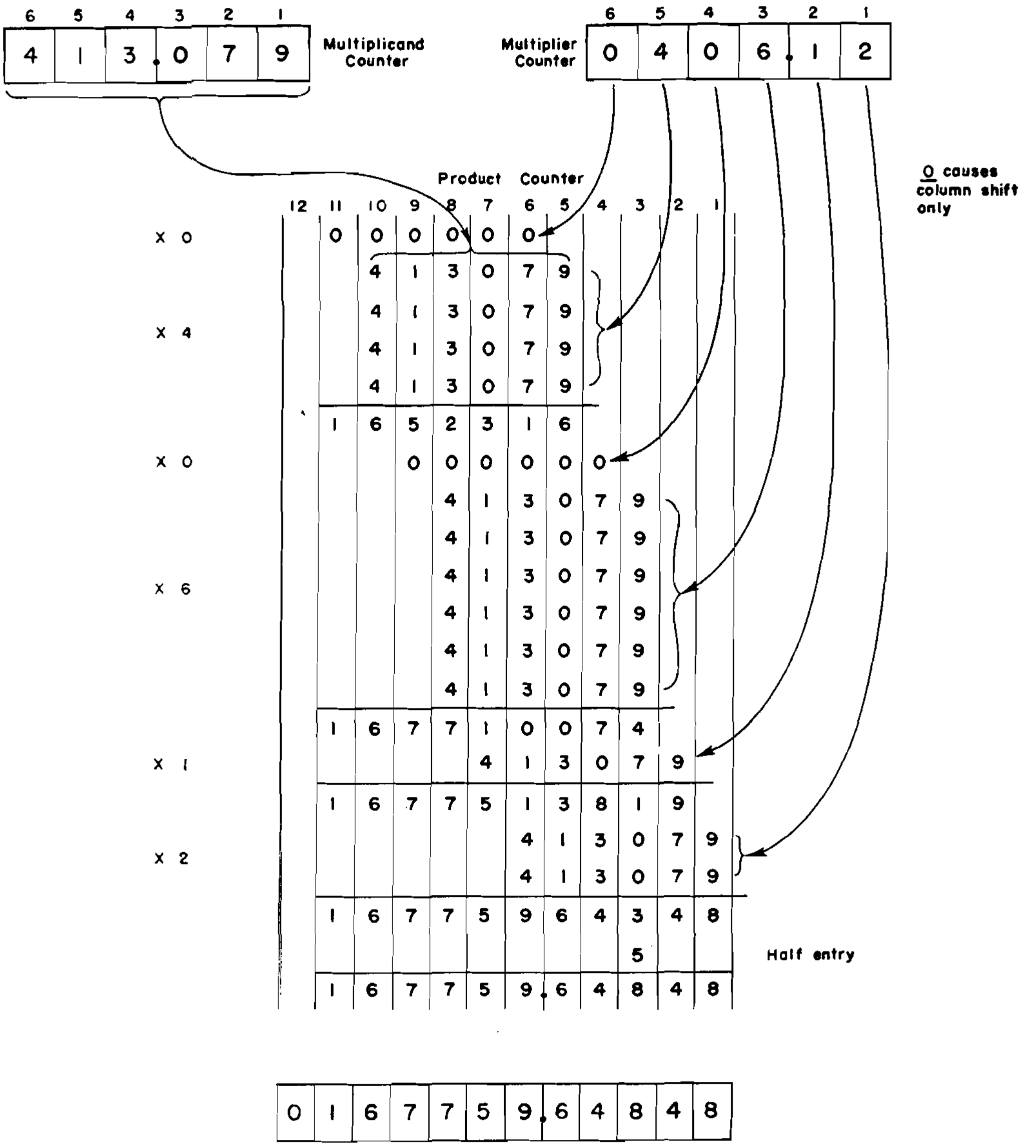


Figure 58. Principle of Multiplication

2 for setting up certain circuits. It is obvious then that one multiplication will require a total of 960 pulses, since there are 60 adding cycles of 16 pulses each. In order to establish these cycles electronically it is necessary to provide pulse counters. Three of these pulse counters are provided—one to count pulses and establish the basic adding cycle; one to count adding cycles and determine when to column shift; and one to count column shift cycles. These three pulse counters are called the primary timer, secondary timer, and tertiary timer. Figure 59 is a block diagram showing the operation of the three timers in schematic form. A careful study of Figure 59 is essential for proper understanding of the electronic cycle. All pulses for the electronic computing operation are generated by a multivibrator which is an oscillator generating essentially square waves of 35,000 cycles per second frequency. The multivibrator generates pulses continually as long as the power is ON,

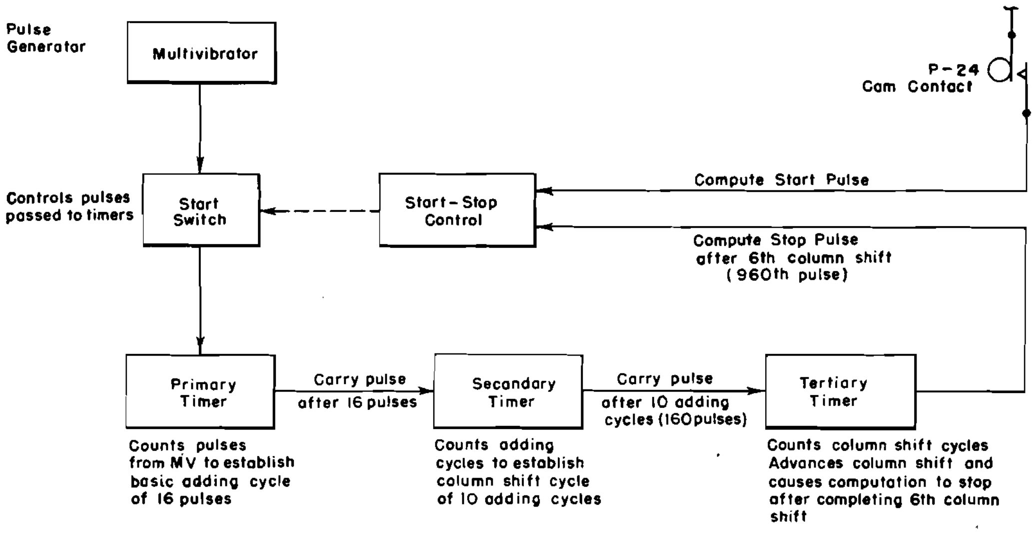


Figure 59. Block Diagram of Timers

but these pulses cannot pass to the timers until permitted by the electronic start switch. The start switch is controlled by an electronic start and stop control which opens the switch and closes it. For an analogy, the electronic switch may be visualized as a valve. An open switch permits pulses to pass while a closed switch prevents passage of pulses. After the factors are read into the counters from a card passing the entry brushes, the compute start contact P24 makes (at 11.5 on the punch index) to start computing. This is done by opening the start switch and permitting pulses to pass to the electronic timers (or pulse counters). On every 16th pulse entering the primary timer, a carry pulse is passed to the secondary timer which advances 1 to indicate that one adding cycle has been completed. When 10 adding cycles are completed, the secondary timer carries, and a pulse is passed to the tertiary timer to signal a column shift. When 6 column shift cycles have been completed, a pulse from the tertiary timer passes to the compute stop control, and the start switch is again closed, thus stopping the pulses from passing to the timers after 960 pulses have been counted and indicating the completion of the problem. This entire operation requires only 27 milliseconds during which time the punch index moves 6 teeth.

As an example of the multiplication operation, 4 x 8 may be used as a problem. The multiplier 4 indicates that the multiplicand 8 is to add into the product counter 4 times. The 8 in the multiplicand counter indicates that the product counter is to receive 8 impulses during each of four adding cycles for a total of 32 pulses.

Figure 60 indicates the machine operation in schematic form. Since the only digit in the multiplier is in the units position, not until the sixth column shift cycle will there be signals to cause addition in the product counter. Then during the sixth column shift, 8 pulses are added into the product counter during each of the last four adding cycles. Observe that the machine goes through all adding cycles and all column shift cycles even though addition occurs only during the last four adding cycles of the last column shift cycle.

For a more complete illustration, the same problem shown in Figure 58 is worked out in detail in Figure 61, showing all the adding cycles through which the machine goes to complete one multiplication. Notice that during the entire first column shift cycle consisting of ten adding cycles no adding takes place because there is a 0 in 6th position of the multiplier. During the second column shift cycle the multiplicand is added into the product

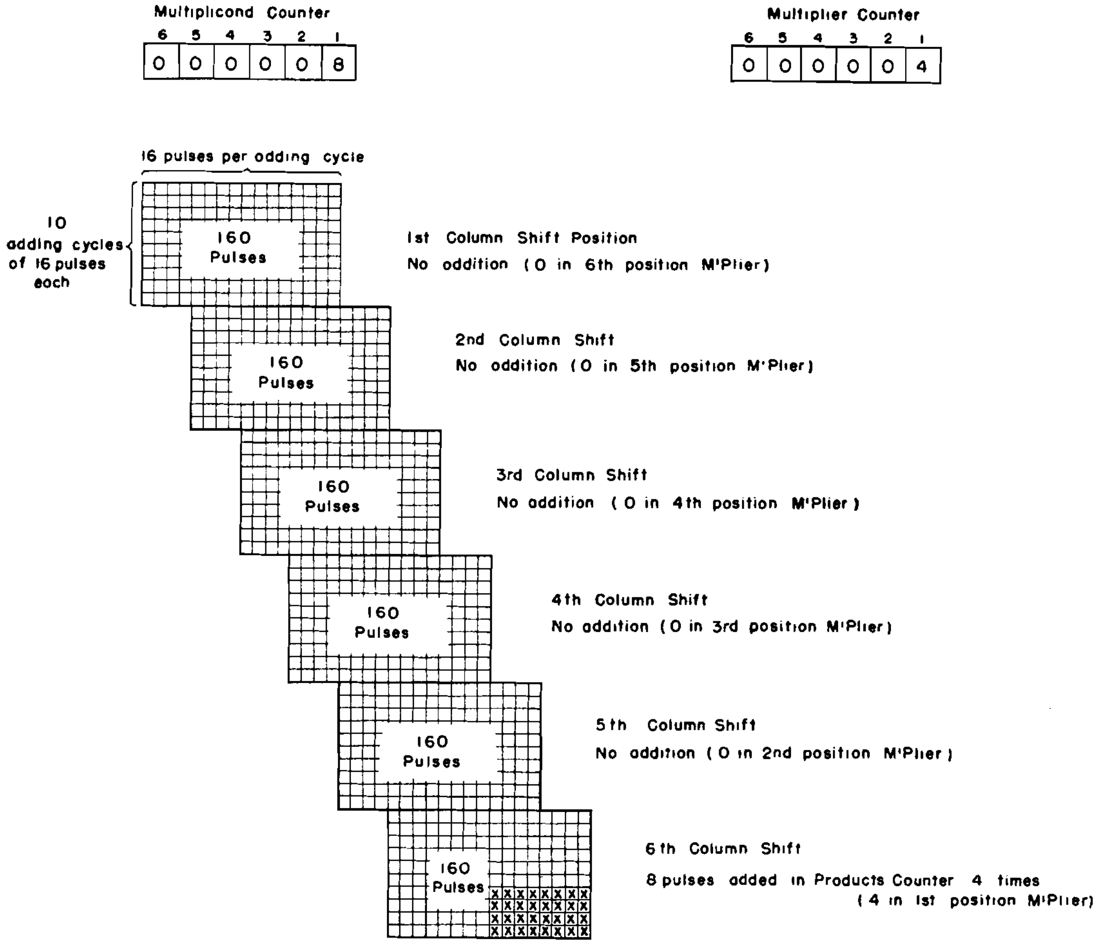


Figure 60. Block Diagram of Multiplication by Over-and-Over Addition

counter only during the last four of the ten adding cycles, because the multiplier digit in the 5th position is a 4, etc.

If half-entry is being used, a 5 is added into the proper position of the product counter during the first adding cycle of the last column shift cycle. Observe that except for half-entry, no adding takes place in the products counter during the first adding cycle of each column shift. One reason for having ten adding cycles in each column shift cycle is to permit half-entry during a cycle when no other addition is taking place.

Figure 61 indicates how the machine determines the number of times to add the multiplicand amount in the product counter during any given column shift. One position of the multiplier is advanced 1 during each adding cycle. Since there are ten adding cycles in each column shift, each position will advance through 0 and back to where it started. When the counter position goes from 9 to 0, a signal is provided to start adding the multiplicand on the next adding cycle and to continue through the tenth adding cycle. Figure 61 shows this operation for all six column shift cycles. There are no carry circuits in the multiplier counter; hence adding ten pulses to each position will return the counter to its original reading. The chief reason for having ten adding cycles in each column shift instead of nine is to permit restoration of the counter to its original reading at the completion of a multiplication. This is necessary when group

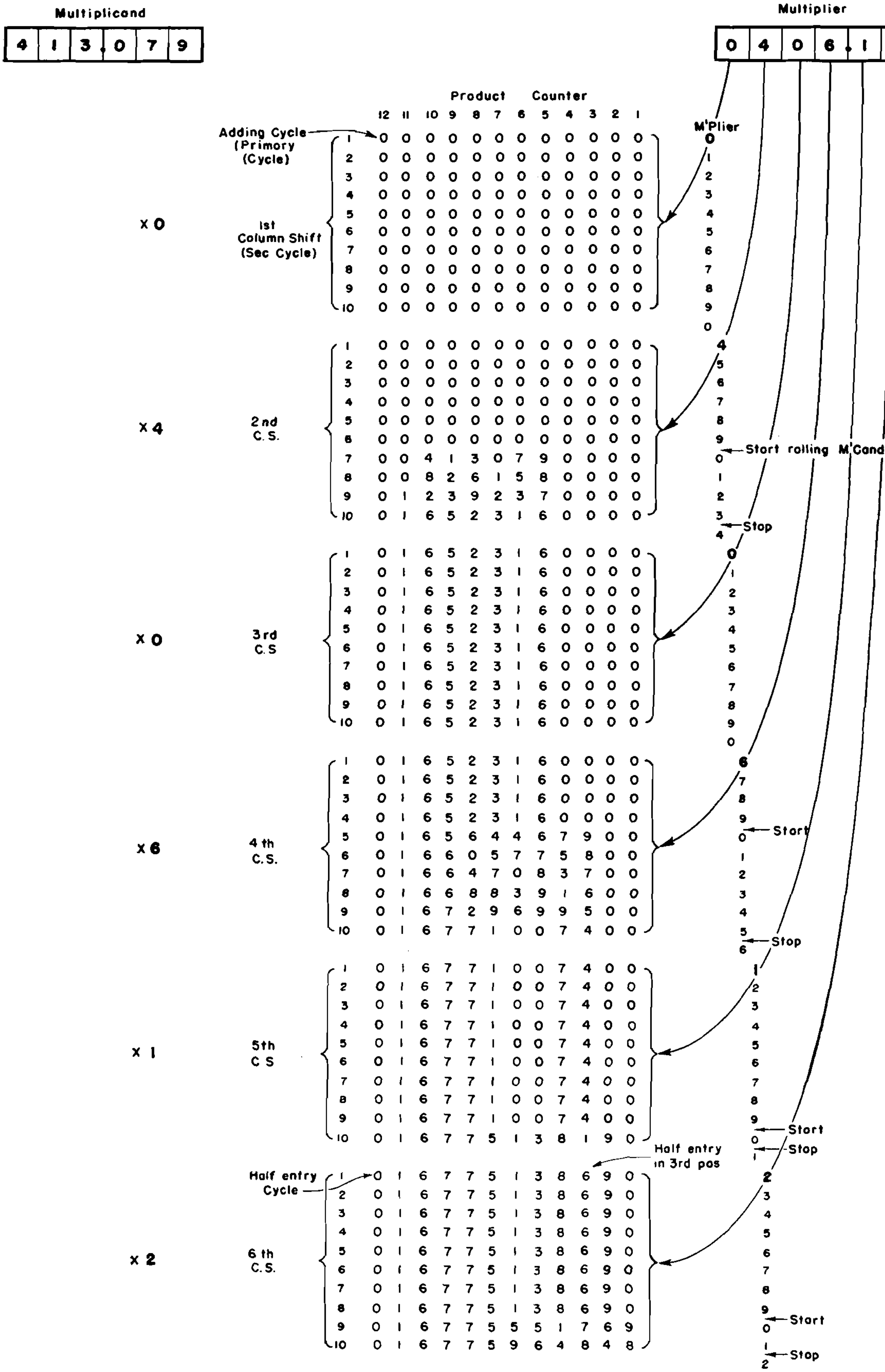


Figure 61. Principle of Multiplication Showing Detailed Operation

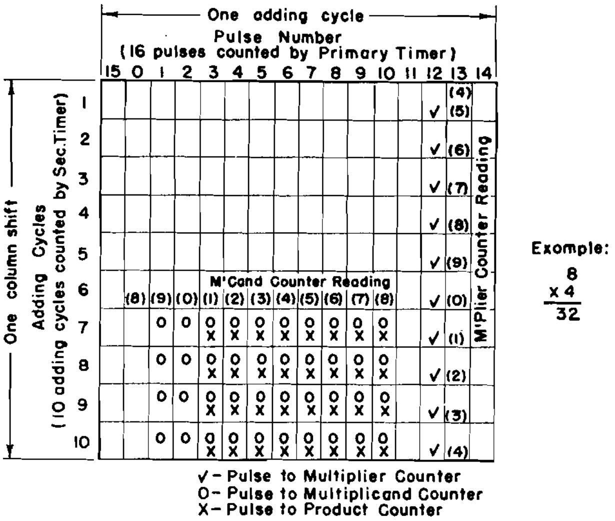


Figure 62. Schematic Showing Details of Operation of One Position

multiplying, because the same multiplier is used for a large number of multiplications.

For a more complete understanding of the multiplying operation, the last column shift cycle in the illustration in Figure 60 is analyzed in detail in Figure 62. This schematic shows all that takes place in one position of the multiplicand and product counters during one column shift cycle. All column shift cycles are alike except for the digit in the multiplier; consequently, a careful study of Figure 62 should illustrate the principles employed by the 603.

Observe that Figure 62 illustrates 10 adding cycles (laid out horizontally) divided into 16 pulses each (vertical divisions). Also observe that the pulses are not numbered from zero; the first pulse is number 15. This method of counting the pulses is used for the same reason that the first division on the punch index after unlatching is 14 instead of 9. A short time is necessary for setup before addition starts, and it is desired to have the pulse number correspond to the actual number of pulses added into the multiplicand counter.

As indicated in Figure 62, near the end of each adding cycle one pulse is added to the multiplier position corresponding to the column shift cycle. This pulse is the number 12 pulse of each cycle (14th pulse from the start of the cycle). Since there are ten adding cycles, the multiplier position will return to its original reading in the tenth adding cycle. During the 6th adding cycle the multiplier position advances from 9 to 0. This provides a signal to the multiplicand to add into the product once during each of the 4 remaining adding cycles.

The method of transferring the multiplicand to the product counter is also shown in Figure 62. When the signal is received from the multiplier counter, each position of the multiplicand counter receives 10 pulses during *each of the remaining adding cycles* of the column shift cycle. This means that each position of the multiplicand is "rolled" once each adding cycle and returned to its original reading. Since there are no carry circuits for the multiplicand counter, the counter may be rolled as many times as desired without changing the reading of the counter. When a position of the multiplicand counter is rolled, it passes from 9 to 0 sometime during the adding cycle, as determined by the value of the digit in that position. When this occurs, it is a signal for the product counter to receive all the remaining pulses of the group of 10. This effectively transfers the multiplicand digit to the product counter; this transfer will occur once each time the multiplicand counter is rolled. An examination of Figure 62 will reveal that in the illustrated problem the multiplicand is rolled 4 times, and the product counter receives 8 of the 10 rolling pulses during each adding cycle that the multiplicand rolls. Since it requires 2 pulses to bring the multiplicand to 0, it means that the 8 remaining pulses pass to the product counter.

Figure 62 illustrates only one position of the multiplicand counter. Remember that all six positions will be rolling simultaneously during an actual multiplication. From Figure 61 it will be remembered that the multiplicand is transferred to the product counter many times during the multiplication. However, each transfer is identical to

Multiplicand Counter Position

Pulse Number	6	5	4	3	2	1
15	4	1	3	0	7	9
0	4	1	3	0	7	9
1	5	2	4	1	8	0
2	6	3	5	2	9	1
3	7	4	6	3	0	2
4	8	5	7	4	1	3
5	9	6	8	5	2	4
6	0	7	9	6	3	5
7	1	8	0	7	4	6
8	2	9	1	8	5	7
9	3	0	2	9	6	8
10	4	1	3	0	7	9
11	4	1	3	0	7	9
12	4	1	3	0	7	9
13	4	1	3	0	7	9
14	4	1	3	0	7	9

Pulses to M'Cond start here

Pulses to Product Counter start after M'Cond passes from 9 to 0, as indicated by double lines.
(No carry in M'Cond counter)

Pulses stop here

Transferring 413079 from M'Cond to Product Counter

Figure 63. Operation of Multiplicand Card Counter During Transfer to Product Counter

the other except for the positions of the product counter which receive the multiplicand. Figure 63 illustrates in detail one adding cycle during which the multiplicand is transferred to the product counter once. Observe that each position of the multiplicand is rolled through 0 and back to its original reading. In each position a double line is drawn at the pulse number where that position passes from 9 to 0. The corresponding position of the product counter will receive all the pulses remaining of the 10 rolling pulses. In this way six positions of the product counter, as determined by the column shift position, will receive the proper number of pulses to add the multiplicand amount in the product counter.

A block diagram showing all the operations taking place when multiplying in the computing section is shown in Figure 64. All slow-speed pulses, which travel through the cable either to or from the punch unit in synchronism with the card movement through the punch, are shown in heavy lines to distinguish from the high-speed computing pulses in the electronic unit. Dotted lines indicate locking circuits, and light solid lines indicate pulsing circuits.

The master timer for the computing section is the multivibrator, which is a square wave oscillator generating essentially square waves of 35,000 cycles per second frequency. The clipper clips the multivibrator output to square the top of the wave, and its output is fed to the "A" and "B" pulse tubes which produce almost perfect square waves 180° out of phase with each other. In other words, "A" pulses are going positive at the same time "B" pulses are going negative, and vice versa. These pulses are used throughout the computing section for high-speed computing. "A" and "B" pulses are being produced continuously as long as power is on the tubes, but nothing happens until the start switch is opened to allow the pulses to start a computation. The reason for two pulse sources will become apparent when the actual circuits are discussed.

The multiplier and multiplicand factors are read into their corresponding counters from the card as it passes the entry brushes. The principle used in reading into electronic counters will be discussed later in the circuit description.

After the factors are read into the counter, P24 cam contact makes to start the computation. P24 trips the start trigger and opens the start switch to start the primary timer by feeding a stream of "A" pulses to it. As previously explained, the primary timer is an electrical timer which counts 16 pulses to establish the basic adding cycle. The operation of all computing circuits is based on this timer. The primary timer counts 16 pulses and then returns to zero to produce a 16-point cycle effectively. Thus the reading of the primary timer is equivalent to the index used in the punch unit.

The primary timer in turn operates the secondary timer which in turn operates the tertiary timer. For every primary cycle (or adding cycle) the secondary timer receives one pulse and advances one. After 10 pulses the secondary timer returns to zero and starts over, at the same time advancing

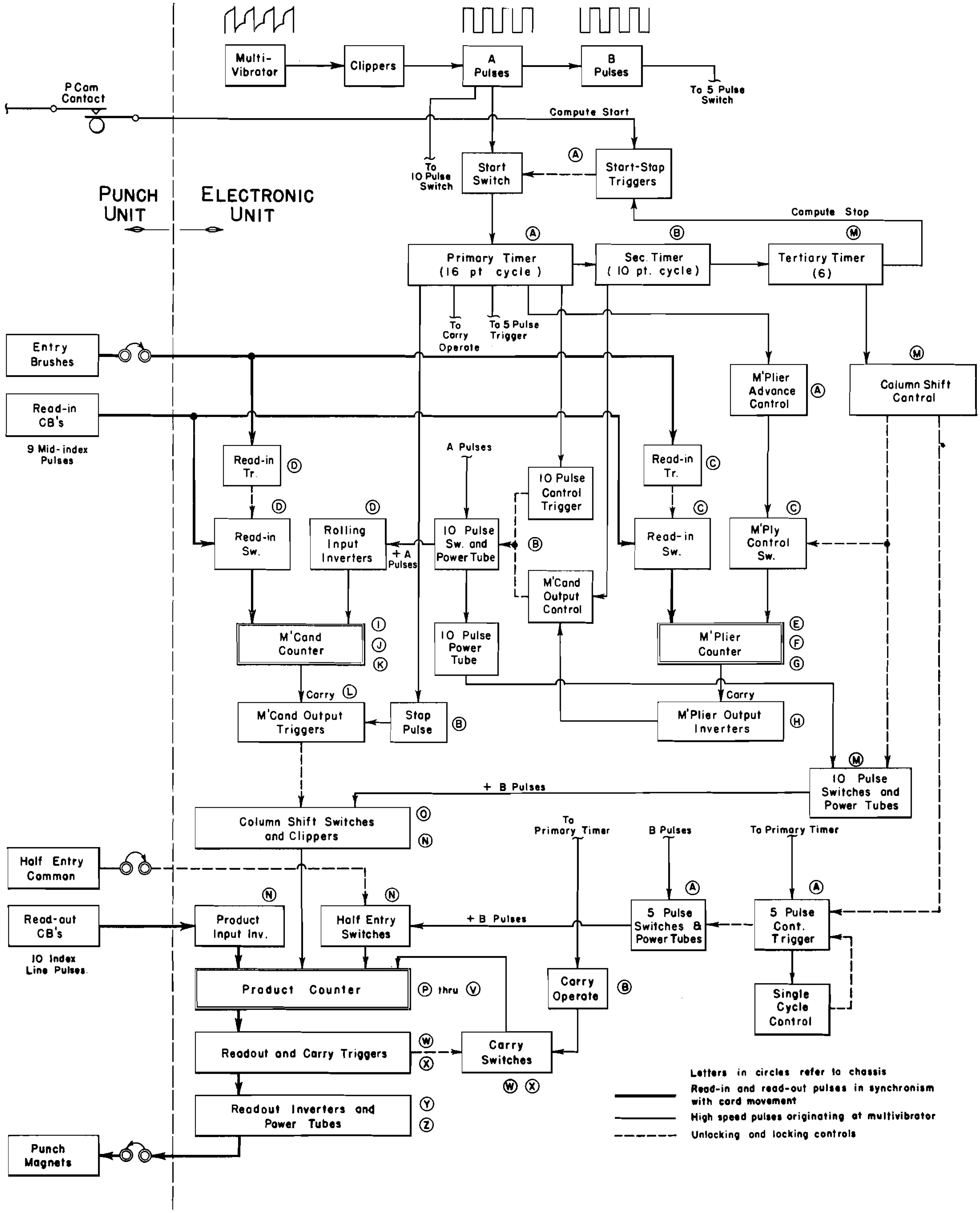


Figure 64. Block Diagram of Type 603 Circuits

the tertiary timer one; hence, it is obvious that the tertiary timer advances once for each 10 primary cycles. The secondary timer provides 10 adding cycles in each column shift position while the tertiary timer controls the column shift.

During each primary cycle, a pulse is passed to the multiplier counter by the multiplier advancing control through the multiplying control switch, thus advancing the proper position of the multiplier 1. The multiplier counter position receiving the pulse depends upon the column shift position as indicated in Figure 64 by the dotted line from the column shift control to the multiplying control switch. Thus, at the beginning of a computation the pulse is passed to the 6th position of the multiplier counter, since column shifting is from left to right. During the adding cycle that the 6th position passes from 9 to 0, a carryover pulse through the multiplier output inverters opens the 10-pulse switch through the multiplicand output control to start rolling the multiplicand counter. For example, if the 6th position of the multiplier contains a 3, this counter position would pass from 9 to 0 during the cycle in which it received its seventh pulse from the multiplier advancing control. This means that there are 3 adding cycles left in the first position of column shift, and the multiplicand counter will be rolled three times in this column shift position.

Rolling the multiplicand counter is accomplished by adding 10 pulses to *all* positions of the multiplicand counter. Since there are no carry circuits for the multiplicand (or multiplier) counter, after ten pulses, each position will return to the same reading from which it started; a signal carry pulse will be provided from each position through the multiplicand output control when that position advances from 9 to 0. This carry pulse opens the column shift switches which have been conditioned for the first column shift position, and "B" pulses start adding into the product counter. The 10th rolling pulse then closes the column shift switches through the stop pulse control, and the product counter will have received as many pulses as the reading of the corresponding position of the multiplicand counter. In this same manner the figures in the multiplicand are rolled into the products counter three times during the first column shift cycle if there is a 3 in the 6th position of the multiplier. All carry pulses in the products counter are stored in the carry control section, and carry takes place at the end of each adding cycle (primary cycle).

When 10 primary (or adding) cycles have been completed, the tertiary timer is signalled to advance. The column shift control then feeds pulses to a new set of column shift switches to shift the output of the multiplicand over one column to the right in the product counter, and the 5th position of the multiplier counter starts receiving advancing pulses. Again when a carryover occurs, the multiplicand starts receiving rolling pulses. After this operation has been performed six times, the computation is complete and the primary timer is stopped.

Five pulses are added into the products counter during the first adding cycle of the 6th column shift cycle, if half-correction is wired on the control panel. An explanation of this operation is reserved for the section on circuit description.

After the end of the sixth column shift cycle, the product is retained until the card in the punch unit moves to punching position. To read out the answer from the product counter, CB's in the punch unit start pulsing the product counter at 9 on the index, and one is added to all positions of the product counter for each index point at the line of index. When a position in the products counter carries over, the carry pulse trips a power tube which energizes the corresponding punch magnet to cause punching of the proper digit in the card. A more complete description of this operation will be found in the circuit explanation.

Computing Circuits — General

The circuits for electronic computing are shown in Sections 21 through 80 of wiring diagram

213639A. The diagram is laid out by chassis to permit a close tie-in with the machine. None of the cable wiring is shown, but each cable wire or jumper is indicated at each chassis terminal on the wiring diagram.

The terminals on the chassis are numbered from 1 through 20 on the right side (facing the *rear* or wired side of the chassis). On the left side terminal strip the terminals are numbered 21 through 40. Across the top or bottom the terminals are numbered 41 through 60. Since no chassis has both a top and a bottom terminal strip, the same numbering is used for either top or bottom. Unused terminals retain their number and must be counted to locate the proper terminal. To prevent possible trouble from capacity coupling in the cables in the electronic unit, all cables carrying high-speed pulses traveling from one chassis to another are shielded.

A color code is used to identify all power lines *within* a chassis. This code does not hold for the cable wires. The wiring diagram indicates the color coding used. For reference it is repeated below.

Ground—Black
+65 volts—Slate
+150 volts—Red
−100 volts—Green
−100 volts—White
(Cancel)
−250 volts—Red-White
115 volts A.C.—Blue
(Filaments)

NOTE: On some chassis on early models the −250 volt lines were purple instead of red-white.

The +65 volt supply was added after the original circuit layout was made, hence the +65 volt line is placed above the +150 volt line on the circuit diagram.

In addition to the color coding used on all the power lines, all controlled grid and suppressor circuits are indicated by yellow wires. In some cases a slight departure from this rule is necessary, but usually a yellow wire indicates a grid or suppressor circuit. The cathodes of all tubes in the computing circuits (except the multivibrator) are connected to the ground line (zero potential), which is shown as a heavy line throughout all the electronic circuits.

There are only three types of tubes used in the computing circuits, namely, types 12SN7, 6SK7, and 25L6. The 12SN7 is a twin triode, used as a trigger, as a blocking tube, and as an inverter switch; the 6SK7 is a pentode used as an electronic switch; and the 25L6 is a beam power tetrode used as a power tube in circuits requiring power. Figure 65A shows the symbols for the tubes used, along with the pin connections on the tube, while Figure 65B shows the socket connections. The tube symbols are also shown in Section 22B of the wiring diagram. Observe that the 25L6 symbol is shown on the wiring diagram as a pentode with the suppressor internally tied to the cathode, whereas Figure 65A shows a symbol for beam-forming plates. The beam-forming plates act as a suppressor and for that reason the symbol often shows a suppressor tied to the cathode internally. In practical circuits, however, neither is shown in order to simplify the symbols. All circuits show the 25L6 with only two grids.

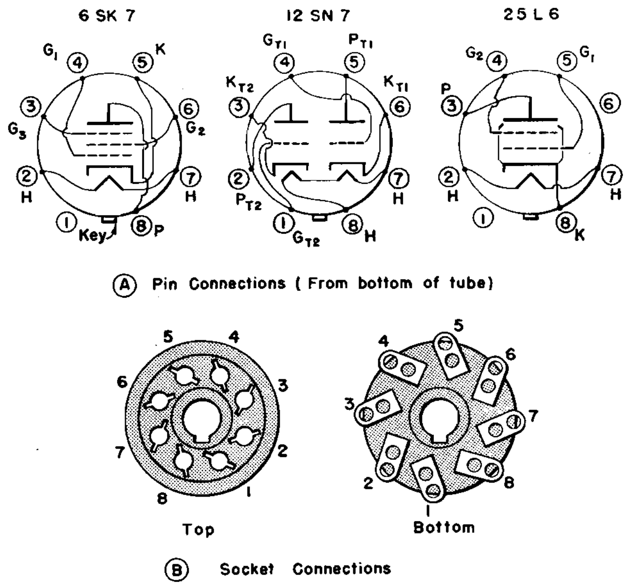


Figure 65. Tube and Socket Connections

Since the three tube types mentioned are the only types used in the computing circuits, they are not labelled by tube type. Merely remember that all triodes are 12SN7's; all tetrodes are 25L6's; and all pentodes are 6SK7's. As an aid to servicing, it is recommended that the pin connections of these three tube types be drawn on a card and the card kept in the bottom of the electronic unit for ready reference.

Spare tubes for replacement purposes are mounted in unused positions on the L, M, and W chassis. These spare tubes are readily identified by white tube sockets. The spares in the L and M chassis are 12SN7's, while the W chassis carries spare 25L6's, 6SK7's, one 6SJ7, and one 25Z6.

All the tubes used in the computing circuits draw the same filament current of 0.3 amperes, consequently the tube filaments can be wired in series in any arrangement. In order to allow connection to a common source, the filaments are connected in series strings providing a total potential drop of approximately 113 volts. In some cases a string of filaments may include tubes from two different chassis. The exact arrangement will be found on the circuit diagrams for the individual chassis. The filaments do not directly affect the circuit operation and for this reason no further reference will be made to the filament circuit. In several instances dummy tubes are used to fill out a filament string. These can be readily identified because the tube socket is painted red.

In describing the circuits, the control grids of all tubes will simply be referred to as *grids*, while the suppressor grids of the pentodes will be called *suppressors*. The screen grids of all the 25L6's and 6SK7's are connected to a +65 volt supply line which is shown above the +150 volt line on the circuit diagrams. The screens of 25L6's require a resistor in the circuit to limit the screen current. Resistors are used in the screen circuits of 6SK7's only to prevent parasitic oscillations when several screens are wired in parallel. The screen grids may be ignored in the description of the circuits unless they serve a functional purpose.

The anodes of all the tubes are connected to the +150 volt line through load resistors ranging from 5000 ohms for the 25L6's to 20,000 ohms for the 12SN7's and 6SK7's. The +150 volt line is shown parallel to and directly above the ground line. The 5000 ohm anode load resistors for the 25L6's are 5 watt wire-wound resistors to dissipate the energy in the anode circuit of the 25L6 power tubes, while the 20,000 ohm resistors are 0.5 watt carbon resistors of the BTS type.

The circuits are designed and the tubes are controlled in a manner to assure positive operation and to overcome chance or unavoidable differences between tubes of the same type. For this purpose, a tube is held non-conductive, when so required, by a potential on one of its grids which is considerably below cutoff. To drive a tube to a conducting state, its grid potential is given a tendency to rise considerably above cutoff. The grid resistor has a high value, so that grid current flow will bring the potential of the grid to the cathode potential.

The potential necessary to cut off the various tubes with +150 volts on the anode is as follows:

12SN7	– 9 volts
25L6	–25 volts
6SK7	–17 volts (grid)
	–40 volts (suppressor)

To insure safe operation, the following potentials are maintained at the grids of the various tubes when they are cut off:

12SN7	–25 volts
25L6	–35 volts
6SK7	–35 volts (grid)
	–50 volts (suppressor)

These potentials are maintained through resistor networks. The exact values of resistance in the voltage divider networks can be found in the circuit diagrams for the individual chassis. It must be remembered that exact voltage values are not always attainable because standard available resistors must be used. The values given above are approximate.

If a tube is to be maintained in a conductive state, its grid is connected to a high positive potential through a high value resistor. The grid current flowing through the grid resistor will reduce the grid potential to the cathode potential. Any tendency of the tube current to drop will be accompanied by a reduction in grid current, hence the grid potential will rise and overcome the tendency of the tube current to drop. This method of connecting the grid in normally conducting tubes overcomes any difficulty which is due to variations in individual tubes. All normally conducting tubes are indicated on the wiring diagram by placing an X under the cathode symbol.

In many parallel arrangements, grid resistors are used to prevent *parasitic oscillations.* A parasitic oscillation is any undesirable oscillation in a circuit which interferes with its normal operation, or lowers its efficiency. Parasitics may result from a momentary fluctuation of current through a tube which causes grid potentials on other tubes to change. This would cause current through these other tubes to change, which in turn changes the potential on the grids of the first tube, and creates a continuous interaction or oscillation. By placing resistors in the grid circuits, the effect of potential variations in one tube on the grid of another is decreased to a point where interaction is eliminated. An example of parasitic suppressing resistors is shown on the circuits for the C and D chassis. On the C chassis (Section 31) the suppressors of six 6SK7's are in parallel, while the D chassis (Section 34) shows six grids in parallel.

By-pass capacitors are also used in many cases throughout the computing section to prevent undesirable effects by *transient voltages.* Transient voltages are very rapid voltage changes resulting from load changes, fluctuation in supply voltage arcs resulting from breaking inductive circuits, etc.

Transients can cause parasitic oscillations if proper precautions are not taken. Also transients can cause improper operation of triggers. To eliminate possible transients caused by arcs, extreme care must be exercised to eliminate all arcs in the punch unit.

The trouble resulting from arcing at HD1 relay points may be used as an example. Although these points in the motor circuit are on the shielded side of the transformer, a heavy arc across its points will cause the product counter read-out trigger to operate and add 1's in the product counter. Of course this will happen only when the motor is being started. This trouble was eliminated by suppressing the arc with a 2 mfd capacitor across the HD1 points.

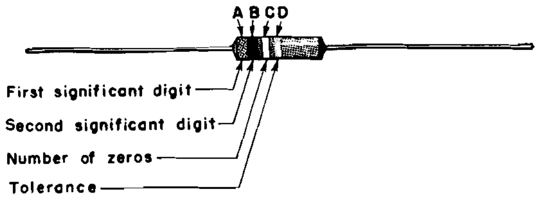
Transient voltage pulses may be transferred from one circuit to another by capacity coupling between wires in a cable. To minimize this possibility, all high-speed pulses traveling from one chassis to another not adjacent to it are carried by shielded cable.

An example of by-pass capacitors used to eliminate trouble from transients can be found in the circuit for the C chassis (Section 31). The .05 mfd capacitors at the input to the read-in triggers are by-passes for transients.

All resistor values are shown on the circuit in *megohms.* All capacitor values, shown as *whole numbers,* are in micro-microfarads, while capacitor values shown as *decimals* are in microfarads.

All tubular capacitors and wire-wound resistors are stamped with their value. However, the value of molded mica capacitors and carbon resistors is indicated by color code only. The code used is shown in Figure 66.

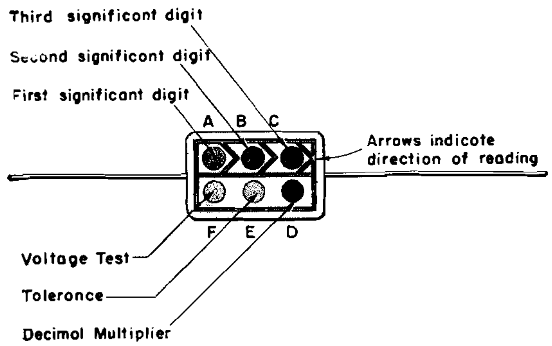
As an example, a resistor with a yellow stripe on the end, followed by a violet stripe, another yellow stripe, and a gold stripe will have a resistance of 470,000 ohms, and the value will be within ±5%. For another example, assume a molded mica capacitor with a yellow dot at the upper left, followed by two black dots. The lower left has a green dot followed by a red dot and a gold dot. This code



Ⓐ Resistor Color Coding (Values in ohms)

Values in Ohms

Color A	1st Significant Figure	Color B	2nd Significant Figure	Color C	Decimal Multiplier	Color D	Resistive Tolerance
Black	0	Black	0	Black	—	None	± 20%
Brown	1	Brown	1	Brown	10	Silver	± 10%
Red	2	Red	2	Red	100	Gold	± 5%
Orange	3	Orange	3	Orange	1,000		
Yellow	4	Yellow	4	Yellow	10,000		
Green	5	Green	5	Green	100,000		
Blue	6	Blue	6	Blue	1,000,000		
Violet	7	Violet	7	Violet	10,000,000		
Gray	8	Gray	8	Gray	—		
White	9	White	9	White	—		



Ⓑ Capacitor Color Coding (Values in micro-microfarads)

Capacitance in micromicrofarads *(μμf.)*

Dot Color	Significant Figures A	Significant Figures B	Significant Figures C	Decimal Multiplier D	Capacitive Tolerance E	DC Test Voltage F	Dot Color
Black	0	0	0	—	—	—	Black
Brown	1	1	1	10	± 1%	100	Brown
Red	2	2	2	100	± 2%	200	Red
Orange	3	3	3	1,000	± 3%	300	Orange
Yellow	4	4	4	10,000	± 4%	400	Yellow
Green	5	5	5	100,000	± 5%	500	Green
Blue	6	6	6	1,000,000	± 6%	600	Blue
Violet	7	7	7	10,000,000	± 7%	700	Violet
Gray	8	8	8	100,000,000	± 8%	800	Gray
White	9	9	9	1,00,000,000	± 9%	900	White
Gold	—	—	—	0.1	± 5%	1,000	Gold
Silver	—	—	—	0.01	± 10%	2,000	Silver
No Color	—	—	—	—	± 20%	500	No Color

Figure 66. Color Coding Used on Carbon Resistors and Mica Capacitors

will signify a 40 mmfd capacity accurate within ±2% and tested for operation up to 500 volts.

BASIC CIRCUITS

Before proceeding with the actual electronic circuits, several elementary principles will be reviewed and several basic circuits which will facilitate later explanations will be discussed.

In all the electronic circuits, voltages are referred to the cathode. The cathode will thus be at zero voltage and all voltages positive with respect to the cathode will be considered *above* the cathode and will be indicated with a plus sign (+). All voltages negative with respect to the cathode will be considered *below* the zero voltage of the cathode and will be indicated with a minus sign (–). For example, in the simple triode circuit of Figure 67A, the grid is at –25 volts and the anode is at +150 volts.

In Figure 67A it is assumed that the triode will cut off at –15 volts; therefore, no current flows in the anode circuit since the grid is at –25 volts. With no current flowing through the load resistor R there will be no potential drop across it, and point A will be at the same potential as the battery + terminal, i.e., +150 volts. In Figure 67B the switch S has been transferred over to the cathode, thus placing the grid at cathode potential. Conduction will take place through the tube and through the load resistor R. Assume that 10 milliamperes of current pass through the tube. With the given value of 10,000 ohms for the load resistor, the potential drop across R will be 100 volts. The direction indicated is the direction of electron flow in conformity with the direction of flow through the tube. The potential drop across the tube will be $E = Ea - IR = 150 - 100 = 50V$, since the sum of the potential drops across the series components of a circuit must equal the potential of the source. The potential at the midpoint tap M in Figure 67A is +150 volts before conduction starts. However, when the tube is conducting, the potential at point M is +100 volts.

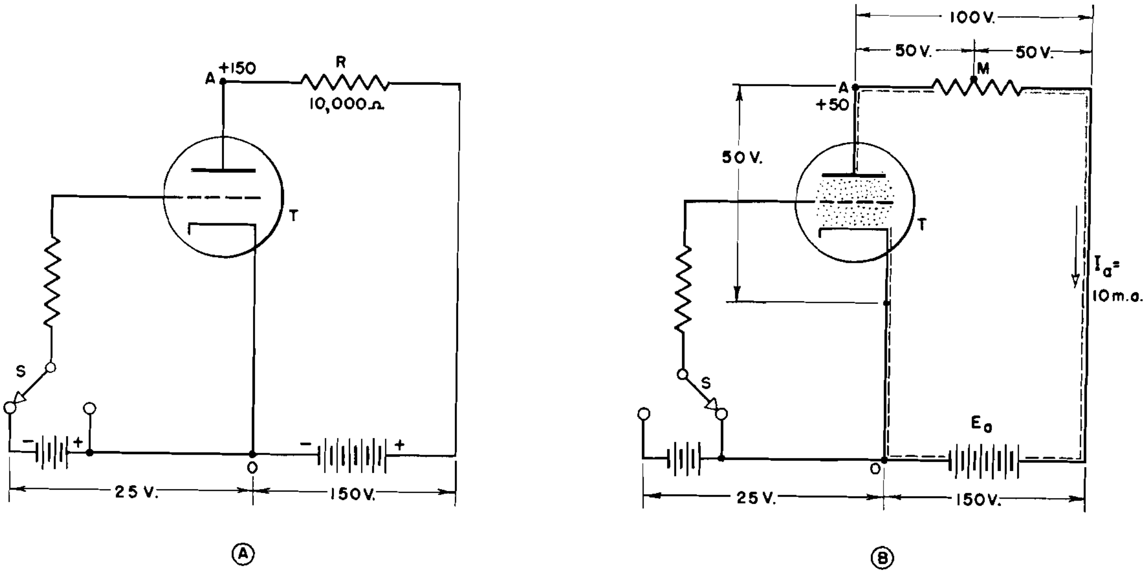


Figure 67. Basic Notation

This is evident from the fact that the two halves of resistor R can be considered as two equal resistors with a 50 volt drop across each.

This change in potential at the anode of a tube, when conduction takes place, can be utilized to control another tube by connecting the grid of the second tube to the anode of the first as shown in Figure 68. The grid battery Eg2 is necessary to reduce the potential on the grid of T2 to the desired negative potential when the tube is cut off. The potential of this battery must be the potential at point A when T1 is conducting plus the desired negative bias for T2. Assuming the same tube as shown in Figure 67, the potential at point A when T1 is conducting is +50 volts. It is desired to bias T2 at –25 volts; hence Eg2 must be a 75 volt battery. As long as T1 is conducting, the grid of T2 is at –25 volts and T2 cannot conduct. However, when the switch S is transferred to the –25 volt tap, T1 is cut off, and no current flows

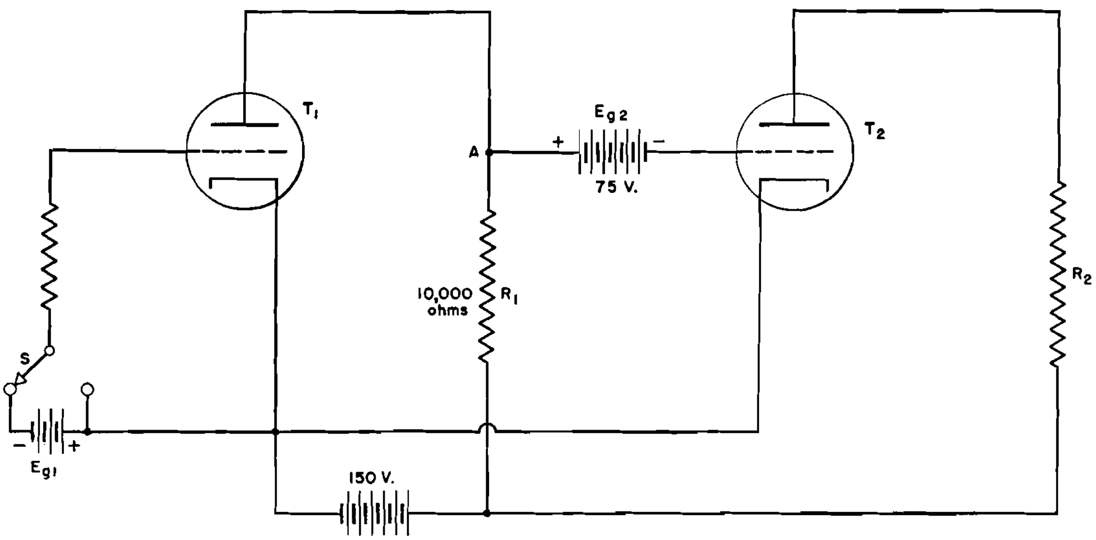


Figure 68. Control of One Triode by Another

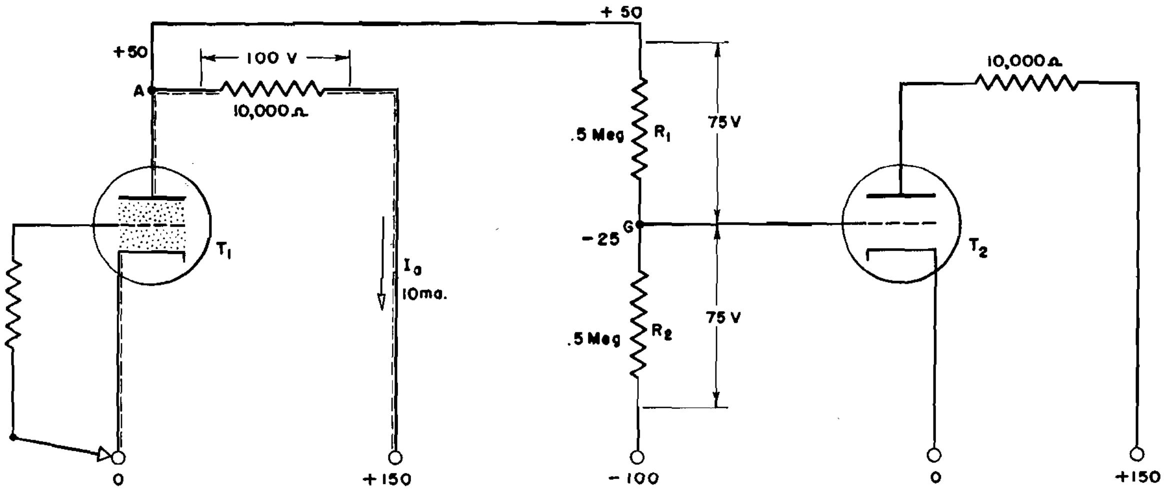


Figure 69. Direct-Coupled Triodes

through R1. With no IR drop across R1, the potential at point A is the same as the 150 volt battery potential at the plus terminal, i.e., +150 volts. This means that the grid of T2 will now be at +75 volts (150 volts – 75 volts) and conduction will take place through T2. Therefore, *T2 can conduct only if T1 is not conducting.* In this manner T2 can be controlled by controlling T1.

The circuit of Figure 68 is not a practical one. A more practical circuit using a resistor network to obtain the grid bias of T2 is shown in Figure 69. In this circuit a voltage divider consisting of R1 and R2 is connected between the anode of T1 and the –100 volt line. When T1 is conducting, point A is at +50 volts as shown in previous illustrations. Under these conditions, there are 150 volts across R1 and R2 (from +50 volts to –100 volts is 150 volts). Since R1 and R2 are equal, there is a 75 volt drop across each. The IR drop across R1 and R2 is of a polarity opposite to the –100 volt supply; therefore, the potential at point G (grid of T2) is –100 + 75 or –25 volts. Assuming T2 cuts off at –15 volts, it is evident that T2 is cut off, *providing T1 is conducting.* When T1 is not conducting, point A is at +150 volts, and the total potential across R1 and R2 is 250 volts (+150 to –100). This means a 125 volt drop across each resistor and a potential of +25 volts at the grid of T2 so that T2 conducts. Actually, the grid of T2 will not go very much positive; it will only *tend* to rise to +25 volts. As soon as the grid reaches cathode potential, some grid current starts to flow through R1 from cathode to grid, through R1, to point A, through the 10,000 resistor to +150 volts. The resulting IR drop across R1 due to the grid current is of a polarity opposite to the positive potential at the grid, and the grid potential is thus reduced. The grid potential will stabilize at approximately cathode potential (zero).

The values of R1 and R2 must be very large compared with the load resistor R otherwise the potential at points A and G will not be of proper value. In the preceding calculations involving Figure 69 it was assumed that R1 and R2 were so large compared with R, that R could be ignored in calculating the grid potential of T2. This is not strictly true, because there is always a current flowing from the –100 volt line through R2, R1, R and back to the +150 volt line, even though tube T1 is out of its socket. A rigid analysis would show that there is a 2.48 volt drop across R at all times. However, compared with the total potential of 250 volts across the resistor network, the potential drop across R due to this current is so small that it can be ignored for practical calculations.

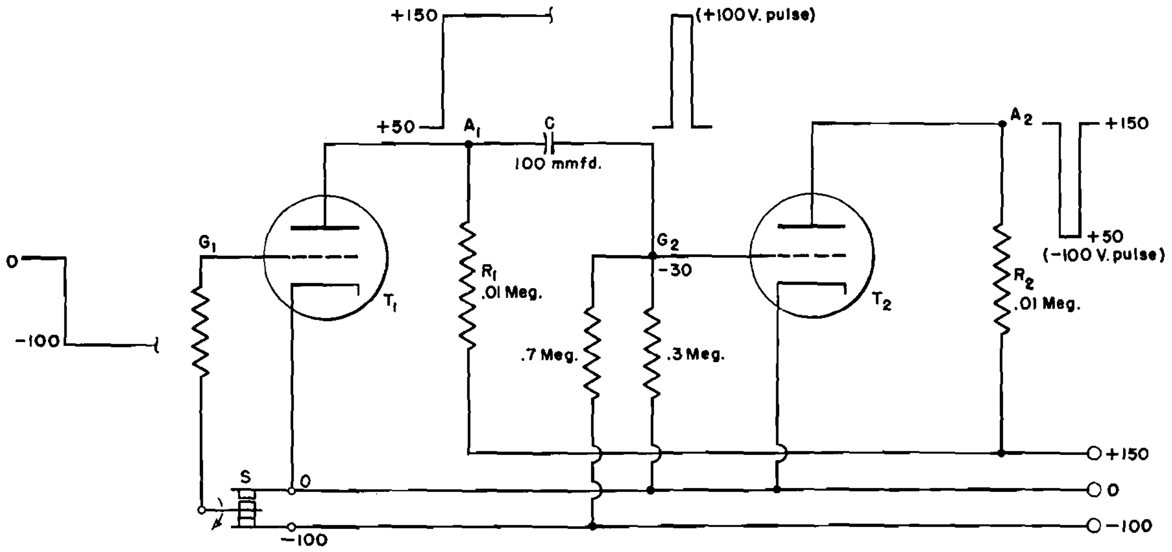


Figure 70. Capacity-Coupled Triodes Showing Phase Inversion

Often it is not desirable to couple one circuit directly to another. In these cases capacity coupling is used to pass a pulse from the anode of one tube to the grid of the next. In studying capacity-coupled circuits it is important to remember that *the reactance of a capacitor decreases as the frequency of the applied potential increases.* Direct current cannot pass through a capacitor, since direct current has a frequency of zero and results in an infinite reactance. Conversely, an infinite frequency will pass through a capacitor with zero reactance. Infinite frequency implies an *instantaneous* change of voltage. Obviously, this is impossible in practice; but very rapid changes can be obtained. Very rapid changes in voltage are equivalent to very high frequencies; consequently, very rapid changes in voltage can easily be transmitted through a capacitor, even an extremely small one.

Figure 70 shows a capacity-coupled circuit wherein changes in the anode potential of T1 control T2. The anode of T1 is coupled to the grid of T2 through capacitor C. Only *changes in potential* will be transmitted through C. Once point A1 reaches a steady value of potential, no further effect is felt at point G2.

With T1 conducting, the steady state potential at A1 is +50 volts (assume the same circuit constants as previous illustrations). Point G2 (grid of T2) is connected to the cathode through a 300,000 ohm resistor and to the −100 volt line through a 700,000 ohm resistor. This voltage divider places point G2 at −30 volts normally, thus cutting off T2 (assume −15 volt cutoff).

Assume now that contact S is suddenly transferred to the −100 volt line as shown in Figure 70. If it is assumed that the transfer takes place instantaneously, then there will be an instantaneous shift of potential on the grid of T1 from 0 to −100 volts. This shift in potential can be represented by the square wave shown at the grid of T1. This shift in potential is toward a more negative point and is thus a negative pulse. This shift of potential causes T1 to be cut off with the resultant increase in potential at point A1 from +50 volts to +150 volts as shown by the square wave at point A1. This voltage shift passes through C as a positive pulse to point G2, thus tending to drive point G2 to +70 volts. Only the *change in voltage,* i.e., 100 volts will be felt through the capacitor. Since the grid of T2 is at −30 volts, it will tend to approach +70 volts. Actually, grid current will

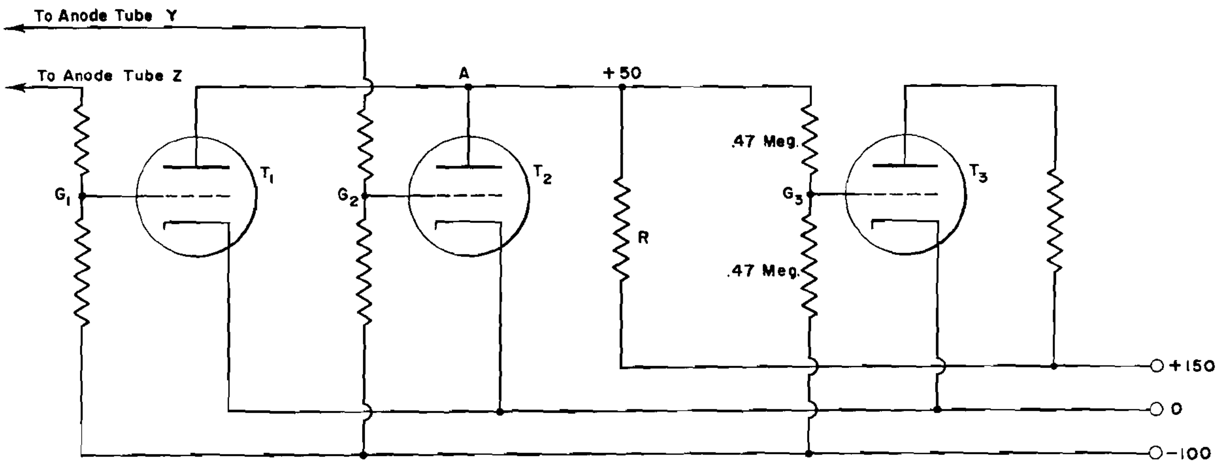


Figure 71. Use of Blocking Tubes

start to flow through the grid resistors as soon as the grid tries to go positive, the resultant IR drop opposes the tendency for the grid to go positive, and the grid potential will not go much above cathode potential. It is important to note here that although the potential at point A1 rises to +150 volts and remains there, the pulse through capacitor C is of short duration. The actual duration of the pulse is determined by the capacitance of C. This means that although point A1 *remains* at high potential, point G2 will be at high potential for only a short instant, i.e., for the time required to charge the coupling capacitor C.

Tube T2 will then conduct as long as point G2 is at cathode potential or above, with a resultant IR drop across load resistor R2. Thus the potential at point A2 drops from +150 to +50 volts. This illustrates the inversion of pulses by a tube. A negative shift in potential applied to the grid of T1 causes a positive shift in potential at the anode of T1. In turn, the positive pulse at point G2 produces a negative pulse at point A2. This is a most important fact to remember in the study of electronic circuits.

On the circuits illustrated so far one tube has been controlled by another. Sometimes it is desirable to block the action of the controlling tube under certain conditions. This can be done by connecting two controlling tubes in parallel with a common load resistor and providing separate grid controls, as shown in Figure 71. The value of the load resistor R is chosen so that the tubes are operated on the portion of their characteristic curve where most of the potential drop is across the load resistor and where changes in potential at the anode are very slight with a change in anode current. This means that the potential at point A in Figure 71, is essentially the same whether one tube is conducting or both are conducting. Hence with *either* T1 or T2 conducting, point A is essentially at +50 volts and point G3 at -25 volts, since the grid resistors between +50 volts and -100 volts are equal. This means that as long as T1, T2, or both are conducting, T3 is cut off. Only when *neither T1 nor T2 is conducting* does point G3 go positive and allow T3 to conduct. When neither T1 nor T2 is conducting, point A rises to +150 volts, and the grid of T3 tends to rise to +25 volts. Thus, T1 can nullify the action of T2, or vice versa. As indicated in Figure 71, T1 and T2 have separate grid controls in the form of other tubes which are indicated as tube Y and tube Z, which are not shown in this figure.

Another method of obtaining dual control is to use a pentode and provide grid control on both the control grid and the suppressor grid as shown in Figure 72. Since the suppressor is spaced much farther from the cathode than the control grid, a

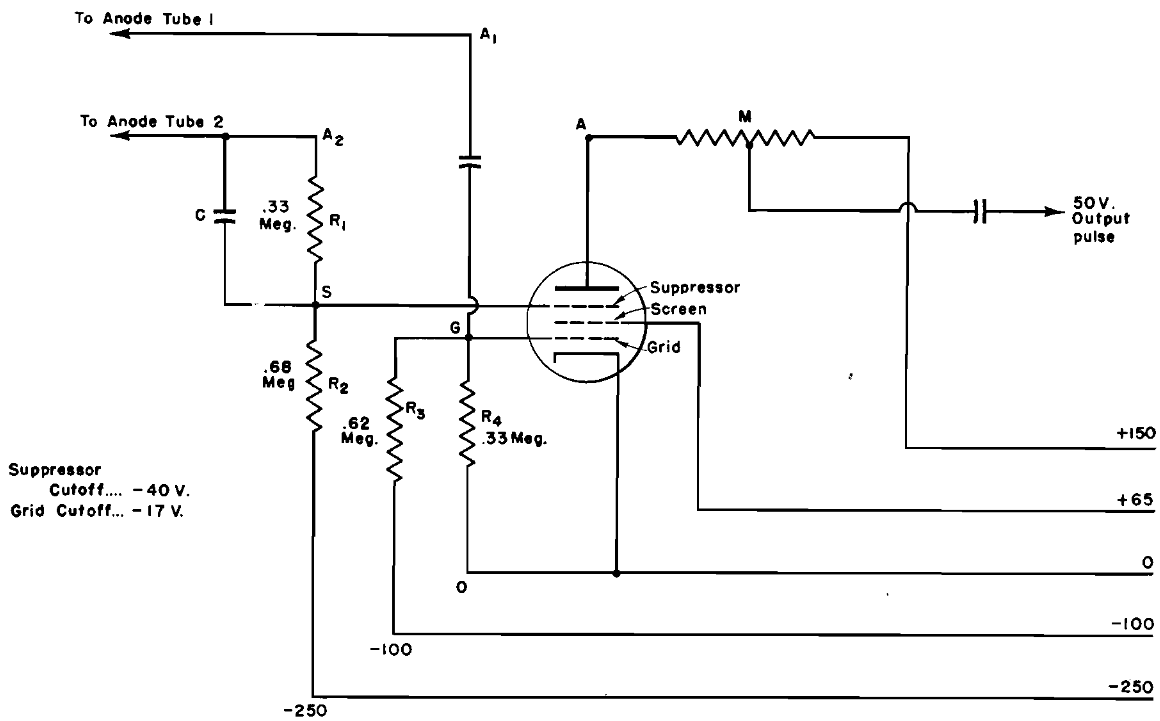


Figure 72. Two-Circuit Control of a Pentode

greater negative potential is required to cut off the tube by means of the suppressor than is required for cutoff by means of the control grid. In this case, assume the tube can be cut off by –17 volts on the control grid or by –40 volts on the suppressor. Either the control grid or the suppressor grid can stop conduction. In order for conduction to take place *both grids must be above cutoff potential.*

In Figure 72 it is assumed that the grids of the pentode are controlled by the anode potential of preceding tubes. Assuming that both tubes controlling the pentode are conducting and that they are of the same type illustrated in previous examples, the potential at their anodes will be +50 volts. This will place the suppressor at –50 volts, which is determined as follows:

Total potential across R1 and R2 is 300 volts (from +50 volts to –250 volts).

Suppressor is at point S and the potential at S is determined by the ratio of the resistors R1 and R2 as follows:

$$\frac{300 \times R2}{R1 + R2} = \frac{300 \times 680{,}000}{1{,}010{,}000} = 200\text{V (approximately)}$$

Hence point S is 200 volts above the –250 line, or at –50 volts.

The control grid is normally at approximately –35 volts as determined by the voltage divider R3 and R4 between the cathode and the –100 volt line. With both grids negative no conduction can take place.

Now assume that the tube controlling the suppressor stops conducting. Point A2 will rise to +150 volts potential and point S will tend to rise to approximately +17 volts. Thus the suppressor has been conditioned to allow conduction through the pentode; but the control grid is still blocking conduction, since it is below cutoff. When point A1 rises in potential, a positive pulse will be passed to point G and the tube will conduct for an instant, providing the suppressor is still conditioned to conduct.

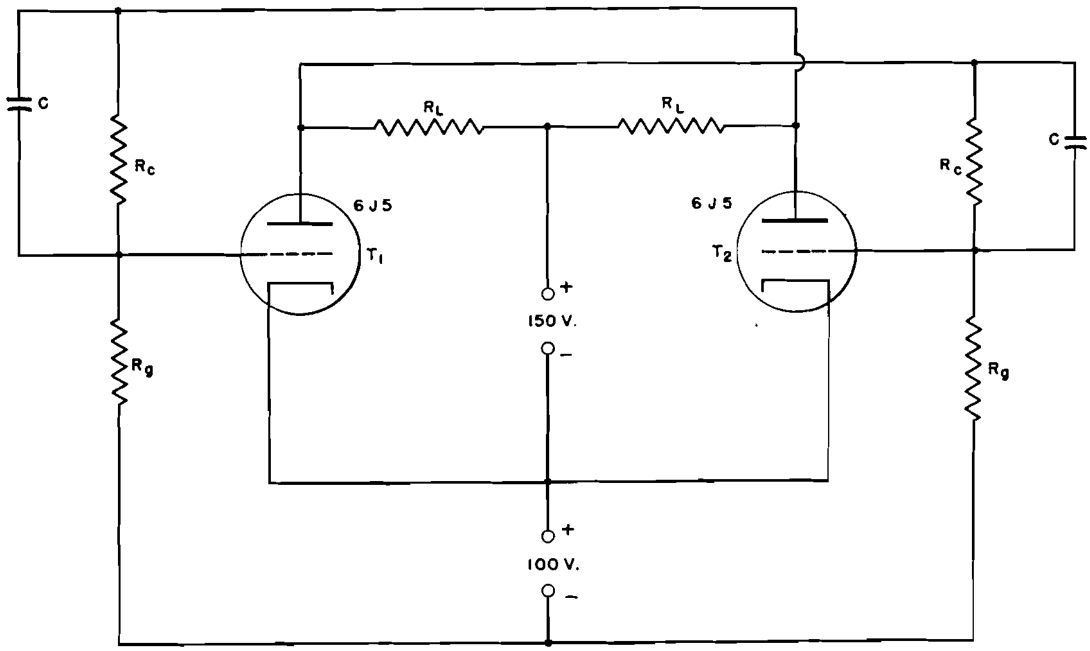


Figure 73. Basic Eccles-Jordan Trigger Circuit

When the tube conducts, the potential at point A drops because of the IR drop across the load resistor of the pentode. In this case the output is taken from a midpoint tap M on the load resistor. This would be done if the voltage shift desired is only half the voltage shift at point A. Assume the potential at point A changes from +150 volts to +50 volts. When conduction starts, a 100 volt negative pulse is produced at A. However, at point M the potential only changes from +150 volts to +100 volts, producing a 50 volt negative pulse at M.

The screen grid in Figure 72 is shown at a fixed potential of +65 volts supplied by a 65 volt screen voltage supply. The capacitor C across R1 is necessary to balance the interelectrode tube capacity so that the grid of the tube can follow the applied potential without any time delay.

TRIGGER CIRCUIT

Theory of Operation

The most important and basic circuit used in the electronic computing section is the trigger circuit. For this reason a detailed analysis of the operation of a trigger circuit will be presented. Although a detailed knowledge of the theory of operation of a trigger is not necessary to repair the machine, a thorough knowledge of the theory will assist in analyzing trigger troubles. A trigger circuit is one which has two states of equilibrium for fixed values of supply potential and circuit components. The trigger circuit derives its name from the fact that it can be made to "trigger" abruptly from one state of equilibrium to the other by means of small controlling potentials. The trigger circuit used in this machine is basically the Eccles-Jordan trigger circuit shown in Figure 73. The use of this circuit is based on the fact that current can flow through only one tube at a time. A change in grid potentials or anode potentials can be made to transfer conduction abruptly from one tube to the other.

As mentioned above, the trigger circuit is a device using two triode tubes so interconnected that one tube is conducting while the other is non-conducting. As shown in Figure 73 the grid of T2 is coupled to the anode of T1 through the coupling resistor Rc and capacitor C. The grid of T1 is

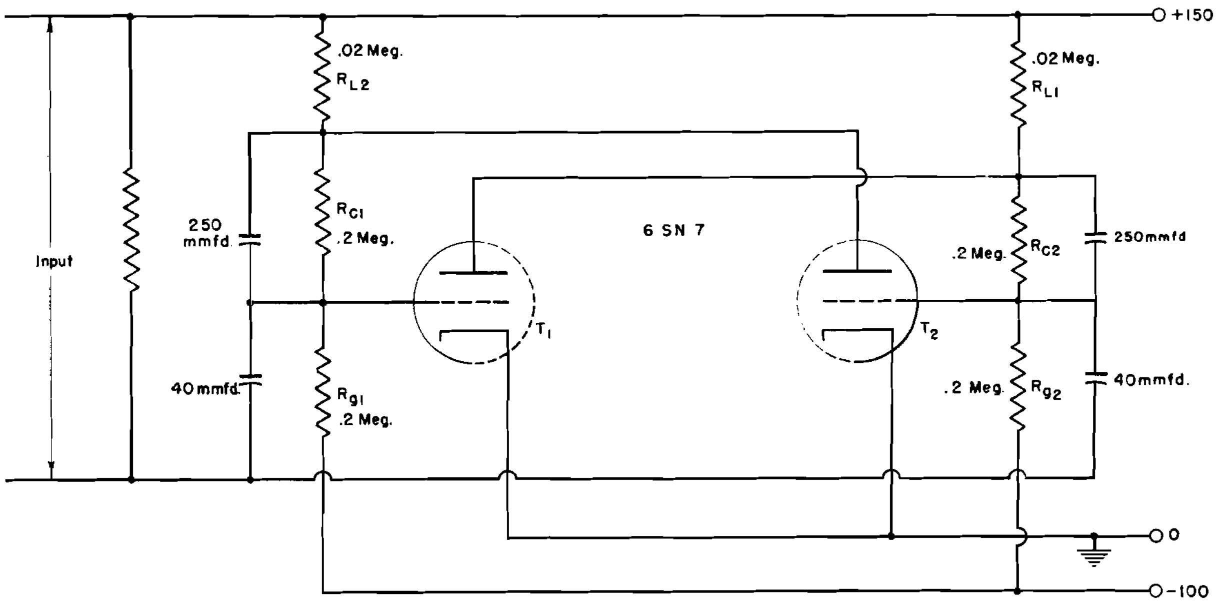


Figure 74. Practical Eccles-Jordan Trigger Circuit

similarly coupled to the anode of T2. The resistors RL are the anode load resistors while the grid bias is normally furnished through the grid resistors Rg. The values of RL, Rc, and Rg are not critical as to their exact value but *it is essential that the circuit be symmetrical.* Rc and Rg must be matched within 2% and they should be approximately ten times as large as RL. The value of C determines to a great extent the speed of response of the trigger circuit to an applied pulse.

A suitable voltage pulse applied at the proper points causes the conducting tube to stop conducting and the non-conductive tube to start conducting. A second pulse restores the original condition. This cycle may be repeated at will at any speed from zero up to speeds in the low radio-frequency range, depending upon the circuit constants used.

The tubes used in the circuits illustrated in Figure 73 are 6J5's or the equivalent. The two triodes can just as well be the two halves of a twin triode.

Figure 74 shows the Eccles-Jordan trigger circuit in a form more suitable for analysis. A close study of Figure 74 will reveal that it is the same circuit as Figure 73 with only the input circuit added. The resistance and capacitance values shown in this figure are the values used in the actual triggers in the electronic computing circuits: In this illustration the two triodes are the two halves of a twin triode, Type 6SN7.

Figure 75 shows how T2 can control T1. Assuming that both tubes are non-conducting, the potential at the grid of T1 can be determined by the ratio of the resistors between the +150 volt line and the –100 volt line, or by determining the current flow and computing the IR drop across each resistor. In this manner the potential at G1 is found to be +19 volts; or 19 volts positive with

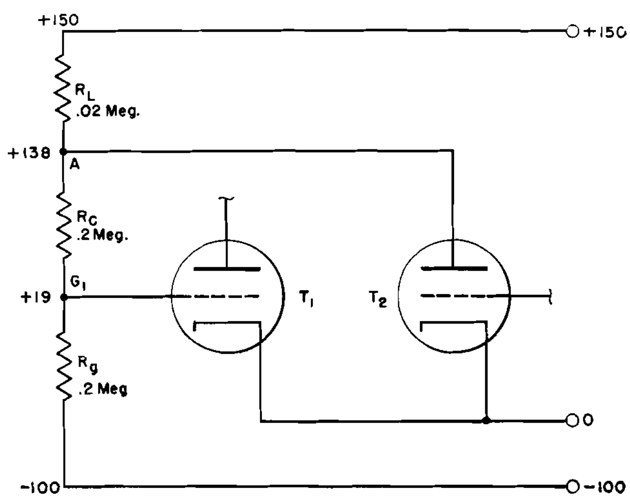


Figure 75. Anode of T_2 Controls Grid of T

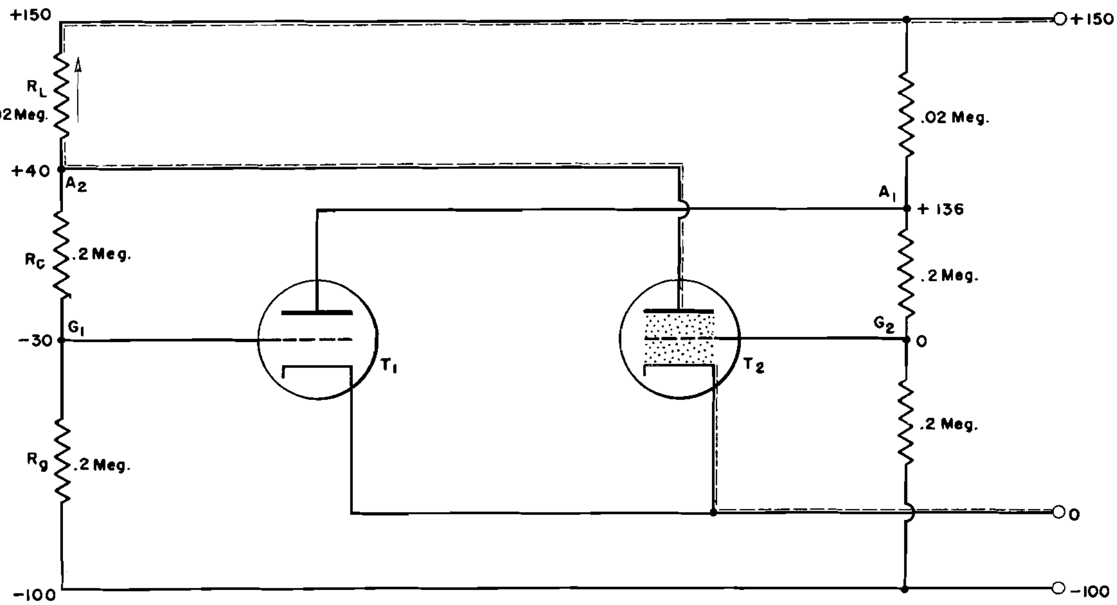


Figure 76. Retroactive Coupling

respect to the cathode since the cathode is at zero potential. Actually, point G1 will only tend to reach +19 volts, since this positive potential will cause T1 to conduct, and sufficient grid current will flow through Rc to hold the grid down to approximately cathode potential.

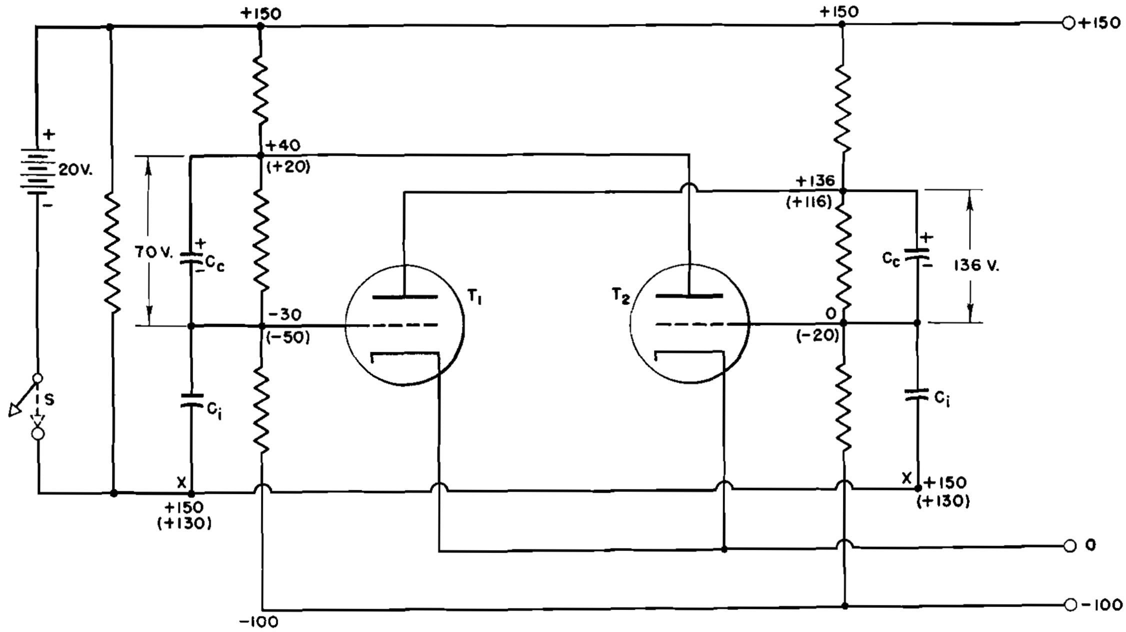
Now suppose that T2 is made to conduct by some means as shown in Figure 76. Assuming the potential drop across T2 when conducting is 40 volts, point A1 will have to be at +40 volts. Another method of looking at this is as follows: when T2 conducts, approximately 5 milliamperes of current flow as determined by the anode potential and the load resistor. This current flow through RL causes an IR drop of .005 × 20,000 or 100 volts. Naturally, this is in the same direction as and *in addition* to the drop resulting from the bleeder current always flowing from the –100 volt line to the +150 volt line. Therefore, the potential drop across RL is increased by 100 volts, making point A1 100 volts more negative than it was previously. In practice, this potential at point A1 is +40 volts instead of +38 volts with T2 conducting, since the current is not *exactly* 5 milliamperes.

A new analysis of the potential at point G1 will show that the grid of T1 is at –30 volts when T2 conducts, thus cutting off T1. Since Rg and Rc are equal, G1 is halfway between +40 volts and –100 volts.

From +40 to –100 volts is 140 volts, and the drop across Rg is 70 volts. Therefore, G1 is 70 volts above the –100 volt line or at –30 volts. From this analysis it is obvious that if T2 is conducting, it prevents T1 from conducting.

If the grid of T2 is connected to the anode of T1 by means of a similar network (Figure 76), T1 can control T2 in the same manner described above, and the desired condition in which only one tube can be conducting at a time is obtained. In Figure 76 point A2 is shown at +136 volts instead of +138 volts. This is because the grid current reduces the potential at point G2 to zero. On analyzing the potential between point G2 and the +150 volt line, it is found that point A2 is at +136 volts.

In order to provide a means of applying a triggering pulse, both grids must be coupled to a source providing the pulse as shown in Figure 77.



Instantaneous Potentials in Parenthesis

Figure 77. Use of Capacitors in Trigger Circuit

The potential values shown outside parenthesis are those existing when T2 is conducting and before a pulse is applied. This circuit is designed to trigger on the application of a 20 volt negative pulse to both grids. In order to operate properly, the triggering pulse must have a very steep wave front. For this reason a square wave is used as a source of pulses.

When a negative pulse of 20 volts with a steep wave front is impressed across the input, there is a sudden drop of 20 volts at point X. Since a steep wave front is equivalent to an extremely high

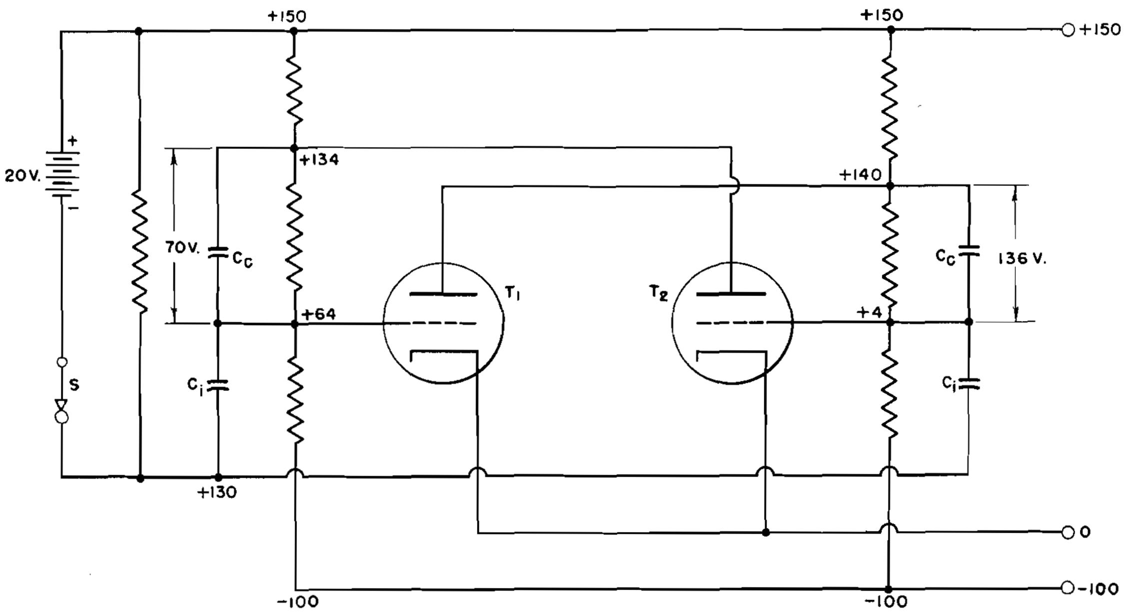


Figure 78. Voltages Existing after Ci Discharges but before Cc Discharges with Neither Tube Conducting

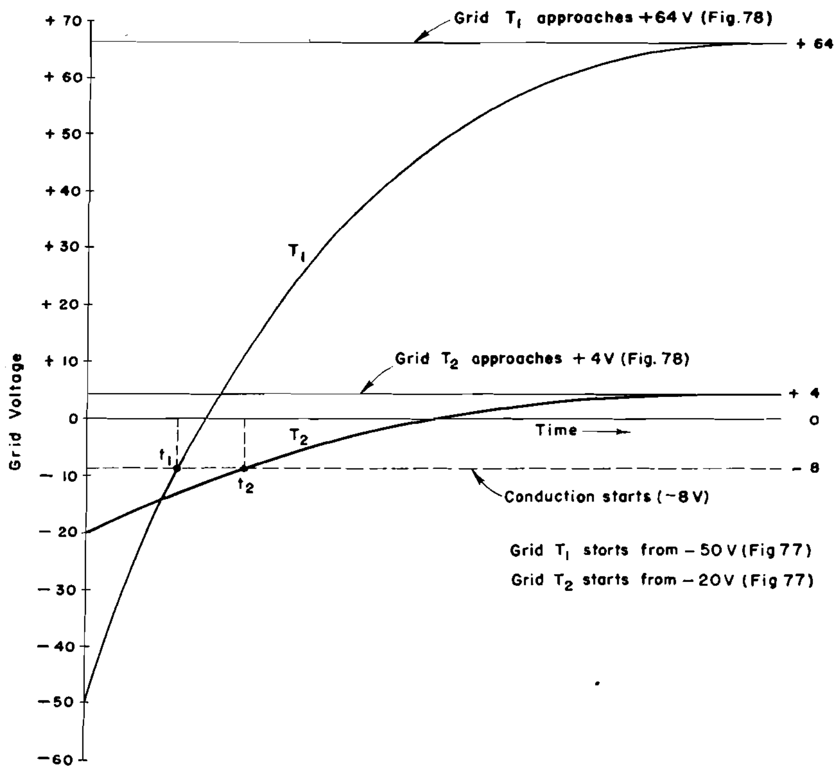


Figure 79. Calculated Rise of Grid Voltage as Circuit Voltages Change from Those in Figure 77 to Those in Figure 78.

frequency, the input coupling capacitors Ci will offer practically no reactance to the pulse and the sudden drop of 20 volts will be felt at points G1 and G2. The potential values shown in parenthesis are the instantaneous values obtained when the −20 volt pulse is applied. This pulse will render both tubes non-conducting for an instant.

In order for the trigger to operate, the Cc capacitors must be considerably larger than the Ci capacitors so that there will be very little change in the potential across the Cc capacitors in the time required for the smaller input coupling capacitors to reach a steady state condition. To simplify the explanation, assume that there is no change in potential across the Cc capacitors in the time required for the Ci capacitors to reach steady state values. As shown in Figure 77, both tubes are rendered non-conducting by the instantaneous potentials resulting from the −20 volt pulse, since these tubes cut off at −8 volts. If both tubes could be held non-conducting by some external means, the potentials shown in Figure 77 in parenthesis would soon change to those shown in Figure 78. The potentials shown in Figure 78 exist with the input coupling capacitors Ci in equilibrium, with capacitors Cc not yet discharged, and with neither tube conducting. If it is assumed that the Cc capacitors are not discharged, they will maintain the potential across them, and they can be considered as batteries with a potential equal to the charge on them at the time the pulse was applied. The potentials at the various points can then be analyzed on this basis.

Since the tubes are not held non-conducting, the potentials shown in Figure 78 will never be reached. The grids will only *tend* to reach the values shown. However, on the basis of the tendency of the grids to approach the limiting values shown in Figure 78, the actual rise of potential on

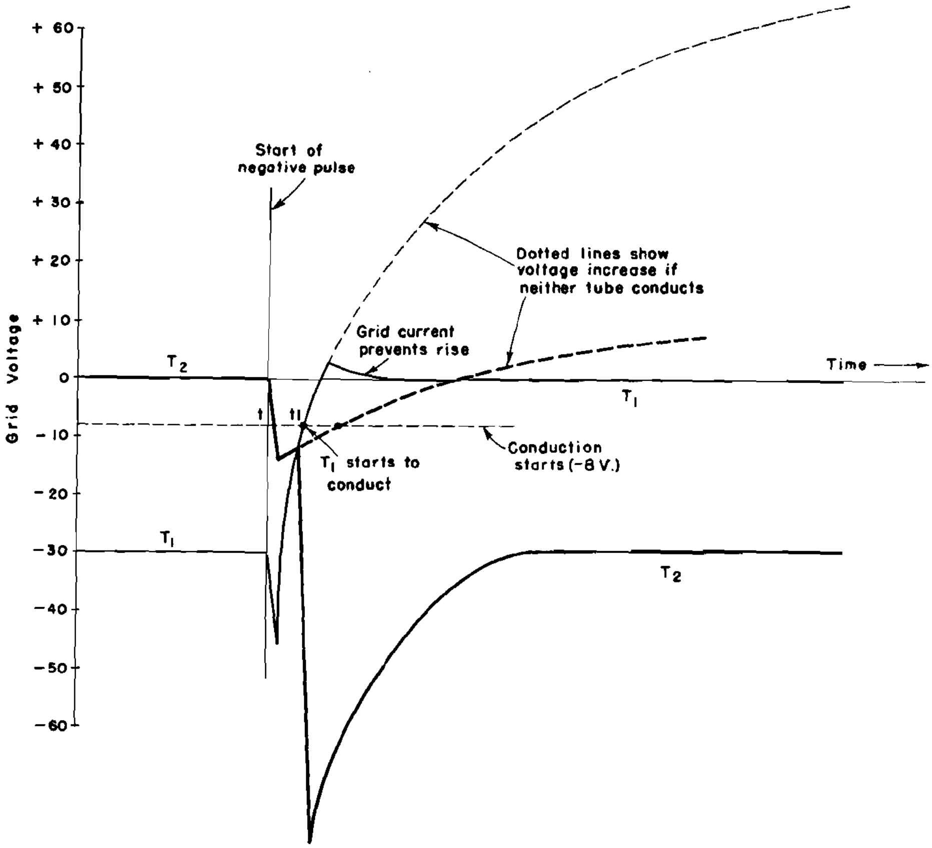


Figure 80. Oscillogram of Actual Grid Voltages During Triggering

the grids can be determined as shown graphically in Figure 79.

While these curves could be accurately calculated, they were actually obtained by plotting an e^x curve between the known limits of grid potential. This gives a theoretical capacitor discharging or charging curve. Because of the much greater swing in potential on the grid of T1, caused by the relatively low potential existing on the capacitor Cc between the grid of T1 and the anode of T2, it is obvious that the rate of potential rise will be much greater than the rate of rise in the potential on the grid of T2. It is evident that the grid of T1, which has been non-conducting, is the first to rise above the conducting point of –8 volts. These tubes cut off at –8 volts, therefore conduction will start as soon as a grid goes above this potential. Hence T1 starts conducting and blocks T2 from conducting, as previously explained, and the trigger is reversed. The action of the capacitors Cc produce the desired trigger action, and the trigger will now reverse itself every time the grids are given a negative pulse of 20 volts or more.

In Figure 78 it was assumed that the capacitors Cc were much larger than the grid capacitors Ci. As evidence that this assumption does not alter the general shape of the curves of grid potential rise, Figure 80 shows a sketch of the grid potential rise in an actual trigger circuit. This sketch is adapted from an actual oscilloscope pattern and shows exactly what happens to the grids of T1 and T2.

Originally T2 was conducting and T1 was held non-conducting by the –30 volt potential on its grid as shown previously. At time t (Figure 80) a 20 volt negative pulse is applied to both grids through the input capacitors Ci. Owing to the fact that the square wave input is not perfectly square, the negative pulse as it appears at the grids is not

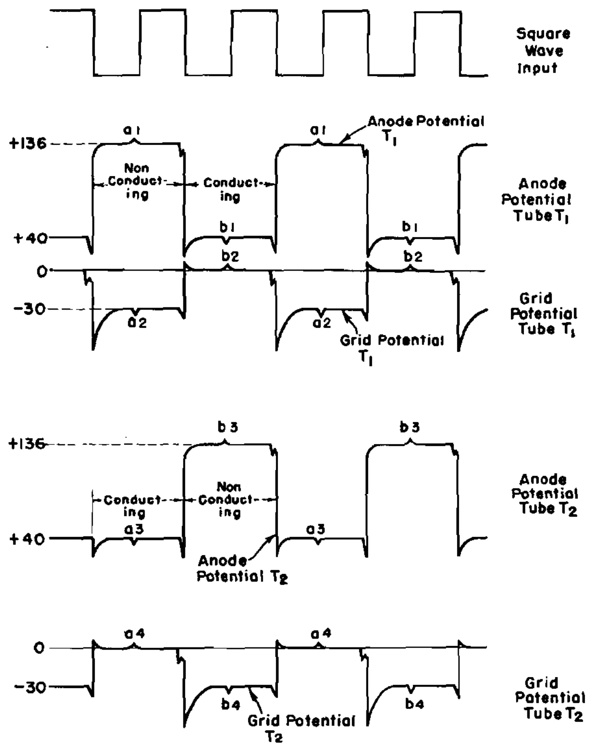


Figure 81. Oscillogram of Overall Trigger Operation

quite square, and at the grids the peak negative dip is only −15 volts. As soon as the maximum negative potential is reached, both grids start to rise in potential. As previously shown in Figure 79, the grid of T1 rises much faster than that of T2 and reaches the conducting point of −8 volts first. As soon as T1 starts to conduct, the potential at its anode starts to drop, forcing the grid of T2 down and holding T2 non-conductive. With the circuit constants shown in Figure 74, after a time interval of approximately 3 to 5 microseconds, the charges on all capacitors will have been equalized and the circuit will be as before except that T1 is now conducting instead of T2. The dotted lines indicate what the rise in the grid potentials might look like if the tubes could be held non-conducting by some external means. It is important to note that, although the triggering action is very fast, a definite time interval is required, hence a peaked pulse of extremely short duration (say 1 microsecond) may not trigger the circuit.

Figure 81 shows a sketch of both grid and anode potentials adapted from patterns taken directly from an oscilloscope. The potential graphs represent the potentials when the trigger is triggered or reversed continually by a square wave input. Note that the shape of the grid potential is the same as shown in Figure 80.

So far nothing has been said about the ability of this trigger circuit to distinguish between positive and negative pulses. The constants of this trigger are such that it is considerably more sensitive to negative pulses than it is to positive pulses. Therefore, if the input pulse is kept within reasonable limits, the trigger will respond only to the negative pulses of a square wave (Figure 81). For example, a −20 volt shift in potential will cut off the conducting tube, enabling the trigger to transfer; but a +20 volt shift will not bring the grid of the non-conducting tube up to the conducting point and thus cannot make the tube start to conduct. The only action of a +20 volt pulse on the conducting tube is to drive the grid slightly positive. Therefore, the trigger will transfer only on a negative pulse (or shift in potential), and the trigger can be made to distinguish between negative and positive pulses. The limits within which the trigger will respond only to negative pulses for the circuit constants given is approximately 20 to 80 volts. That is, at least −20 volts are required to trigger, but around 80 volts the trigger responds to positive pulses as well as negative. For this reason the triggers in this unit are operated by 50 volt pulses, or roughly at the middle of the range.

Figure 81 shows why the trigger is not reversed on a positive pulse which is theoretically large enough to bring the grid of the non-conducting tube up to the conducting point. Notice that at point a2 the grid of the non-conducting tube T1 actually appears to go negative although the square wave input is shifting in a positive direction. This is because the positive pulse acting on the grid of the conducting tube T2 drives the anode potential of T2 down almost 20 volts as shown at point a3.

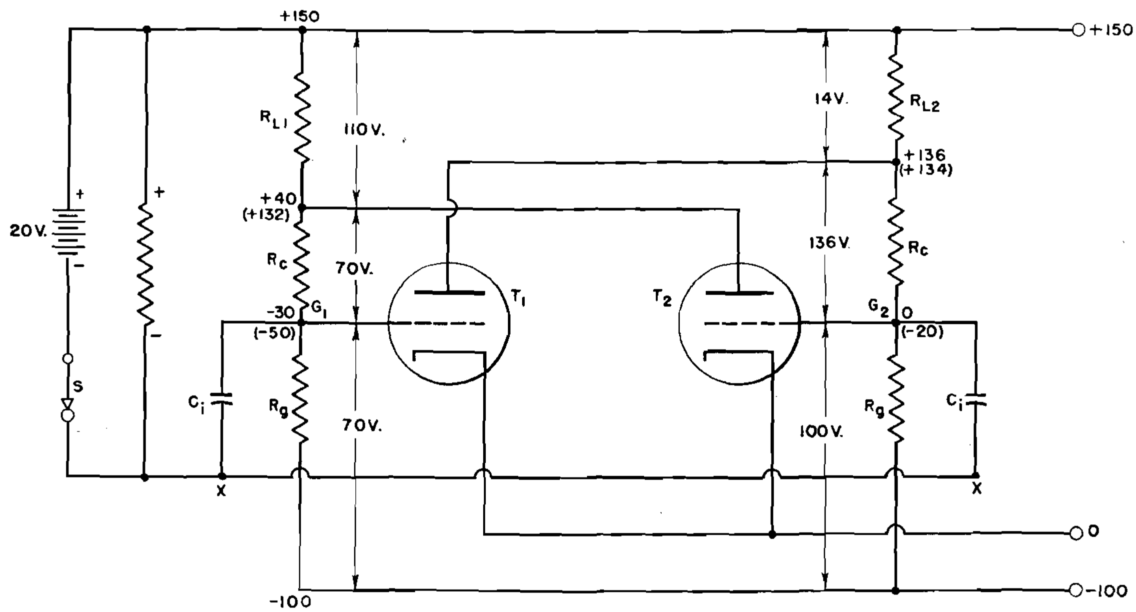


Figure 82. Application of Pulse to Trigger Circuit Without Cc Capacitors

Through this anode to grid coupling capacitor Cc, this dip in anode potential of the conducting tube over-rides the positive pulse on the grid of the non-conducting tube, producing a negative dip as shown at a2 (Figure 81). The dip in the anode potential of the conducting tube shown at a3 is in this case caused by the same positive pulse acting on its own grid.

For a positive pulse to trigger the circuit, the pulse must be sufficiently positive to overcome the initial bias plus the negative swing produced at the grid of the non-conducting tube by the dip in anode potential of the conducting tube.

If properly designed, triggers such as those described above are very stable, dependable, and independent of reasonable variations in supply potentials. A 20% variation in either bias or anode potential supply, or more if both vary together, can be tolerated.

In order to illustrate the importance of the Cc

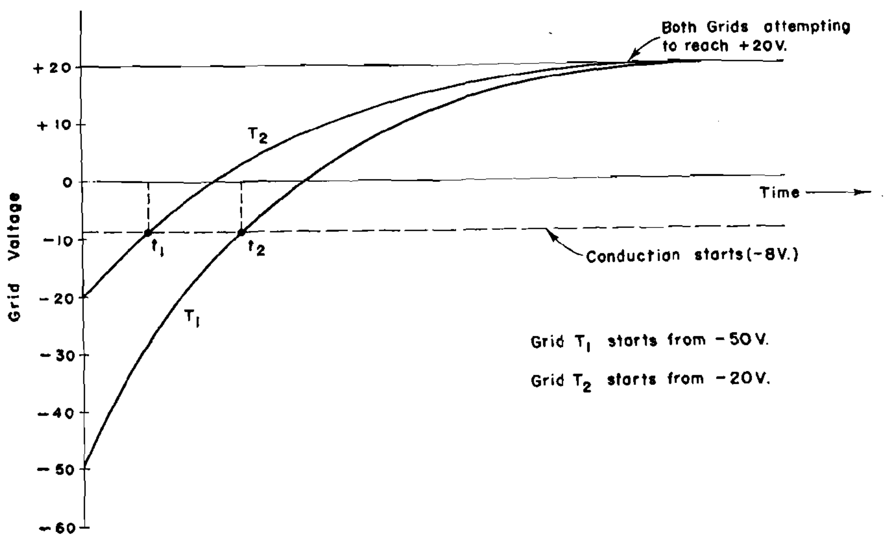


Figure 83. Rise in Grid Voltage as Capacitors Discharge

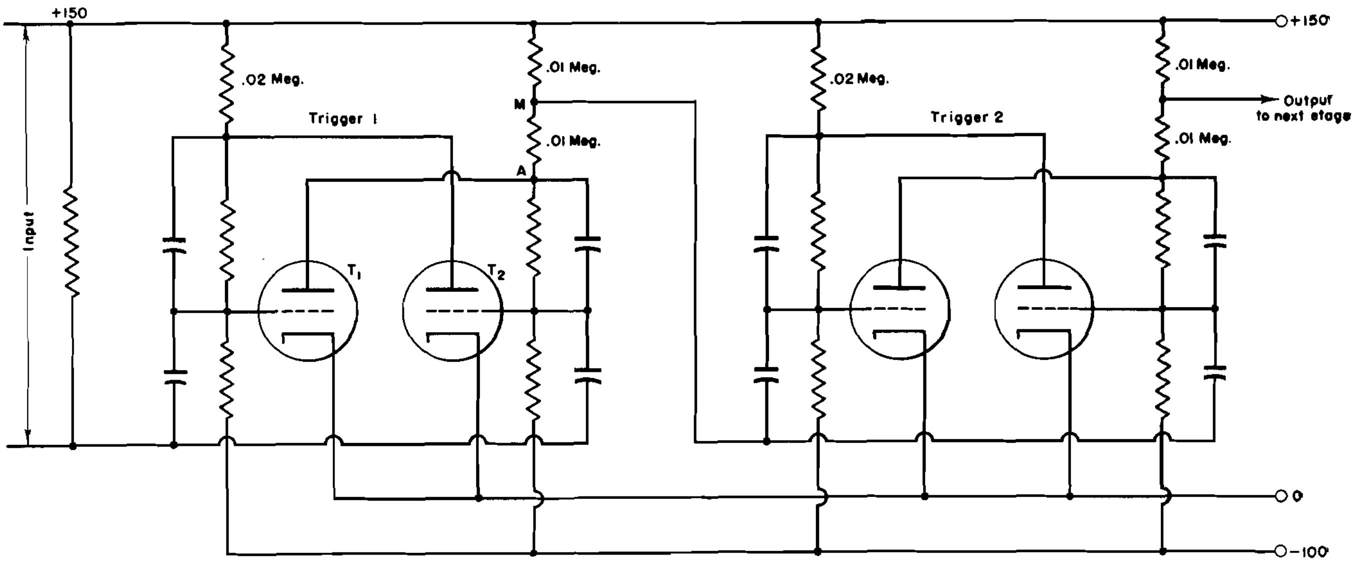


Figure 84. Coupling Trigger Circuits

capacitors, an analysis will be made without the Cc capacitors in the circuit. Figure 82 shows a trigger circuit without the Cc capacitors; it will be shown that this circuit is fundamentally incapable of reversing on application of a pulse to both grids.

The potential values shown outside parenthesis are those existing when T2 is conducting and before a pulse is applied. When a negative pulse of 20 volts is impressed across the input, there is a sudden drop of 20 volts at point X. The potential values shown in parenthesis are the instantaneous values obtained when the −20 volt pulse is applied. This pulse will render both tubes non-conducting for an instant.

The new potential values at the anodes are determined by an analysis of the IR drops across Rc and Rg using the new instantaneous values of grid potential and assuming both tubes are cut off. However, both grids will immediately start to rise to the resistor network limited value of +19 volts. The rate of rise is determined by the time constant of the resistor-coupling capacitor network. Since these are the same for each tube, the time constant will be the same for both grids.

The exponential rise of potential on both grids will be as shown graphically in Figure 83. These tubes cut off at −8 volts; hence, conduction will start as soon as a grid goes above this potential. Obviously, the grid of T2 will be the first to reach the −8 volt line, which means that T2 will start conducting first and prevent T1 from conducting as before. In other words, the trigger has not been reversed. Likewise, a positive pulse will not reverse the trigger, since the only effect it might have on the non-conducting tube will be offset by a stronger effect on the conducting tube.

Coupling of Trigger Circuits

To couple two triggers together, it is only necessary to tap one anode resistor of the first trigger at approximately mid-point and couple it to the input capacitors of the second trigger (Figure 84). This provides a means of tripping the second trigger under control of the first trigger. Tapping the anode resistor at one-half of its value serves to furnish a voltage pulse of one-half the voltage shift in the anode resistor. Point A in Figure 84 changes from +136 when T1 is not conducting to +40 when T1 is conducting, thus providing a negative shift of approximately 100 volts; whereas point M changes from +143 when T1 is not conducting to +95 when T1 is conducting, thus providing a negative shift of approximately 50

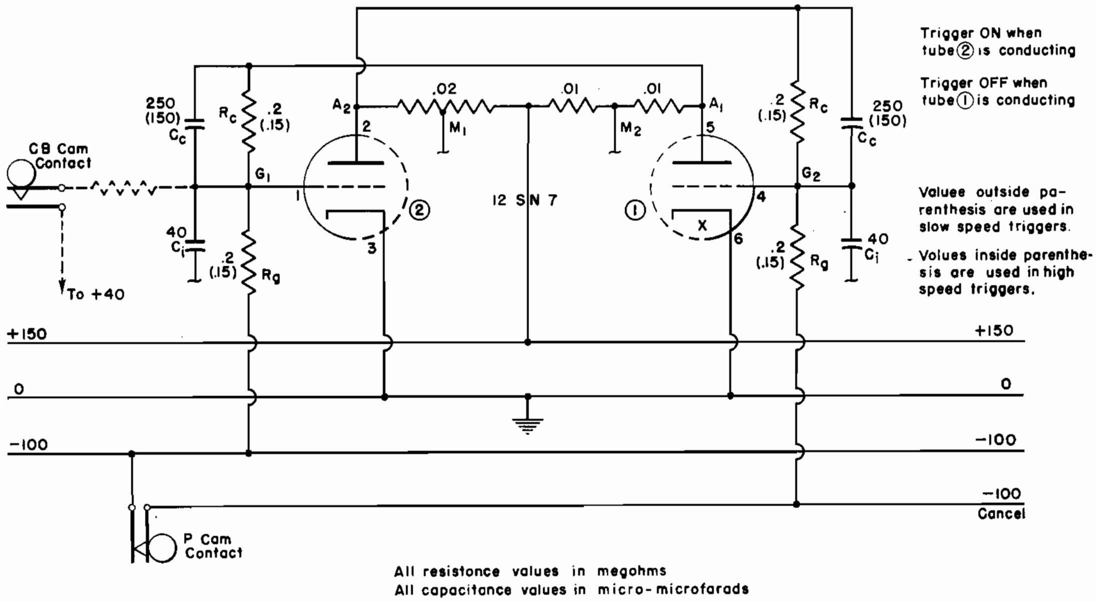


Figure 85. Actual Trigger Circuit Used in Type 603

volts. Since a −50 volt pulse is within the limits wherein the trigger will distinguish between negative and positive pulses, the first trigger can operate the second by passing this −50 volt pulse to the second trigger. Note that the second trigger will change its status only when conduction in the first trigger transfers from T2 to T1. When conduction in the first trigger transfers from T1 to T2, a 50 volt positive voltage shift occurs at point M, but as previously explained, a positive pulse will not operate the second trigger. As many triggers as desired may be coupled together by the method shown in Figure 84 to obtain any desired frequency reduction, the frequency being reduced by a factor of two for each trigger. Such a device may be used for high-speed counting, for providing timed pulses, as an electronic storage device, etc.

Trigger Circuits Used in Electronic Computing

The computing section of this machine uses a large number of triggers of the type just described. The only difference found is in the method of pulsing the trigger. All triggers are pulsed between ground and the input coupling capacitors.

Figure 85 shows a trigger as it is actually connected in the circuits. This arrangement of components is used to simplify the circuit diagram. All power lines are shown parallel at the bottom of the diagram. The ground line (zero potential) is shown heavy throughout the circuit. The tubes 1 and 2 are the two halves of the twin triode of the 12SN7 type. The circuit component values are as shown. The values of Rc and Rg must be matched within 2% for proper operation, although the exact value of the resistors may be within 5% of the nominal value. The capacitors should be within 5% of the nominal value.

As explained in the section on trigger theory, the size of the Cc coupling capacitors primarily determines the speed of response of the trigger. Also, the size of Cc should be as large as possible compared with Ci, the input capacitor. In practice then, a compromise must be reached between desired speed of response and stable operation. If Cc is made too large with respect to Ci, the trigger may respond too slowly to operate at 35,000 cycles per second. On the other hand, if a trigger never receives high-speed pulses, it is permissible to make Cc larger and thereby more nearly approach the theoretical ideal. Of course, the speed of response is determined to some extent by the size of the resistors Rc and Rg. Therefore, the speed of response can be raised both by using smaller values of Rc and Rg and by using smaller values of Cc. For the above reasons two types of triggers are used in the Type 603 computing circuits, as indicated in Figure 85. All triggers receiving pulses at relatively slow rates are known as slow-speed triggers, whereas triggers receiving computing pulses at high speed are known as high-speed triggers.

The earlier models of this machine employed a standard trigger throughout. This trigger had the same values as the slow-speed trigger except that the Cc capacitors were 100 mmfd. The first ten machines were shipped with these old type triggers in all chassis except the A, B, and M. In cases where trouble is experienced on these machines because of the old triggers, they may be replaced and the old chassis returned to Endicott.

For convenience in reference, the trigger is said to be ON or OFF depending upon which tube section is conducting. When tube 2 is conducting, the trigger is said to be ON: and when tube 1 is conducting, the trigger is said to be OFF. The tube notation is in conformity with the number of the tube sections used in tube manuals.

In the discussion of the trigger circuit theory the only method of pulsing mentioned was by means of simultaneous pulses to both grids through the input coupling capacitors. Often it is desirable to turn a trigger ON from one source and turn it OFF from another source. In this case the input capacitors Ci are not tied together. Each input capacitor is connected to its pulsing source. When the grids of the trigger are separately pulsed, the exact action of the trigger differs somewhat from the theory as presented, but the end result will be the same.

Tripping may be effected only by applying a *negative* pulse to the grid of the tube conducting. For instance, with the trigger OFF (tube 1 conducting), a negative pulse received by the grid of tube 1 turns the trigger ON (tube 2 conducting) even though tube 2 receives no pulse whatsoever. Such negative pulses decrease current flow in tube 1 and the attendant positive pulse on its anode is transferred by capacitor Cc to the grid of tube 2 with the same result described before. If the trigger is ON, any further negative pulses at the grid of tube 1 will have no effect, but a negative pulse at the grid of tube 2 will turn the trigger back OFF in the same manner explained before. As explained in the theory, the circuit is much more sensitive to negative pulses than to positive. Thus, a positive pulse applied to the grid of tube 2 through Ci, when the trigger is OFF (tube 1 conducting), must be considerably greater than the negative pulse in order to trip the trigger. Therefore, within the operating range, positive pulses have no effect.

Often it is desired to trip triggers with a positive potential. In these cases, the grids of one or both of the tubes in the trigger are *directly coupled* to a positive potential sufficiently high to raise the grid potential above its critical value. The direct coupling instead of capacity coupling is necessary to hold the positive potential at the grid of the non-conducting tube long enough to insure triggering. This may be done as shown by the dotted circuit in Figure 85. Here a cam contact directly connects the grid of tube 2 to +40 volts. If the trigger is OFF, it will be turned ON since tube 2 is forced to start conducting, and by the retroactive coupling of its anode to the grid of tube 1, tube 1 is cut off. Once the trigger is ON, it will stay ON even after the CB contact opens. To turn the trigger OFF a negative pulse must be applied to the grid of tube 2 or a positive potential must be impressed on the grid of tube 1. When a positive potential is impressed on the grids for tripping the triggers, the input capacitors Ci are connected to the +150 volt line, and they serve only as stabilizing capacitors.

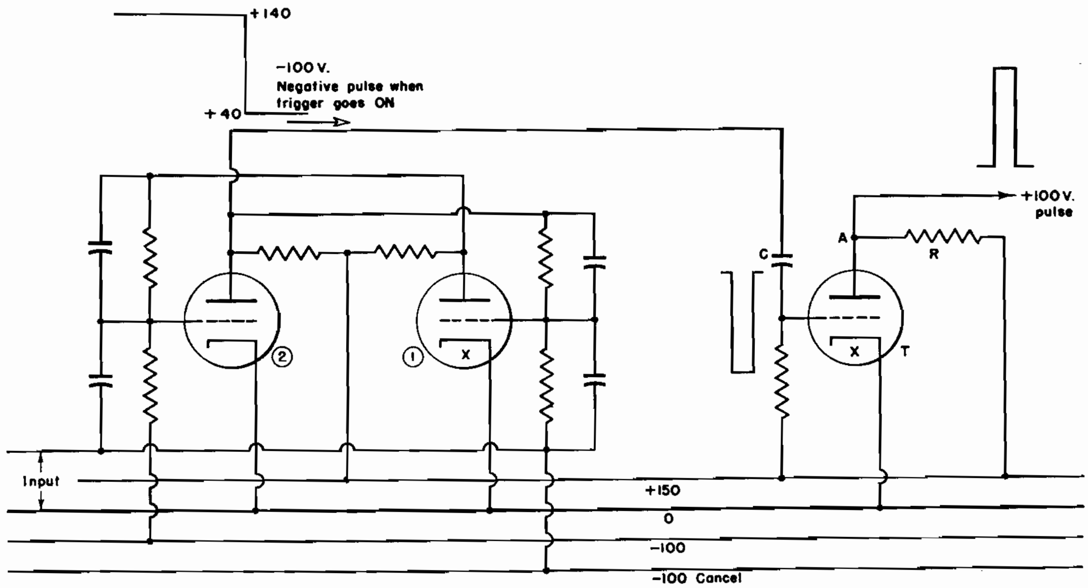


Figure 86. Use of Trigger to Control Triode

It will be noted that the grid resistor for tube 1 is connected to a line marked *–100 cancel.* The only difference between the –100 volt line and the cancel line is that the cancel line can be opened by means of a P-cam contact. When the contact is opened, potential is removed from the cancel line, and negative bias potential is removed from the grid of tube 1. This leaves the grid of tube 1 connected to the +150 volt line through the coupling resistor Rc and the load resistor of tube 2. Tube 1 will thus start conducting if it had not been previously conducting (trigger goes OFF.) This arrangement provides a means of resetting the triggers to the desired stand-by state. When power is first applied to a trigger, there is nothing but chance to determine which tube will start conducting. Hence, before starting a computing operation, all triggers are cancelled to their proper stand-by state.

Some of the triggers have the grid resistor of tube 2 connected to the cancel line instead of the grid resistor of tube 1. Such triggers are ON in their stand-by state. When the cancel line is opened these triggers will go ON if they were previously OFF.

The proper stand-by state of any trigger can always be determined from the circuit diagram by observing which grid resistor is connected to the cancel line. However, for simplification the normal state of a trigger is noted on the circuit diagram by placing a small "x" under the cathode of the normally conducting tube (Figure 85).

When the trigger shown in Figure 85 is OFF, tube 1 is conducting; its anode and the points of its load resistor and grid resistors Rc and Rg are at their low potentials. On the other hand, tube 2 is non-conductive and the corresponding points on this branch of the circuit are at their high potentials. Upon reversal of the trigger, positive and negative shifts in potential (potential pulses) are produced at different points of the circuit. For instance, upon reversal of the trigger from ON to OFF, a drop in potential (negative pulse) is produced on the anode of tube 1. As mentioned in the theory, a 100 volt shift is produced at points A1 and A2, whereas a 50 volt shift is produced at the mid-point taps on the load resistors M1 and M2. Points G1 and G2 are at cathode potential when their corresponding tube is conducting and at –30 volts when their corresponding tube is non-conducting.

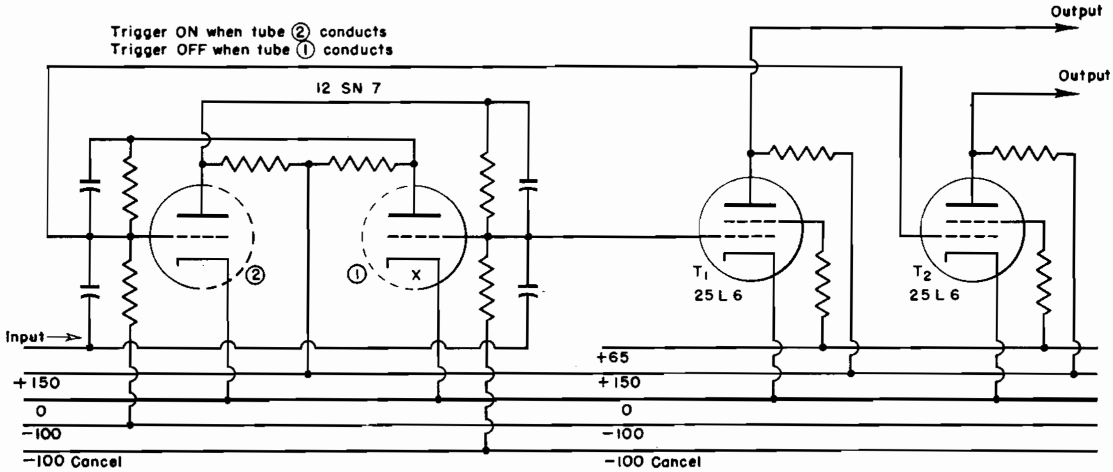


Figure 87. Control of Power Tubes by Trigger with Grid-to-Grid Connections

Control of Other Tubes by Triggers

The shift in potential at the various points on a trigger can be utilized to control other triggers, or to control electronic switch tubes and power tubes. As mentioned before, the triggers used in this unit will trigger on negative pulses, from 20 to 80 volts (approximately), when both grids are pulsed simultaneously. At 80 volts and above, a positive pulse will trip the trigger as well as a negative. For this reason the triggers are operated by 50 volt pulses, or roughly at the middle of the range. This means that when one trigger is controlled by another, potential pulses are taken from the midpoint of the load resistor. However, when a switch or power tube is controlled by a trigger, a +100 volt shift is required and the pulses are taken from the anodes of the trigger. A switch or power tube may also be controlled by connecting the grid of the controlled tube to the proper grid of the trigger. The controlled tube then acts as a follower. In controlling other circuits with a trigger precautions must be taken not to load the trigger. *The trigger cannot be loaded and still operate properly.*

Figure 86 shows a method commonly used in these circuits for providing a +100 volt pulse when a trigger goes ON. The grid of tube T is connected to the +150 volt line, therefore T is normally conductive. There is approximately a 50 volt drop across T when it is conducting; therefore, point A is normally at +50 volts potential. The grid of T will of course be at approximately cathode potential owing to grid current. When the trigger is turned ON by an input pulse, tube 2 conducts, and its anode drops approximately 100 volts in potential. Since the grid of T is normally at cathode potential, the negative shift in potential at the anode of tube 2 will be transmitted through coupling capacitor C and momentarily drive the grid of T negative, thus stopping conduction through T momentarily. Point A will momentarily rise in potential from about +50 volts to +150 volts and provide a +100 volt pulse to operate some other tube. Note that tube 1 is shown normally conductive. This is determined by the fact that the grid of tube 1 is connected to the cancel line. Thus, this trigger is cancelled OFF.

Figure 87 shows a method of controlling power tubes by a grid-to-grid connection with a trigger. In this case the trigger itself could be used without the power tubes if it were not for the fact that the trigger cannot be loaded. The circuits being controlled require appreciable power; therefore, power tubes T1 and T2 controlled by the trigger are used to provide high and low potentials according to the status of the trigger. When the trigger is OFF

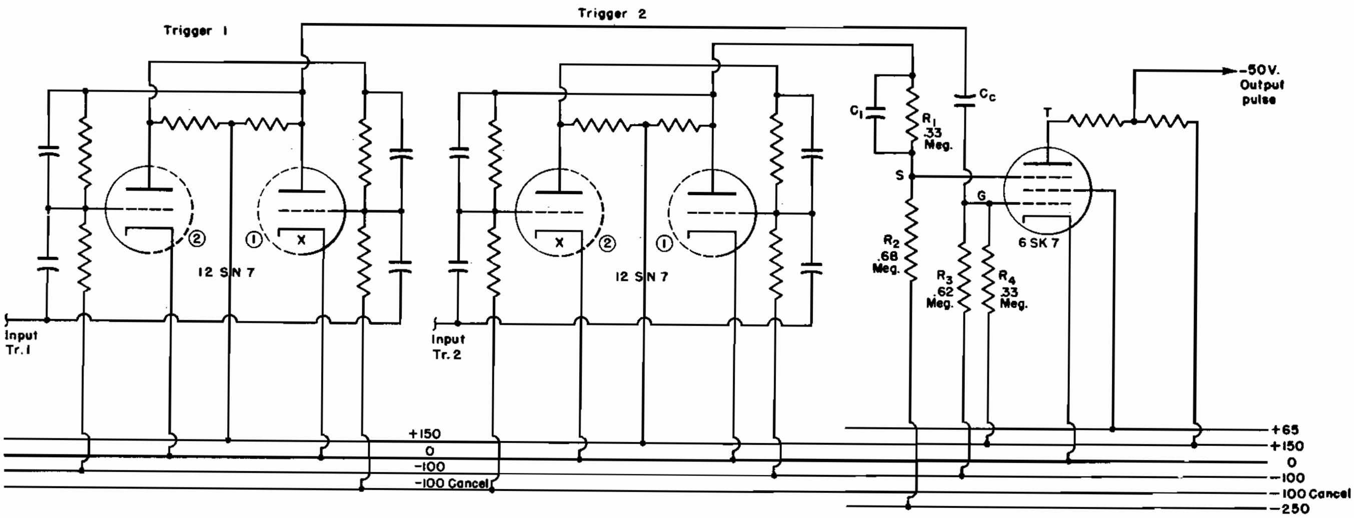


Figure 88. Control of Pentode Switch with Two Triggers

(stand-by state), tube 1 is conductive and its grid is at cathode potential, whereas the grid of tube 2 is below cutoff. Since the grid of T1 power tube is directly connected to the grid of tube 1, T1 will conduct whenever the trigger is OFF, and the anode of T1 will be at low potential. On the other hand, the grid of T2 is connected to the grid of tube 2, which is cut off when the trigger is OFF, thus holding T2 non-conductive and its anode at high potential. Conversely, when the trigger is ON, T2 conducts and T1 does not, thus placing line A1 at high potential and line A2 at low potential.

Figure 88 shows two triggers working in combination to control a pentode switch tube. Pentode tube T is connected so that either its grid or suppressor can stop conduction independently of the other. The grid is normally at approximately −35 volts as determined by the resistor network R3 and R4 between the ground line and the −100 volt line. The suppressor is at approximately −50 volts when the top of R1 resistor is at low potential, as determined by the network R1 and R2 between the anode of tube 1 of trigger 2 and the −250 volt line. Before conduction can occur through the pentode, *both grids must be driven positive.*

Note that trigger 1 is normally OFF and that the anode of its tube 1 is connected to the control grid of T through coupling capacitor Cc. Also note that trigger 2 is cancelled ON, and thus is normally ON with tube 2 conducting. The anode of tube 1 in trigger 2 is directly coupled to the suppressor of T via resistor R1. The shunting capacitor C1 is a compensating capacitor to compensate for the interelectrode capacity of the tube and thus permit more instantaneous response of tube T. When trigger 2 is ON, the anode of tube 1 is at high potential and the suppressor of T will be conditioned to conduct. However, no conduction can take place until the control grid is driven positive. This occurs when trigger 1 goes ON and the anode of its tube 1 rises in potential. Since the coupling from the anode of tube 1 of trigger 1 to the grid of T is through a capacitor, the grid of T will be driven positive only momentarily, and conduction will occur through tube T momentarily. When T conducts, there is a drop in potential at its anode and at any point on its load resistor. Thus when T conducts, a −50 volt pulse is produced at the midpoint of its load resistor. Note that tube T can conduct *only when trigger 1 goes* ON, *providing trigger 2 is* ON *at this time.*

Practically all the tubes controlled by triggers are controlled by one of the foregoing means. These methods will be recognized throughout the circuits for the computing section, and hence they should be carefully studied before proceeding with the actual computing circuits.