## ELECTRONIC COUNTER

We are accustomed to using the decimal system when dealing with numbers, that is, to think in terms of tens, hundreds, thousands, etc. Our machine computation methods and number storage devices for the most part employ the decimal systems, perhaps because of our thought habits rather than because of machine parts, economy, or operating speed. Figuring mentally will very likely remain in the decimal system but machine methods are slowly evolving to a special system where results warrant the use. For example, to store a number in relays (or tubes), *using the decimal system,* it is necessary to use one relay (or tube) to represent each digit, or 10 relays (or tubes) per position. For this reason it is expedient to make use of a number system other than the decimal system, which will mean a definite saving in relays or tubes for storage. By using a number system with the base *2*, known as the *binary* system, it is possible to store a digit value in only 4 relays instead of 10. This is done by assigning to 4 relays the values *1, 2, 4,* and *8*. Any digit in the decimal system can then be expressed by means of one or more of the relays as indicated below.

| Digit | Relays Energized |
|---|---|
| 0 | None |
| 1 | 1 |
| 2 | 2 |
| 3 | 1, 2 |
| 4 | 4 |
| 5 | 1, 4 |
| 6 | 2, 4 |
| 7 | 1, 2, 4 |
| 8 | 8 |
| 9 | 1, 8 |

Once a reading is sensed, it must be maintained in order to store the number. Also, a means must be provided to read out the number. When using relays, this is accomplished by using one contact point on the relay for holding and other points for reading out. The relays can just as well be tubes; but when using tubes, this cannot be done by means of one tube. It can be accomplished by using *one trigger* for each position, because a trigger remains ON, once it is turned ON by an input pulse, until another pulse turns it OFF. Therefore, by using four triggers in a tandem connection and designating them as *1, 2, 4,* and *8,* a digit may be stored as indicated by the chart below.

| Digit | Triggers ON |
|---|---|
| 0 | None |
| 1 | 1 |
| 2 | 2 |
| 3 | 1, 2 |
| 4 | 4 |
| 5 | 1, 4 |
| 6 | 2, 4 |
| 7 | 1, 2, 4 |
| 8 | 8 |
| 9 | 1, 8 |

The problem then resolves itself to providing a means of turning the proper triggers ON for a given number. Remember that if triggers are coupled as shown in Figure 84, *when the first trigger goes* OFF, *the second trigger goes* ON. If four triggers are coupled in the manner shown in Figure 84 and designated as shown in Figure 89, the following results are obtained:

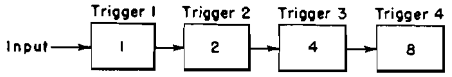
Trigger 1 will turn ON every 2 impulses.

Trigger 2 will turn ON every time trigger 1 turns OFF, or every 4 impulses.

Trigger 3 will turn ON every time trigger 2 turns OFF, or every 8 impulses.

Trigger 4 will turn ON every time trigger 3 turns OFF, or every 16 impulses.

Obviously the system illustrated in Figure 89 cannot be used in storing numbers in the decimal system, since the counter does not restore to zero on the tenth pulse as it should in the decimal system. The device in this case counts on the binary system, that is by 2's, and 16 pulses are required to restore the counter to starting position at *0*.



| Pulse No. | Trigger 1 | Trigger 2 | Trigger 3 | Trigger 4 | Code |
|---|---|---|---|---|---|
| 0 | OFF | OFF | OFF | OFF | 0 |
| 1 | ON | OFF | OFF | OFF | 1 |
| 2 | OFF | ON | OFF | OFF | 2 |
| 3 | ON | ON | OFF | OFF | 1,2 |
| 4 | OFF | OFF | ON | OFF | 4 |
| 5 | ON | OFF | ON | OFF | 1,4 |
| 6 | OFF | ON | ON | OFF | 2,4 |
| 7 | ON | ON | ON | OFF | 1,2,4 |
| 8 | OFF | OFF | OFF | ON | 8 |
| 9 | ON | OFF | OFF | ON | 1,8 |
| 10 | OFF | ON | OFF | ON | 2,8 |
| 11 | ON | ON | OFF | ON | 1,2,8 |
| 12 | OFF | OFF | ON | ON | 4,8 |
| 13 | ON | OFF | ON | ON | 1,4,8 |
| 14 | OFF | ON | ON | ON | 2,4,8 |
| 15 | ON | ON | ON | ON | 1,2,4,8 |
| 16 | OFF | OFF | OFF | OFF | 0 |

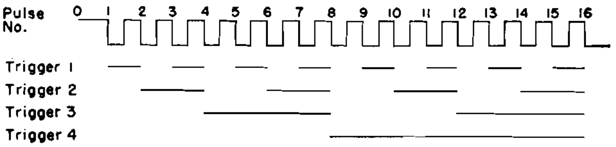


*Figure 89. Binary Counter Operation*

Note from Figure 89 that the counter follows the decimal system up through 9. Now if some means can be provided to restore the counter to *0* on the tenth pulse, the counter can be used to store and add numbers on the decimal system. This is done in the electronic counter by means of special coupling between triggers and by the use of a special blocking tube, as illustrated by the circuits for one position of an electronic counter shown in Figure 90. The triggers are designated by their digital value and the blocking tube is designated as B.

Note that triggers 1, 2, and 4 are coupled in tandem in conventional manner. However, trigger 8 has special connections to the input capacitors, and tube B is connected in parallel with tube 1 of trigger 2 to serve as a blocking tube. Tube B is normally non-conductive and conducts only when trigger 8 is ON. This arrangement operates exactly as shown in Figure 89 up through the ninth pulse. Then, on the tenth pulse trigger 8 must be turned OFF and trigger 2 must be blocked from turning ON as it normally would on the tenth pulse. The special coupling from trigger 1 to the left side of trigger 8 turns trigger 8 OFF on the tenth pulse, while tube B blocks trigger 2 on the tenth pulse. Thus all triggers are OFF on the tenth pulse, and a negative pulse is available at the output for carry. Figure 91 shows the operation of one position of an electronic counter in chart form, indicating the special coupling from trigger 1 to trigger 8 and the blocking of trigger 2 on the tenth pulse.

Addition in an electronic counter is accomplished by successive impulses, the number depending on the value of the digit to be entered. A

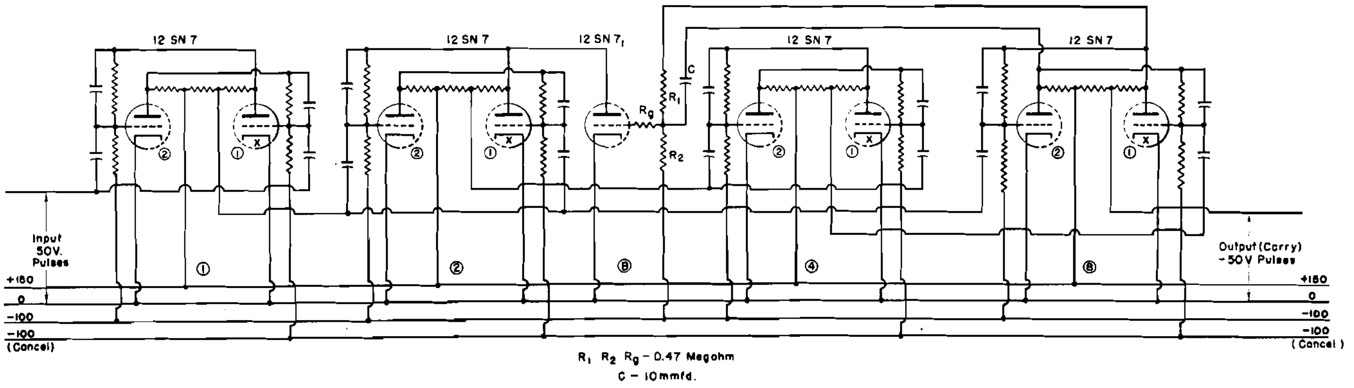
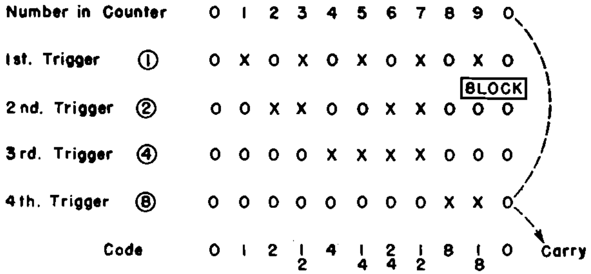


*Figure 90. One Position of an Electronic Counter*



| Number in Counter | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st. Trigger | ① | O | X | O | X | O | X | O | X | O | X | O | |
| | | | | | | | | | | | BLOCK | | |
| 2nd. Trigger | ② | O | O | X | X | O | O | X | X | O | O | O | |
| 3rd. Trigger | ④ | O | O | O | O | X | X | X | X | O | O | O | |
| 4th. Trigger | ⑧ | O | O | O | O | O | O | O | O | X | X | O | |
| Code | | 0 | 1 | 2 | 1<br>2 | 4 | 1<br>4 | 2<br>4 | 1<br>2<br>4 | 8 | 1<br>8 | 0 | Carry |

Note—X Indicates Trigger ON
O Indicates Trigger OFF

*Figure 91. Electronic Counter Chart*

carry to the left is effected each time a position of the counter changes from 9 to 0. Two tubes are required for carrying from each counter position except the last. A trigger is turned ON when the counter advances from 9 to 0. The trigger conditions a switch tube to permit a carry impulse to be fed to the next higher order counter position. If the position receiving the carry impulse stands at 9 and advances to 0, its carry trigger is turned ON to condition the switch and continue the carry to the next higher counter position. The carry is not instantaneous to two or more positions, but the carry impulse is of sufficient duration to complete the carry to all counter positions if necessary. The carry impulse is made available after the adding portion of the cycle, and the carry triggers that have been turned ON are restored to the OFF position at the completion of carry. The carry operation is shown in block diagram form in Figure 92. The details of the carry circuit are described in a later section after the computing circuits have been described.

Pulses may be delivered to a counter at the comparatively slow rate of card cycle point timing, or at the 35,000 cycle per second rate as in the case of counter transfers. Counters have been successfully operated at impulse rates up to 150,000 cycles per second. The impulse admittance is controlled by tube switches, to be described later.

A detailed explanation of the operation of one position of an electronic counter circuit is presented below (Figure 90).

Triode B has its grid connected between the anode of tube 1 of trigger 8 and the −100 volt line by means of a voltage divider $R_1R_2$. The anode of tube 1 of trigger 8 is at +40 volts as long as trigger 8 is OFF. (See discussion of *Trigger Circuits.*)

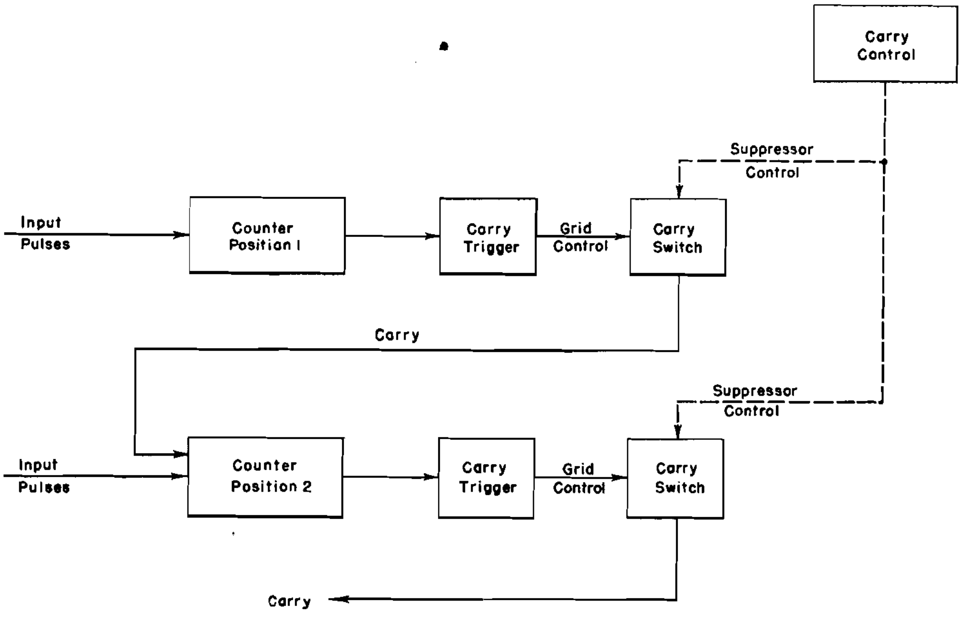


*Figure 92. Block Diagram of Carry Controls*

This means that the grid of B is midway between +40 volts and –100 volts, that is, –30 volts as long as trigger 8 is OFF. This is considerably below the cutoff potential of tube B, therefore B is non-conductive as long as trigger 8 is OFF.

When trigger 8 goes ON, the potential at the anode of its tube 1 rises to +136 volts. The grid of tube B is then midway between +136 volts and –100 volts, or +18 volts. Of course, the grid does not actually go to +18 volts, because grid current starts flowing through Rg as soon as the grid tries to go positive. This current flow through Rg and R1 is the reverse of the normal current flow through R1 resulting from the +136 volt and –100 volt potentials; consequently the potential at the grid is kept from rising above zero and remains substantially at zero, or cathode potential. With tube B conducting, the potential at its anode is +40 volts. Since the anode of B is directly connected to the anode of tube 1 of trigger 2, the anode of tube 1 of trigger 2 will be maintained at +40 volts regardless of what trigger 2 attempts to do. From the theory of operation of a trigger it will be remembered that the rise in potential at the anode of one tube is necessary to cause the other tube to conduct. If trigger 2 is OFF when tube B is conducting then *trigger 2 cannot be turned* ON regardless of the pulses applied, because the anode of tube 1 of trigger 2 cannot rise above +40 volts, and as a result, the grid of tube 2 of trigger 2 cannot go above cutoff potential.

The input pulses to the counter are 50 volts square wave pulses. From the theory of operation of a trigger it will be remembered that the trigger will recognize only negative pulses provided the voltage amplitude of the pulses is kept within certain limits. Hence, only the negative shifts in voltage are recognized by the triggers. The entry pulses are fed to both input capacitors of trigger 1 to turn it ON and OFF on successive pulses. Each time trigger 1 goes ON, a 50 volt positive pulse is produced at the anode resistor tap of tube 1 of trigger 1. However, this positive pulse is not recognized and consequently can be ignored. Each time trigger 1 goes OFF, a 50 volt negative pulse is produced at the anode resistor tap of tube 2 of trigger 1, and this negative pulse is fed to both input capacitors of trigger 2.

Assuming the counter position is at zero, all four triggers are OFF and tube B is non-conductive. One entry pulse turns trigger 1 ON, and the counter position stands at 1. The resulting positive pulse to triggers 2 and 8 has no effect. A second entry pulse turns trigger 1 OFF which in turn trips trigger 2 ON, and the counter stands at 2.

Note that the negative pulse which turned trigger 2 ON also is fed to the left side of trigger 8. Trigger 8 is OFF at this time, and the grid of tube $8_2$ is already negative; consequently this negative pulse has no effect. Also, the positive pulse from the anode resistor tap of tube $2_1$ has no effect on trigger 4.

A third entry pulse turns trigger 1 ON again, and a positive pulse is fed to trigger 2. This positive pulse has no effect; consequently, trigger 2 remains in the ON status, and the counter stands at 3 (triggers 1 and 2 ON). A fourth entry pulse switches trigger 1 OFF, which in turn switches trigger 2 OFF. When trigger 2 goes OFF, a negative pulse is produced at the anode resistor tap of tube $2_1$, and this pulse is fed to both input capacitors of trigger 4, turning it ON. This leaves only trigger 4 ON, and the counter stands at 4.

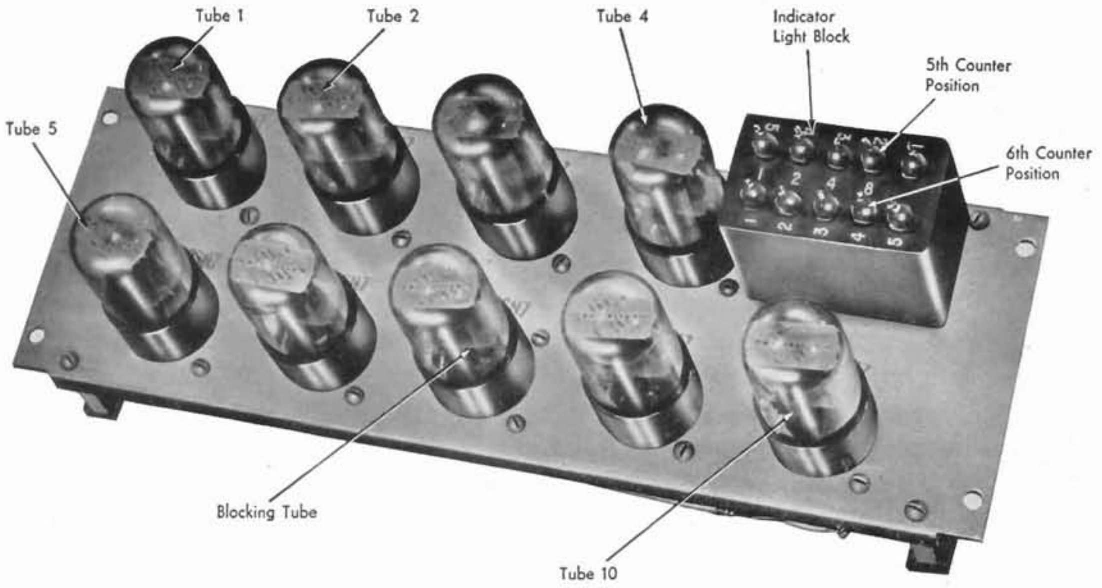
A fifth entry pulse again turns trigger 1 ON, and the counter stands at 5 (triggers 1 and 4 ON). A sixth entry pulse turns trigger 1 OFF, causing trigger 2 to go ON, and the resulting positive pulse has no effect on trigger 4; therefore, the counter stands at 6 (triggers 2 and 4 ON). A seventh entry pulse again turns trigger 1 ON, but has no effect on trigger 2, thus leaving triggers 1, 2, and 4 ON, and the counter stands at 7. An eighth entry pulse turns trigger 1 OFF, causing trigger 2 to go OFF; as trigger 2 goes OFF, it turns trigger 4 OFF. When trigger 4 turns OFF, it produces a negative pulse which is impressed on the grid of tube 1 in trigger 8. This negative pulse stops conduction in tube $8_1$ and causes trigger 8 to go ON and the counter stands at 8.

When trigger 8 goes ON, the anode of tube $8_1$ is at high potential (+136 volts). Since this potential is applied to the grid of tube B through the voltage divider $R_1R_2$, it means that the potential at the grid of tube B will rise above cutoff and tube B becomes conductive. This tube is used on the tenth pulse. A ninth entry pulse will again turn trigger 1 ON and have no effect on other triggers, thus leaving the counter at 9 (triggers 1 and 8 ON). A tenth entry pulse turns trigger 1 OFF which in turn passes a negative pulse to trigger 2 and to the left side of trigger 8. This negative pulse tends to trip trigger 2 ON, but such action in trigger 2 demands a rise in potential at the anode of tube $2_1$. Since tube B is now conductive, it holds the potential at the anode of tube $2_1$ to +40 volts and overcomes the attempted rise in potential at the anode of tube $2_1$ and at the grid of tube $2_2$. Thus, with tube B conductive, trigger 2 is blocked from turning ON. The negative pulse produced by stage 1 is also applied to the grid of tube $8_2$. This causes tube $8_2$ to stop conducting; consequently, trigger 8 goes OFF, and the counter has restored to zero (no triggers ON). When trigger 8 goes OFF, the potential at the anode of tube $8_1$ drops abruptly from +136 to +40 volts, while the potential at the anode of tube $8_2$ rises abruptly from +40 volts to +136 volts. A tap on the anode resistor of tube $8_1$ furnishes a −50 volt pulse to operate the carry trigger. If a positive pulse is desired to operate a switch when a carryover occurs, a tap on the anode of tube $8_2$ can be used.

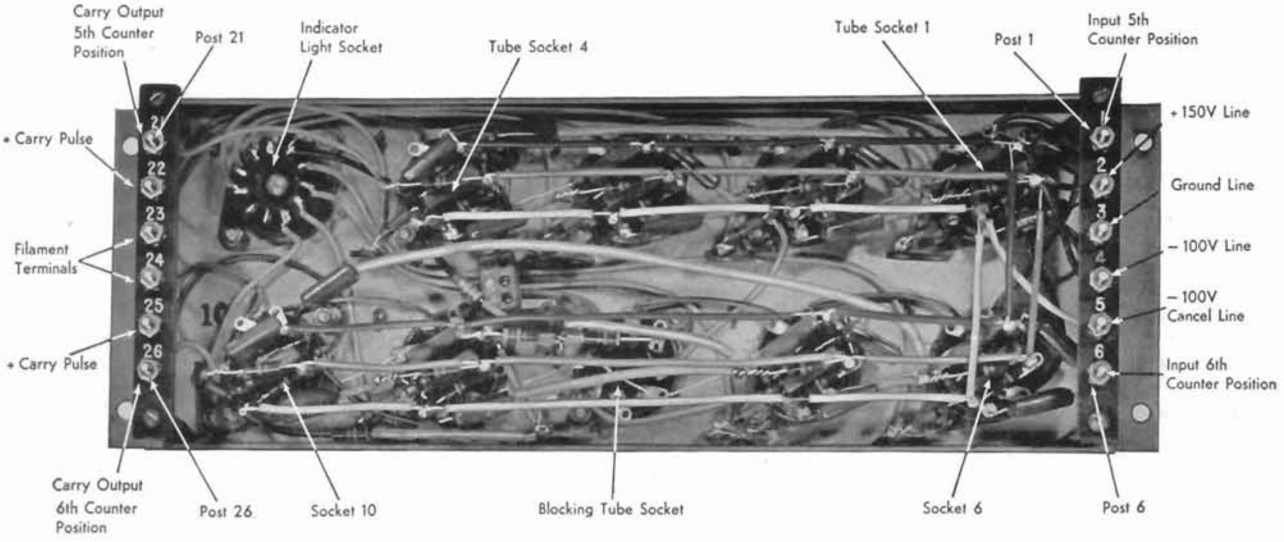
Any digit can then be added into this counter by applying the proper number of negative pulses. If 6 pulses are applied, the counter will stand at 6, since triggers 2 and 4 will be ON. A counter will retain a reading as long as power is applied. When a counter is to be cleared, it is merely a matter of opening the −100 volt cancel line. This applies +150 volts to the right side of all the triggers and they are all turned OFF, thus restoring the counter to 0. Cancelling is always necessary before reading into a counter, because when power is first turned ON, the triggers may assume any status, depending entirely upon chance or upon variations in individual tubes.

Observe that on the tenth pulse when trigger 8 goes OFF and the potential drops at the anode of tube $8_1$, triode B is rendered non-conductive, and its anode potential immediately rises, thus releasing trigger 2 from the blocking action. If this occurred too soon, the tripping pulse produced by trigger 1 on the tenth pulse might still be effective to turn trigger 2 ON. To insure against this, the blocking action of tube B is maintained for a short time after trigger 8 goes OFF by maintaining conduction through tube B for a short period after trigger 8 goes OFF. This insures that trigger 2 is not unblocked until the tripping pulse from trigger 1 is spent. It is for this reason that the grid of tube B is coupled to the anode of tube $8_2$ through capacitor C. During the reversal of trigger 8 to the OFF status, the potential at the anode of tube $8_2$ is rising rapidly while that at the anode of tube $8_1$ is dropping rapidly. The rising potential is transmitted by way of the capacitor C to grid resistor Rg of tube B. This rising potential counteracts the effect of the dropping potential on the grid of tube B and maintains the grid of tube B above cutoff until capacitor C is fully charged. Thus, the grid of triode B does not follow the anode of tube $8_1$ immediately, but is held above cutoff potential for a definite delay period determined by the charging time of capacitor C. Thereafter, the low potential at the anode of tube $8_1$ is effective to hold tube B cut off as long as trigger 8 is OFF.

In practice the blocking tube is one-half of a 12SN7 twin triode. The other half is used as the blocking tube for another counter position. For this reason and to facilitate the handling of the tube chassis, counter chassis are built with two counter positions per chassis as shown in Figure 93. Each chassis also contains an indicator light block



A. Front View – Showing Indicator Block



B. Rear View – Showing Terminals

*Figure 93. Two-Position Electronic Counter (K Chassis)*

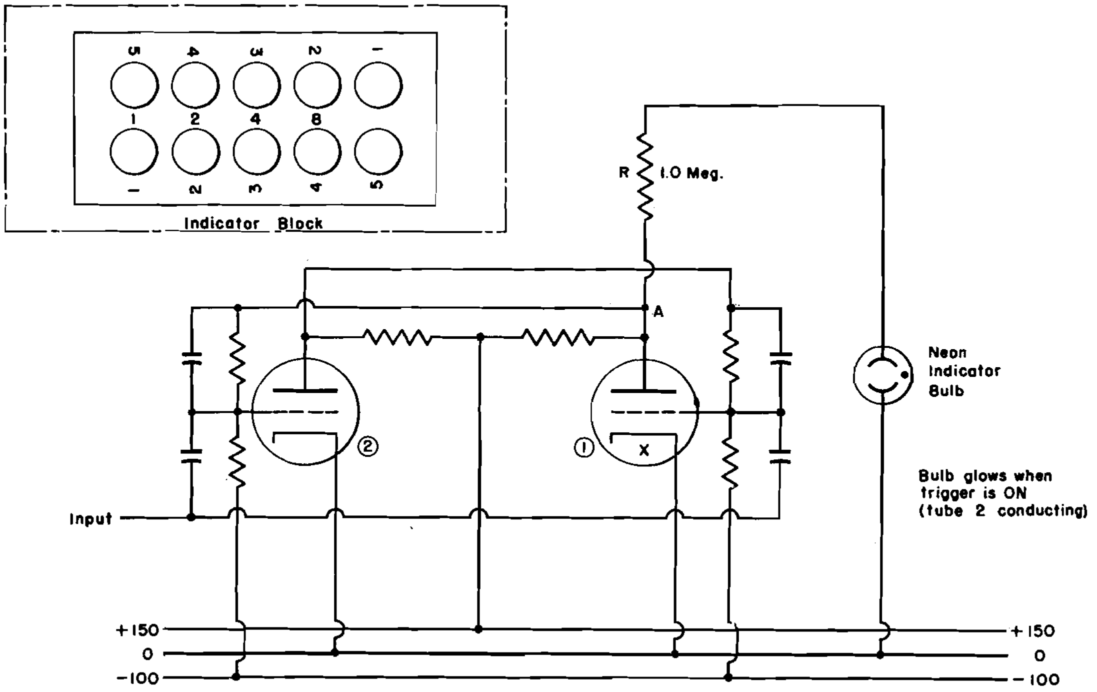


*Figure 94. Indicator Lights*

used to indicate the counter reading at any time by indicating which triggers are ON. One row of lights applies to each counter position. The bottom view of the chassis indicates the terminal connections.

As an example of the circuits for a complete counter chassis, see the circuit diagram for chassis K, the 5th and 6th counter positions of the multiplicand counter (Sections 47 and 48 on wiring diagram). Note that the nine filaments are in series across the 115 volt A.C. line, placing 12.8 volts across each filament. All counter chassis are the same regardless of where they are used. If carry circuits are necessary, the tubes controlling carry are mounted in separate chassis. No carry circuits are used in the multiplier or multiplicand counters; only the product counter requires carry circuits.

Observe that all counters use high-speed triggers. Since counter read-in may be at either high or low speed, it is necessary to employ high-speed triggers throughout.

### Indicator Blocks

Neon indicator lights are used throughout the electronic unit to indicate the status of various triggers. The light is wired to glow when the corresponding trigger is in the ON status. Figure 94 shows how the indicator light is connected to a trigger. As long as the trigger is OFF (tube 1 conducting), the anode of tube 1 (point A) is at +40 volts, and there are 40 volts impressed across the neon bulb since the bulb is connected between ground and the anode of tube 1 through resistor R. This bulb will not glow, however, until at least 90 volts are impressed across it. When the trigger goes ON, the potential at the anode of tube 1 rises to +136 volts, and the neon bulb will glow, indicating that the trigger is ON.

The 1 megohm resistor R limits the current through the neon bulb, isolates the anode of tube 1 from other circuits, and thus prevents capacity coupling in the cables.

As a word of caution, it should be pointed out that the neon bulb will glow when the potential at point A is over +90 volts regardless of the trigger status. For example, if the filament of a trigger tube is burned out, neither tube can conduct. However, the indicator light glows, indicating that the trigger is ON. Sometimes this can be used to detect a faulty trigger tube.

The indicator bulbs are mounted in a block which can be plugged into a socket. An extension cable is provided to permit viewing indicator lights from the rear of the chassis. The layout of the bulbs in a block is shown by the insert in Figure 94. Note that there are ten bulbs in the block. The numbering is designed to permit use of a standard block in all applications. The horizontal numbers between the bulbs (1, 2, 4, 8) refer to the digital value of triggers used in counters while the numbers along the edges of the block merely represent the bulb number. When the socket is used in locations other than counters, it is ordinarily mounted vertically so that the numbers on the outer edges can be read. In these cases the left side is counted first, and number 6 is the first bulb in the row to the right.

To avoid confusion, it is recommended that on the indicator blocks used in counters the outer numbers be blacked out with masking tape or crayon.

### Counter Read-In from Card

Reading into an electronic counter from a card requires that the electronic counter receive a number of negative pulses equal to the value of the digit punched in the card. The method of doing this is illustrated by the block diagram in Figure 95. A set of CB's provides 9 positive pulses which are fed to a switch tube. The pulses from the CB's have no effect, however, until the switch is "unlocked" by the trigger, and consequently no negative pulses can pass through from the switch tube to the counter until the read-in trigger is turned ON. (A tube inverts a pulse so that the positive pulses from the CB's pass to the counter as negative pulses.)

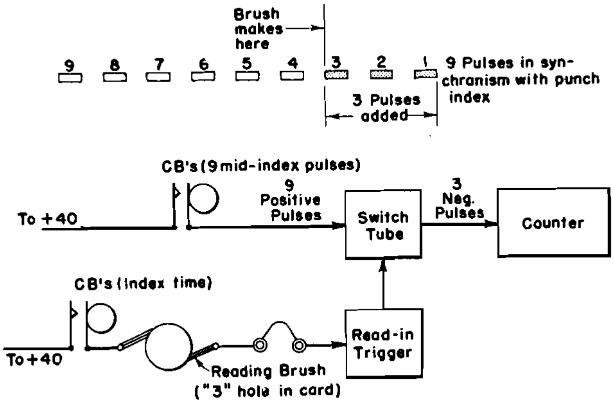
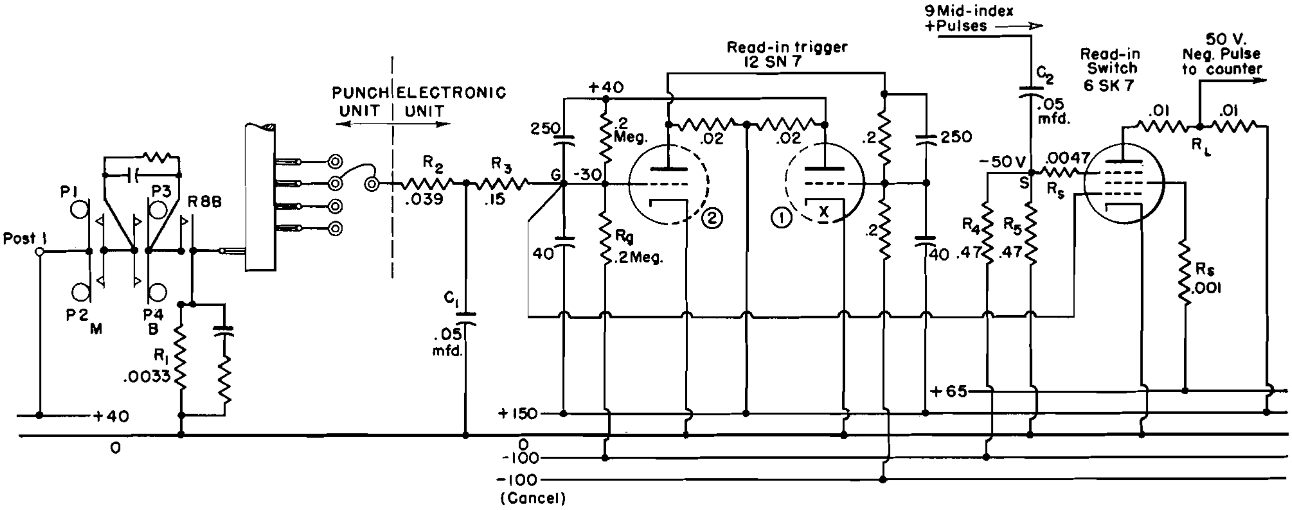


*Figure 95. Block Diagram of Counter Read-in Circuits*

When a brush drops through a hole in the card, the read-in trigger is turned ON, and the switch tube is "unlocked" so that it can start passing pulses. If, for example, the brush drops through a 3 hole, the CB's will make only 3 more times in that cycle and only 3 pulses will be passed to the counter. The trigger is necessary to provide a means of maintaining the switch tube in a conductive state until the end of the cycle, because the impulse from the hole in the card has a duration of only 0.3 of a cycle point on the index. Before a new cycle is started, the read-in trigger is cancelled OFF to prepare it to accept a new reading. The block diagram does not indicate the actual connections, but these can be found in the complete circuit for read-in control of one counter position shown in Figure 96.

Observe that the control grid of the pentode switch tube is tied directly to the grid of tube 2 of the trigger, so that the grid of the pentode follows the grid of tube 2 of the read-in trigger in potential. As long as the trigger is OFF, as indicated in Figure 96, the potential at point G is –30 volts and the pentode switch is cut off. When the trigger goes ON, point G rises to cathode potential and so does the control grid of the pentode, thereby conditioning the pentode to conduct. The positive pulses on the suppressor of the 6SK7 can then be inverted to negative entry pulses for the counter input. The voltage shift at the anode of



All resistance values shown in megohms
All capacitance values shown in micro-microfarads unless otherwise indicated

*Figure 96. Counter Read-in Control Circuit*

the 6SK7 is 100 volts when conduction starts. Since the counter requires only a 50 volt pulse, a center tap is used on the pentode load resistor $R_L$.

The suppressor of the 6SK7 is connected to point S between resistors R4 and R5 which are tied to the −100 volt line and the ground line respectively. Since R4 and R5 are equal, this places point S at −50 volts normally and the tube is cut off regardless of the potential at the grid. However, once the grid is conditioned to conduct, then any time the suppressor rises above cutoff potential, the pentode will conduct and a negative pulse is produced at the anode of the 6SK7. The suppressor rises above cutoff whenever a positive pulse is applied to point S through the coupling capacitor C2. The number of these pulses accepted by the 6SK7 depends upon the point in the punch cycle when the trigger is turned ON from a hole in the card.

The turning ON of the trigger is accomplished as follows: When the card brush makes contact through a hole in the card and the CB's make, a circuit is established from the +40 volt line, through post 1, CB's R8B, common brush, contact roll, hole in card, individual brush, brush hub, control panel wire, counter entry hub, through resistors $R_2$, $R_3$, and Rg to the −100 volt line. This circuit will cause current flow through $R_2$, $R_3$, and Rg. The increased current through Rg, in addition to the normal bleeder current, causes an increased IR drop across Rg and point G rises above cutoff for tube 2 of the trigger so that tube 2 of the trigger starts conducting. Immediately the dropping potential at the anode of tube 2 cuts off tube 1 by means of the retroactive coupling from the anode of tube 2 to the grid of tube 1. This means that the trigger is turned ON. Observe that the input capacitors of this trigger are tied to the +150 volt line and that the tripping pulse from the brush is applied to the left side only.

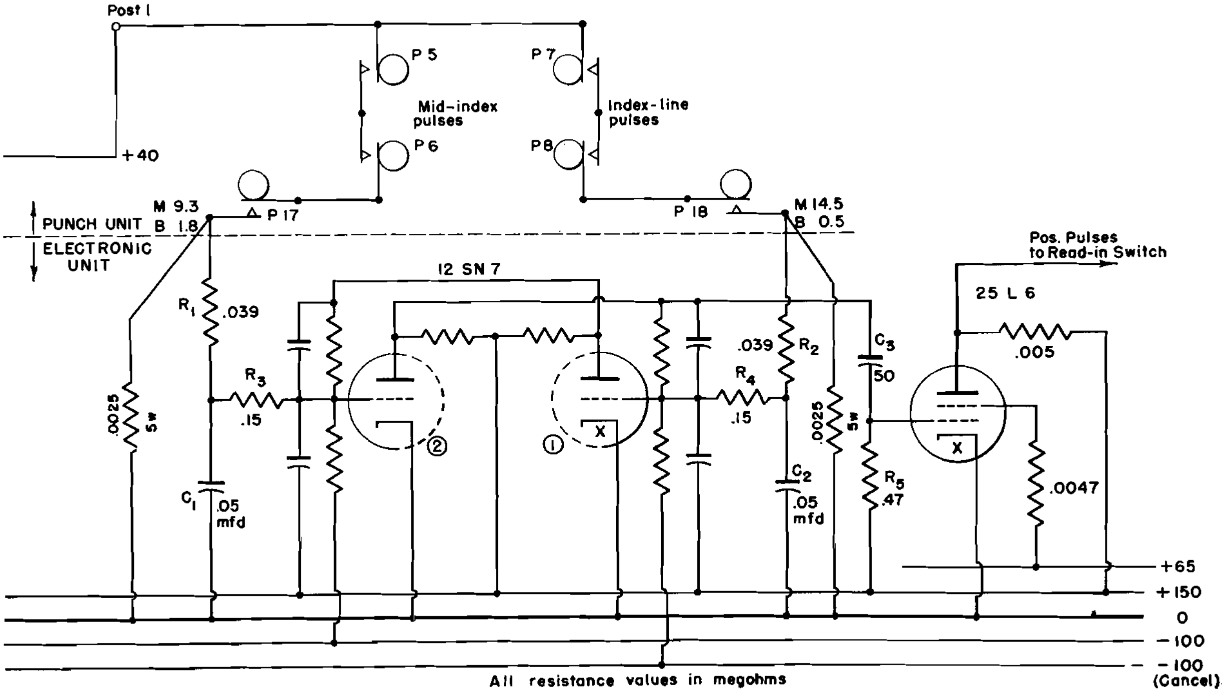
Once the trigger goes ON it remains ON until it is cancelled OFF, and the 6SK7 is conditioned to accept the pulses applied to the suppressor. The use of this arrangement provides a safeguard against "bouncing" brushes or CB contacts. Once the trigger is turned ON, any opening of the circuit due to a "bouncing" brush will not turn it OFF. Also, if the circuit is completed again, the trigger is already ON and no effect is produced. Only a short making time is required to turn the trigger ON, and after that it does not matter what happens to the brush.

The purpose of the capacitor $C_1$ tied between $R_2$ and $R_3$ to ground is to by-pass any stray pulses on the line to ground and thus prevent them from turning the trigger ON. Before the effect of a pulse can be felt at G, the capacitor $C_1$ must be charged, because during the charging time of $C_1$ it is effectively a shunt to ground. This means that any short duration transients will be dissipated in charging $C_1$. The exact time constant is determined by the value of $R_2$ and $C_1$. Of course, this produces a slight delay in the triggering operation when a brush makes, but the delay is not objectionable because the brush contact duration is considerably longer than required to turn the trigger ON.

The purpose of the RC combination R1-CR4 is to ground the CB's between pulses and thus prevent unstable operation resulting from "floating" lines when the CB's are open. The purpose of the resistor Rs in the screen and suppressor circuits of the 6SK7 is to prevent parasitic oscillations. The screen resistor also presents a means of producing equal current flow through all tubes used in parallel. For example, one tube's characteristic may be such that its screen and anode current during conduction are higher than the screen and anode current of other tubes. When all tubes are operated at the same voltage, the higher screen current of this tube will cause a greater voltage drop across the individual screen resistor for this tube and will thereby reduce the screen potential, resulting in a decreased anode current. Thus, variations in tube characteristics produce no variation in operation.

### Read-In Pulse Circuit

The block diagram in Figure 95 indicates that the 9 pulses provided to control reading into a counter are directly from a CB cam contact. Actually, this is not true, because a cam contact is likely to be erratic because of contact bounce, and several pulses may be entered in a counter for one cycle point. To avoid this trouble, the CB's control a trigger which in turn controls a power tube to provide the pulses to control the read-in switch pentodes. A power tube is necessary because if a trigger is loaded, unstable operation results.



All resistance values in megohms

*Figure 97. Read-in Pulse Circuit*

As shown in Figure 97, a set of CB's (P5 and P6) make 5 teeth after each index line and break 8 teeth after. P17 cam contact allows only the pulses from 9.5 through 1.5 to pass. Each time the CB's make, the trigger is turned ON in exactly the same manner described in the section, *Counter Read-in from Card.*

Observe that the 25L6 power tube is normally conductive, since its control grid is tied to the +150 volt line. This means that its anode is normally at low potential. Also observe that the grid of the 25L6 is coupled to the anode of tube 2 of the trigger through coupling capacitor $C_3$. When the trigger goes ON, the anode of tube 2 drops suddenly from about +136 volts to +40 volts. This negative shift in voltage is passed through $C_3$ to the grid of the 25L6 and momentarily cuts it off. When the 25L6 stops conducting, its anode potential rises to +150 volts, and the resulting positive pulse is passed to the suppressors of all the switch tubes controlling the multiplier and multiplicand read-in.

Another set of CB's (P7 and P8) make at each index line and open three teeth after the line. P18 cam contact allows only the pulses from 9 through 0 to pass to the right side of the trigger. Each time that P7 and P8 make from 8 to 0, the trigger is turned OFF in exactly the same manner it was turned ON by P5 and P6. Consequently, the trigger goes ON at mid-index points from 9.5 through 1.5 and goes OFF at index points from 8 through 0, thus providing 9 pulses in synchronism with card movement through the punch for read-in control.

The by-pass capacitors $C_1$ and $C_2$ serve the same purpose as the by-pass capacitor C in Figure 96. As in the case of the read-in triggers, this method of generating pulses eliminates all trouble due to bouncing contacts. For example, once the trigger is turned ON by P5 and P6 making, it makes no difference if they do open and close because of a bounce. The trigger cannot be turned OFF by opening P5 and P6; it can be turned OFF only by P7 and P8 closing. Likewise, once the trigger is turned OFF by P7 and P8 making, any break in the circuit will not turn the trigger ON; only a circuit through P5 and P6 can turn it ON. The two .0025 megohm wire-wound resistors shown connected from ground to P17 and P18 are provided to maintain a sufficient flow of current through the contact points in order to prevent a film forming over these points when no current flows.

The read-in trigger and power tube are tubes B-35 and B-36 in the B chassis. The circuit is shown in Section 30B of the wiring diagram. Observe that the read-in pulse control trigger is a slow-speed trigger.

### Counter Read-In at High Speed

When multiplying, high-speed pulses at the rate of 35,000 per second are fed to the multiplicand counter. For each cycle during which the multiplicand counter is to be "rolled," ten pulses are fed to the counter to provide a timed carry pulse and restoration of the counter back to its original setting. These ten pulses are positive pulses which are applied to the grid of a normally cut-off inverter triode. The positive pulses cause conduction through the tube, and the resulting negative pulses are fed to the counter through an anode resistor tap.

The complete wiring diagram for the multiplicand counter read-in controls in the D chassis may be seen in the circuit diagram in Sections 33 and 34. Posts 1, 5, 8, 12, 15, and 19 are connected to the multiplicand counter entry hubs on the control panel through the connecting cable. Posts 21, 26, 28, 33, 35, and 40 connect to the input of the six multiplicand counter positions. The indicator lights indicate which of the six read-in triggers (D1, D4, D7, D10, D13, D16) is ON, that is, which is accepting card read-in pulses. No indication is given of the high-speed read-in.

Only one voltage divider is used to furnish the −50 volt potential normally applied to all pentode suppressors. This divider is shown under tube D5 connected between the −100 volt line and ground. Also, only one input capacitor is used to feed the read-in pulses to all six suppressors. This same input capacitor is used to supply the read-in switches for the multiplier counter on the C chassis. Post 45 indicates this connection.

The tubes are arranged so that each horizontal row corresponds to one counter position as nearly as possible. Since only a triode is required to control the high-speed input for each position, only three 12SN7 twin triodes are used for the six positions, consequently, the line up of one row per position is not strictly true in the D chassis.

The ten high-speed pulses to roll the multiplicand counter originate in the B chassis and are fed in to post 2 through the 250 mmfd coupling capacitor to the input inverters D5, D11, and D14.

The grids of the input inverters are normally at about −35 volts since they all tie to the voltage divider shown under tube D5. This voltage divider is tied between ground and the −100 volt line and the grids are tapped approximately two-thirds of the way from the −100 volt line or at about −35 volts. Positive pulses entering post 2 drive all grids above cutoff simultaneously so that all six counter positions receive the rolling pulses. Note that the high-speed read-in control triodes utilize a portion

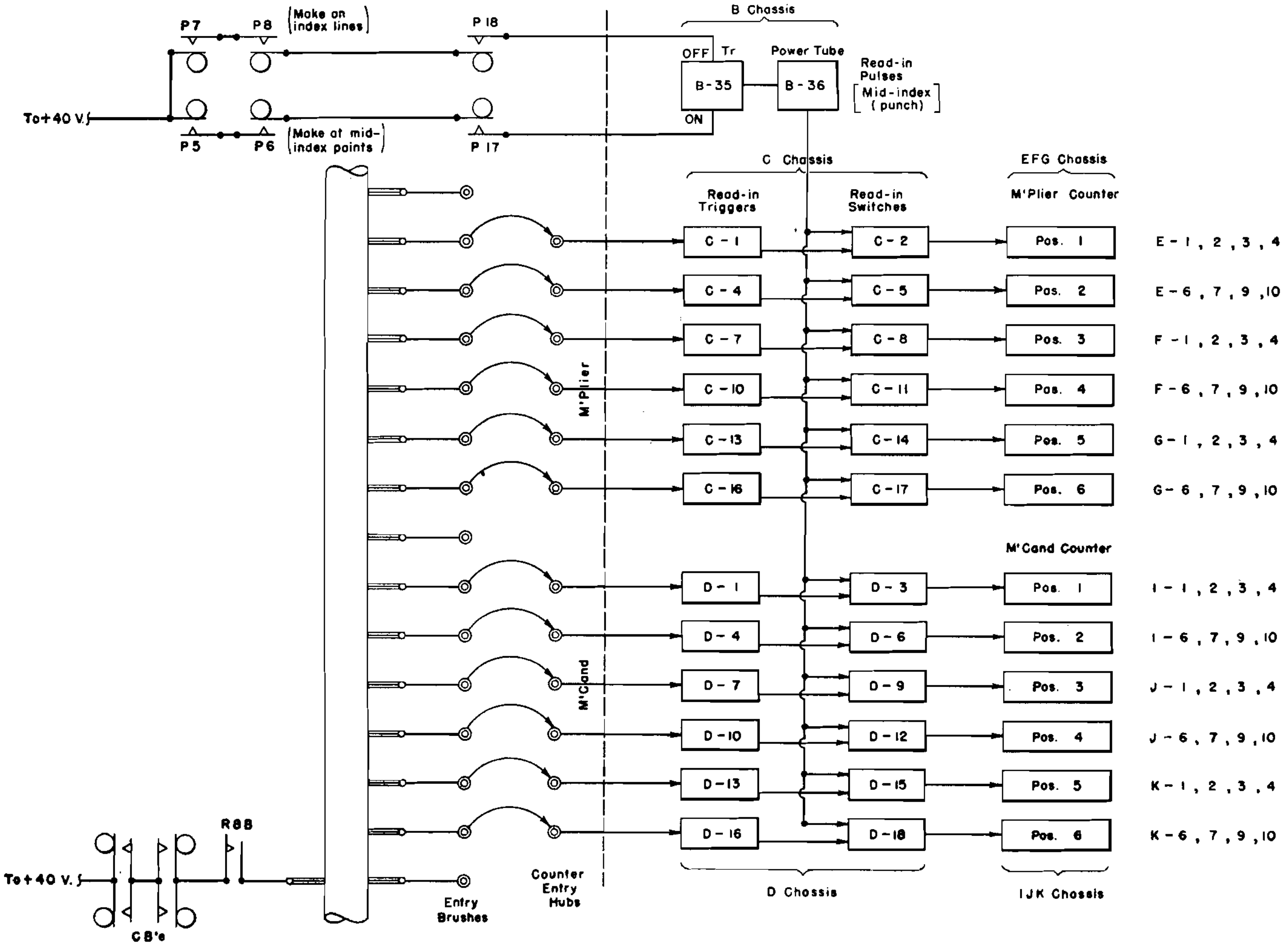


*Figure 98. Block Diagram of Read-in Circuits*

of the anode resistors in the switch tube anode circuit. Since only one circuit is in operation at the time, this permits simpler connections as only one counter input wire is required for both operations.

The multiplicand counter consists of six electronic counter positions on chassis I, J, and K, shown on Sections 43 through 48 of the wiring diagram. All counter positions are exactly the same; therefore, no effort will be made to repeat any counter operations.

The screen potential of the multiplicand read-in switches is under control of the factor reversal switch. When set for group multiplying, with the factor reversal switch ON, the screen supply is open on all cards except the rate card; the switch tubes are non-conductive. Observe that the +65 volt supply on the D chassis is connected to terminal CNp34. This connection places the +65 volt supply for the multiplicand read-in switches under the control of the group multiply and factor reversal relays.

The read-in controls for the multiplier counter appear on chassis C and circuits are shown in Sections 31 and 32. The multiplier read-in switches also have their screen supply connected through the group multiply and factor reversal relays in the punch unit through connector CNp32. This arrangement is used to permit conduction by the read-in switches only when a rate card passes the first set of brushes during a group multiplying run. Use is made of the fact that a 6SK7 will not conduct if there is no potential on its screen. The multiplier counter (chassis E, F, G) circuits are shown in Sections 35 through 40. Figure 98 is a block diagram of all read-in circuits, showing all tubes for all counter positions.

## COMPUTING CIRCUITS

### Multivibrator and Clippers

After the multiplier and multiplicand factors have been entered into their respective counters, the operation of the computing section is initiated by P24 cam contact at 11.5 on the index. Before explaining the starting of computations in detail, means of producing operating pulses for the computing section will be described.

A suitable oscillator is required as a parent source of pulses for performing the computations. The pulses must be square wave pulses for proper operation of triggers; consequently, a multivibrator type of oscillator is used. The multivibrator develops roughly square-topped waves of potential at the outputs of the two tubes, the waves at one output being 180° displaced in phase from those on the other output. In this machine two multivibrators are provided, one to generate square waves at approximately 35,000 per second for normal computations and one to generate 5 cycles per second for slow-speed operation, which permits visual observation of tube operations by watching the indicator lights. A dial switch is provided to switch from one multivibrator to the other.

Fluctuations in the frequency of the multivibrator do not affect the accuracy of the computing operations since the multivibrator is itself the master timer of all computing operations.

As the output of the multivibrator is not a true square wave, some means must be provided to shape the pulse into a square wave. This is done by means of clippers, which utilize only a portion of the wave from the multivibrator and thus produce an almost perfect square wave. The theory of operation of both multivibrators and clippers follows. Thorough knowledge of the theory of operation of multivibrators and clippers is not es-

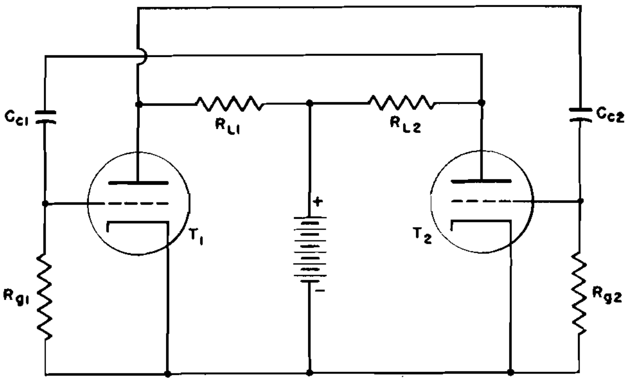


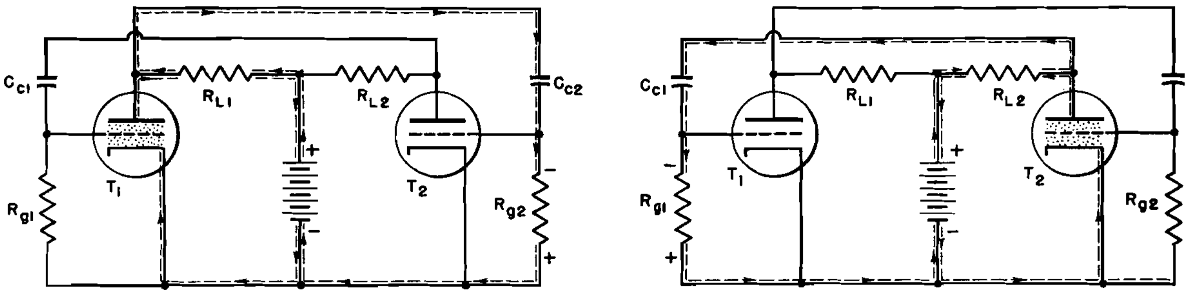
*Figure 99. Basic Form of Multivibrator*

sential to repair the machine and may be skipped if desired. However, for the benefit of those who wish a thorough explanation, the complete theory of operation is discussed.

The basic form of a multivibrator is shown in Figure 99. By comparing this circuit with a trigger circuit, it will be observed that the multivibrator circuit is derived from the Eccles-Jordan trigger circuit by removing the grid-to-anode coupling resistors. In this manner the circuit *reverses itself* as fast as the coupling capacitors charge and discharge, instead of depending upon externally applied pulses.

In order to understand the operation of the multivibrator, assume that on applying power both tubes start conducting and that the coupling capacitors Cc charge. Note that the voltage across $T_1$ is applied to the $Rg_2$-$Cc_2$ combination and that the voltage across $T_2$ is applied to the $Rg_1$-$Cc_1$ combination. Also remember that it takes time for the voltage across a capacitor to change. Consequently, once the Cc capacitors are charged, a voltage change at the anode of either tube will be transmitted through the Cc capacitor and be felt instantaneously at the opposite grid. With both $T_1$ and $T_2$ conducting, assume there is a momentary increase in anode current through $T_1$ caused by a sudden increase in emission. The starting of oscillation actually depends on the fact that no two tubes are exactly alike in characteristics. Any increase in current flow through $RL_1$ increases the IR drop across $RL_1$ and thereby reduces the potential at the anode of $T_1$. This reduction in potential is transmitted through $Cc_2$ to the grid of $T_2$. The reduction in potential at the grid of $T_2$ lowers the anode current through $T_2$, which results in a lower IR drop across $RL_2$ and an increased potential at the anode of $T_2$. This increased potential is transmitted via $Cc_1$ to the grid of $T_1$, and it results in a further increase in anode current through $T_1$. This continues until $T_2$ is completely cut off. The process is cumulative and with proper design the action is almost instantaneous.

When $T_2$ is cut off, it remains so as long as the charge on $Cc_2$ keeps the grid of $T_2$ below cutoff value. Once $T_2$ is cut off, $Cc_2$ starts discharging as indicated in Figure 100A, and as soon as sufficient charge has leaked off through $Rg_2$, the grid potential on $T_2$ rises above cutoff, and anode current again starts to flow through $T_2$. This decreases the potential at the anode of $T_2$; and since the voltage across $Cc_1$ cannot change instantaneously, this decrease in potential at the anode of $T_2$ is transmitted through $Cc_1$ to the grid of $T_1$, resulting in a decreased anode current through $T_1$. The decrease in anode current through $T_1$ increases its anode potential; this increase is transmitted through $Cc_2$ to the grid of $T_2$, which in turn further increases the anode current through $T_2$ and lowers the potential at the anode of $T_2$ which in turn makes the grid potential of $T_1$ more negative. This cumulative process continues until $T_1$ is cut off; $T_1$ remains cut off until $Cc_1$ discharges (Figure 100B), and the cycle repeats itself.



Ⓐ Cc2 Discharging – T1 Conducting

Ⓑ Cc1 Discharging – T2 Conducting

*Figure 100. Current Flow in Multivibrator*

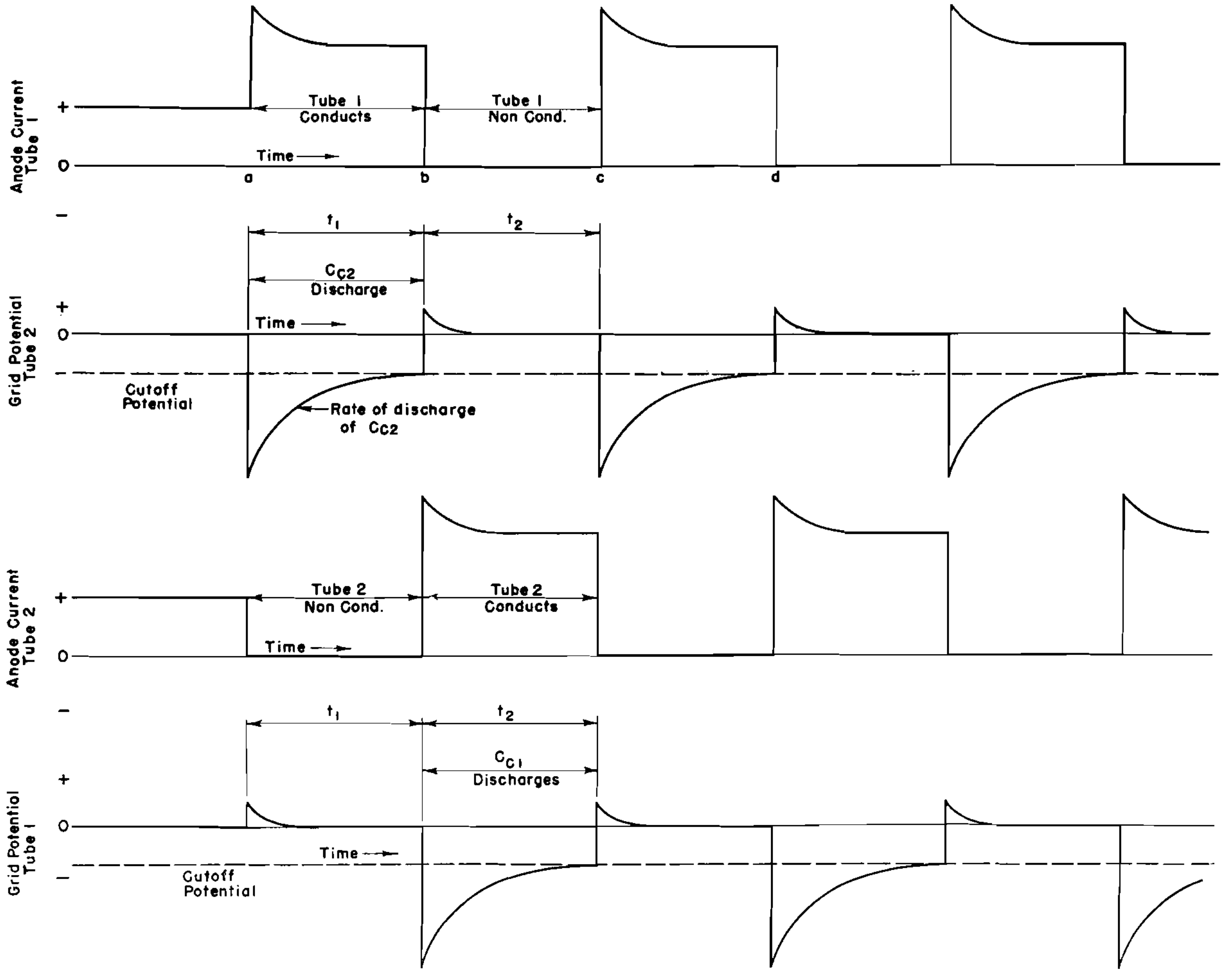
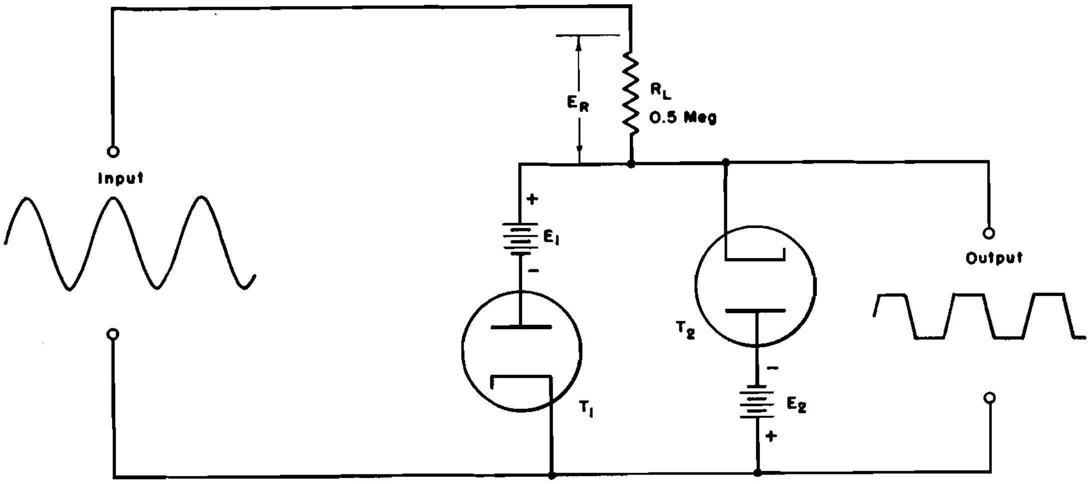


*Figure 101. Voltage and Current Curves for Multivibrator*

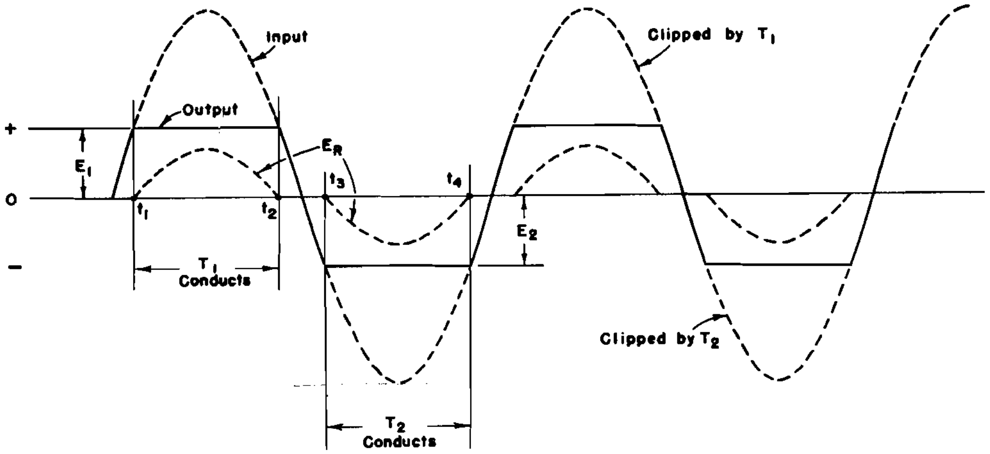
The time interval between the triggering operations, that is, the frequency of oscillation, is determined primarily by the value of Rg and Cc and to a small extent by the value of RL and the supply voltage. The time interval that $T_1$ conducts can be made different from the time interval that $T_2$ conducts by varying the values of $Cc_1$ and $Cc_2$. In this application, the two time intervals must be the same; consequently, the two sides of the multivibrator must be symmetrical.

The voltage across $RL_1$ rises and falls exponentially because of the charge and discharge of $Cc_2$. If $RL_1$ is sufficiently small in comparison with $Rg_2$ so that the capacitor current does not greatly affect the voltage drop across $RL_1$, the voltage pulse across $RL_1$ is approximately rectangular. Therefore it is important to have the value of the RL resistors much smaller than the Rg resistors if a rectangular wave form is desired.

Figure 101 shows the theoretical grid potential and anode current curves for a typical multivibrator. The graphs assume that on starting both tubes are conducting; at time *a*, the first triggering takes place because of an increase in current through tube 1 and continues at regular intervals. Note that the anode current is not constant during conduction. This is due to the discharging current of the capacitors. From Figure 100 it will be observed that the direction of capacitor discharge current flow through the RL resistors is the reverse of the direction of tube current flow.



Ⓐ Diode Peak Clipping Circuit



Ⓑ Input and Output Voltage Waveforms

*Figure 102. Principle of Peak Clipping Circuits*

Hence the net anode current is less than the amount normally flowing through the tube.

The low grid potential during the positive half of the grid potential waveform is explained by the flow of grid current which rises rapidly with an increase in positive grid potential and produces an IR drop across the Rg resistor, thus keeping the grid potential from rising very far above zero.

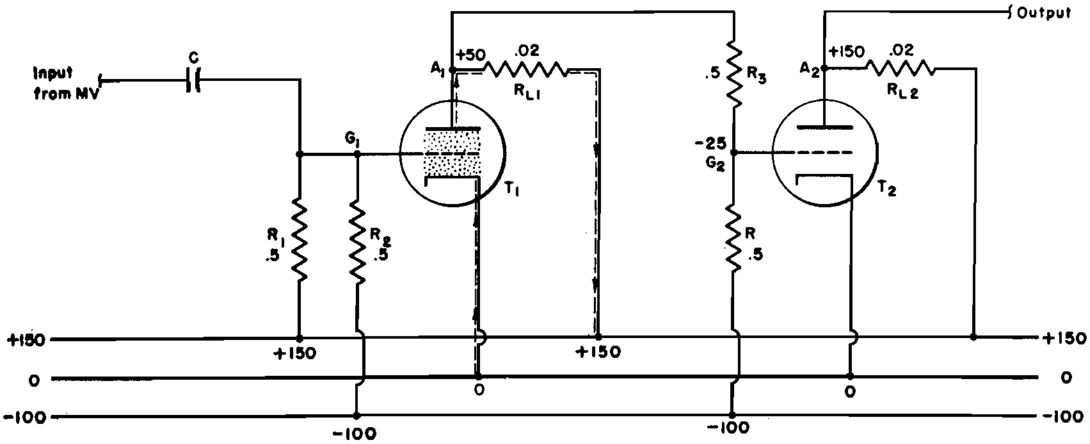
The change in grid potential during the positive half of the cycle is more rapid than during the negative half. This is explained also by the flow of grid current. When grid current is flowing in T$_2$, the grid resistance of T$_2$ is much lower than the resistance of Rg$_2$; therefore during this time, T$_2$ effectively shunts Rg$_2$, and the charging current of Cc$_2$ is limited almost entirely by RL$_1$ which is low compared with Rg$_2$. During the negative half of the cycle, the grid resistance of T$_2$ is almost infinite and the discharge current is limited by RL$_1$ and Rg$_2$. Since Rg$_2$ is much larger than RL$_1$, the capacitor charges much more rapidly than it discharges. Since the grid potential of the conducting tube drops to zero more rapidly than the negative grid potential of the other tube rises above cutoff, triggering is determined by the grid potential of the non-conducting tube, and the frequency of oscillation is determined by the rate of rise of the negative grid potential. This time interval is indicated as $t_1$ and $t_2$ in Figure 101.

The voltage output at any point on a multivibrator is approximately a square wave, but not sufficiently so to use directly for operating triggers. For this reason, the pulses must be shaped to a true square wave. This is done by a *peak clipping* circuit. A simple form is illustrated in Figure 102, together with the voltage waveforms. The diode clipper shown illustrates the clipping of a sine wave and converting it into a flat top wave approximating a square wave. The output voltage exactly follows the input voltage until the impressed voltage reaches the point where conduction starts through one of the diodes, and the resulting IR drop across RL prevents any further rise of the output voltage. This is true because with an increase in current, the IR drop across RL increases rapidly owing to the large value of RL, but the voltage change across the diode is negligible.

The graphs in Figure 102B show the action of the clipping circuit. If it is desired to clip only the top of the positive half of the wave, only tube $T_1$ is necessary. The purpose of the batteries $E_1$ and $E_2$ is to establish the voltage amplitude at which clipping occurs. In practice, these would be replaced by capacitors.

A triode clipping circuit is illustrated in Figure 103. Observe that the grid of $T_1$ is connected midway between the –100 volt line and the +150 volt line through the equal resistors $R_1$ and $R_2$ so that the grid approaches +25 volts. Grid current maintains the grid potential at approximately zero. Consequently, $T_1$ is normally conductive, and point $A_1$ is normally at about +50 volts (100 volt drop across $RL_1$ resulting from anode current through $T_1$). Now observe that the grid of $T_2$ is connected between the –100 volt line and the anode of $T_1$ (point $A_1$), through equal resistors $R_3$ and $R_4$. With point $A_1$ at +50 volts, the grid of $T_2$ (point $G_2$) is at –25 volts, that is, half-way between –100 volts and +50 volts. The cutoff potential of the $T_1$ and $T_2$ triodes is –8 volts, consequently, $T_2$ is cut off as long as $T_1$ conducts and point $A_2$ is at +150 volts.

Now assume the output from a multivibrator with a waveform as shown at A in Figure 104 is applied to the grid of $T_1$ through coupling capacitor C shown in Figure 103. (This capacitor is large enough to maintain its charge during a half cycle so that point $G_1$ can be held to the applied potential for the duration of the pulse.) A positive pulse applied at C will have little effect because



All resistance values in megohms

*Figure 103. Triode Clipping Circuit*

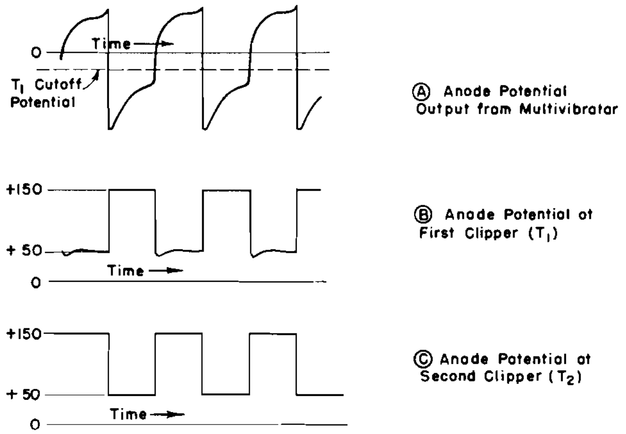


*Figure 104. Output Voltages of Multivibrator and Triode Clippers*

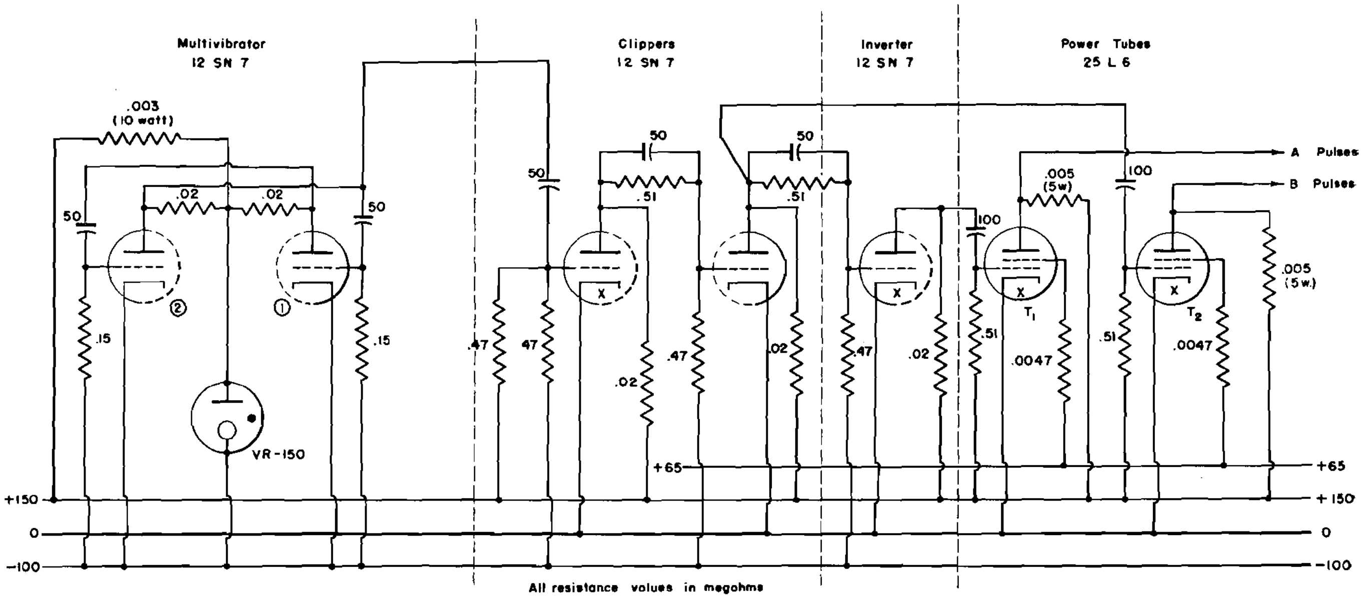
grid current will increase rapidly and cut down the potential at $G_1$ rapidly. The slight increase in anode current through $T_1$ resulting from a positive pulse will produce a slight drop in anode potential at point $A_1$. However, a negative pulse applied at C will drive the grid of $T_1$ negative. If the negative pulse is of more than 8 volts, $T_1$ will be cut off. Actually, the negative pulse from the multivibrator may approach –100 volts and be an almost instantaneous shift; hence, $T_1$ is almost instantaneously cut off, and point $A_1$ rises almost instantaneously to +150 volts (ignoring the bleeder circuit from the –100 volt line through $R_4$, $R_3$, $RL_1$ to the +150 volt line). Point $A_1$ remains at approximately +150 volts as long as point $G_1$ is at –8 volts or less, consequently whatever the shape of the applied waveform is below the –8 volt line, the output of $T_1$ will be a square-topped wave. This is indicated at B of Figure 104. However, to obtain a truly square wave the output of $T_1$ must pass through $T_2$ so that the lower portion can be clipped.

As previously mentioned, $T_2$ cannot conduct as long as $T_1$ conducts. However, when $T_1$ cuts off, point $A_1$ rises to approximately +150 volts and point $G_2$ becomes positive, thus making $T_2$ conductive. When $T_2$ conducts, point $A_2$ is at approximately +50 volts. Since $T_2$ cuts off at -8 volts and the pulse from $T_1$ is approximately 100 volts, the variation from a square wave in the waveform from the output of $T_1$ will not be reflected in the output of $T_2$, and a true square wave is obtained at the output of $T_2$ as indicated in Figure 104C. Bear in mind that the waveforms shown in Figure 104 are theoretical. Practical waveforms differ somewhat because of inductive effect, interelectrode capacity, etc.

As both the multivibrator and clippers are voltage devices, their output cannot be utilized directly as a source of pulses for the electronic unit. To actually supply the pulses for the unit, power tubes controlled by the clippers are used.

The actual circuit for the generation of pulses in this unit is shown in Figure 105. This circuit is taken from the A chassis circuit (Section 23B). Observe that the cathodes of the multivibrator are tied to the –100 volt line and that the anodes are tied to the anode of a VR-150 tube. Thus, the anode voltage supply is taken across the VR-150 voltage regulating tube. The voltage regulating tube is a gas-filled, cold cathode tube which has the property of maintaining a constant voltage drop within its operating limits. The amount of the voltage drop is determined by the gas used and the physical structure of the tube elements. The VR-150 "fires" at 185 volts and then maintains a constant drop of 150 volts within the range of 5 through 40 milliamperes anode current. This method provides a constant anode voltage for the multivibrator even with variations in the supply and thus maintains a constant oscillating frequency. The 3000 ohm resistor between the +150 volt line and the VR-150 anode limits current through the VR-150 to 30-35 ma and provides the means for compensating for supply voltage fluctuations. Variations in supply voltage result in variations in current through the VR-150 and in proportional variations in IR drop across the 3000 ohm resistor, thus maintaining a constant IR drop across the VR-150.

The voltage pulses at the anode of tube 2 of the



All resistance values in megohms
All capacitance values in micro-microfarads

*Figure 105. Generation of A and B Pulses*

multivibrator are passed on to the grid of the first stage of the clipper by means of a coupling capacitor. The output of the first stage is direct-coupled to the second stage, and the voltage output of the second stage is capacity-coupled to power tube $T_2$. The output of the second stage of the clipper is also fed by direct coupling to the grid of the inverter whose output is in turn capacity-coupled to power tube $T_1$. Thus power tubes $T_1$ and $T_2$ produce square wave pulses displaced in phase by 180° from each other. The square waves from $T_1$ will be known as "A" pulses, and any pulses, regardless of their source, may be called A pulses if in phase with the A pulses. The square waves from $T_2$ are known as "B" pulses, and any pulse may be called a B pulse if it is in phase with the B pulses. Remember that the A and B pulses are 180° out of phase with each other; consequently, when an A pulse is fed to the grid of a tube, it appears at the anode as a B pulse. The reason for the two types of pulses is to permit a switch to be conditioned prior to sending any pulses through it. Thus, a switch may be conditioned by an A pulse and then B pulses are passed through it.

The purpose of the 50mmfd capacitors across the .51 megohm resistors in the clipper and inverter circuits is to balance the interelectrode capacitors and thus permit the grids to follow the applied pulses without lag.

A study of Section 1 of the A chassis circuit diagram (Section 23) will show that Figure 105 is taken directly from there. Only the switching arrangement to permit switching from the 35KC multivibrator to either hand pulsing or to the 5-cycle multivibrator is omitted in Figure 105. Observe from the A chassis circuit that tube A10 is the 35KC multivibrator and that the VR-150 is in position A7, while the 5-cycle multivibrator is tube A9 and the manual pulse trigger is A8. A trigger is necessary when manual pulsing is used to provide a true square wave voltage and eliminate multiple pulses passing through the contact because of contact bounce. A neon bulb indicates the status of the manual pulse trigger.

Regardless of which source is used for pulses, the dial switch routes the pulses through the clipper A11 from where the pulses pass to power tube A18 to produce B pulses, and through inverter A17 to power tube A16 to produce A pulses.

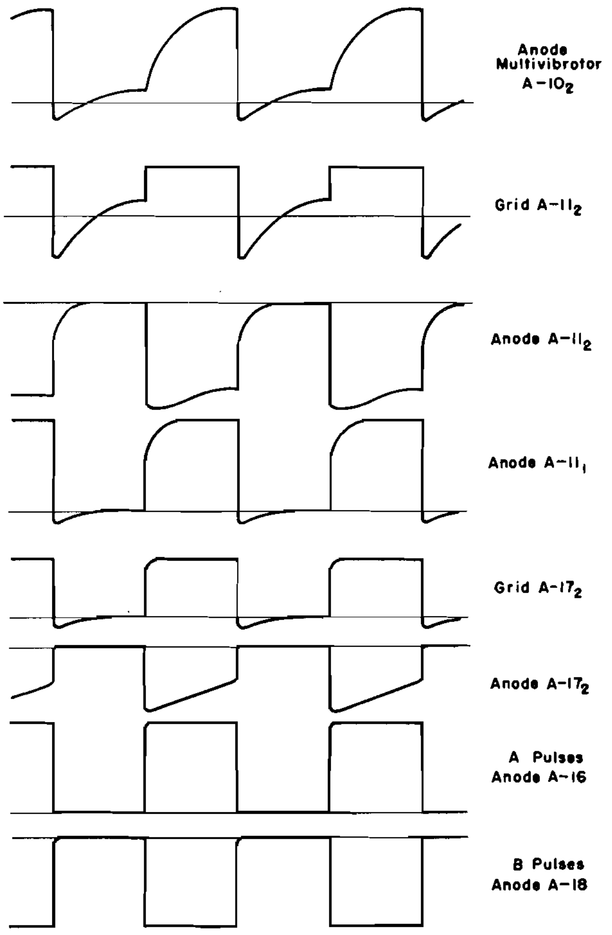


*Figure 106. Oscillograms Taken During Actual Operation*

It may be observed that the 5 cycle multivibrator utilizes half of the A17 tube as a follower to permit direct coupling to the clippers. This is necessary at the extremely low frequency to produce a true square wave.

Figure 106 shows the actual waveforms adapted from oscilloscope patterns taken during actual operation. Note that the clipper output is not a true square wave owing to interelectrode capacity. This is not important, however, as only the output of the A16 and A18 power tubes is used, and these outputs are square waves. Note the effect of grid current by comparing the potential curve at the anode of A$10_2$ with the potential at the grid of A$11_2$. The potential at the grid of A$11_2$ cannot rise because grid current prevents the grid going positive.

### Electronic Timers

There are three electronic timers used in this circuit, namely the primary, secondary, and tertiary timers. The primary timer establishes the basic adding cycle of 16 pulses, while the secondary timer determines that there are 10 primary cycles within each column shift cycle (secondary cycle). The tertiary timer advances the column shift and determines that the multiplication is finished after completing six column shift cycles. Each timer is merely an electronic counter; the reading of the counter at any point determines the point in the computing cycle. Thus, if the primary timer reads 5, it indicates that 5 pulses of the 16 constituting an adding (or primary) cycle have been fed to the timer. If the secondary timer stands at 8, it indicates that the machine has completed the 8th adding cycle within a column shift cycle, etc.

The primary timer is a straightforward binary counter with 4 trigger stages connected as illustrated in Figure 89. As explained with reference to Figure 89, a 4-stage binary counter returns to its 0 status every sixteen pulses; consequently it can be used to establish a sixteen point cycle. In order to establish definite points within a cycle, certain combinations of triggers are used, or use is made of the fact that certain triggers are ON only during a given time, i.e., only after a definite number of pulses have been applied to the timer. For example, the last stage of a 4-stage binary counter goes OFF only on the 16th pulse (or 0 time) and goes ON only on the 8th pulse. In this manner, 0 and 8 time within a primary cycle can be established. Also, 3 time can be established by the fact that at 3 time, the 1st and 2nd stages only go ON; at other times that the 1st and 2nd stages go ON, other triggers are also ON. In this manner any cycle point within the primary cycle can be established by determining the reading in the binary counter composing the primary timer.

The reason 16 pulses are required for a primary cycle is that 10 are necessary for the adding portion of a cycle, 4 are used for carrying and 2 are nec-

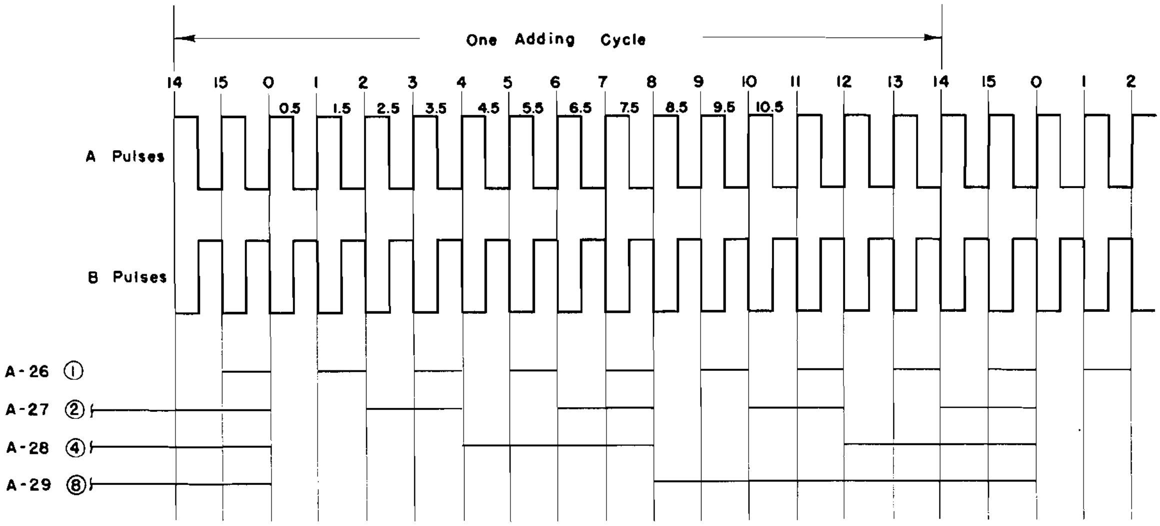


*Figure 107. Use of Primary Timer to Establish Sixteen-point Adding Cycle (Primary Cycle)*

essary to permit certain operations being performed before addition actually starts. In order to allow the cycle point number to correspond to the number of the pulse entering a counter, the primary cycle is actually started at 14. This permits certain operations to be performed at 15 and 0 time and then the first pulse to be added in a counter can be at 1 time. The ten possible adding pulses are then pulses numbered 1 through 10. Starting a cycle at 14 is simply accomplished by cancelling the last three stages of the primary timer ON ($8 + 4 + 2 = 14$) and the first stage OFF. Then the first pulse applied to the primary timer advances it to 15, the next to 0 (16), the next to 1, etc. Figure 107 shows how one primary cycle is established by the primary timer. Observe that the pulse number is analogous to index points in a mechanical cycle. The primary timer may be used as the index of the electronic computing operations. Note also that index points occur at positive A pulses (or negative B pulses). Mid-index points occur at negative A or positive B pulses.

One primary cycle is required to add any number into a counter once. Since over-and-over addition is used to multiply, it means that the multiplicand may have to be rolled into the product counter as many as nine times. This means at least nine primary cycles are required to multiply by one digit. To permit half-entry and to permit the multiplier to return to its original reading after rolling, ten primary cycles are used within each column shift cycle. To establish the ten primary cycles, and thus indicate when the column shift is to occur, a secondary timer is used. The secondary timer must count to 10, consequently a conventional one-position decimal counter is used.

Every time the primary timer completes a cycle (at 14) the secondary timer receives a pulse. When the tenth primary cycle is completed, the tenth pulse is passed to the secondary timer, the secondary timer advances from 9 to 0, and a carry is signalled. This carry is a signal to column shift, and the carry pulse is therefore passed to the tertiary timer which controls column shift.

There are six positions in the multiplier counter, therefore a maximum of six column shift cycles are necessary. A 3-stage binary counter capable of counting to 8 is used for the tertiary timer. Actually it never goes to 8, because computations are stopped at the end of the 6th column shift cycle. Again, by reading the tertiary timer, the column shift cycle can be determined. When the tertiary timer advances from 6 to 7, computing is stopped. This means that computing is stopped on the cycle point that the secondary timer carries. Since the secondary timer receives advancing pulses at 14, it also carries at 14; and consequently computing will stop at 14 in the primary cycle, thus leaving the primary timer where it started (at 14).

### Compute Start Control and Primary Timer

Referring to Section 25 of the circuit, it will be observed that the primary timer consists of four triggers in tandem, namely, A26, A27, A28, and A29. The A26 trigger is normally OFF, while the others are normally ON. The A28 OFF side utilizes half of A20 as a follower, while the two triode sections of A34 are used as a follower for the ON and OFF side of A29. Followers are used to avoid loading the triggers, as excessive loading of a trigger results in erratic operation. Note that the indicator block in position A30 is used to indicate the status of the primary timer at any time.

Operation of the primary timer is effected by negative B pulses developed by a pentode switch tube A25 (Section 23A) after computing is initiated under control of the punch unit. The grid of the A25 switch is connected to the grid of the ON side of A31 trigger, and consequently follows it in potential. Since A31 is normally OFF, A25 cannot conduct, thus preventing response of A25 to the A pulses applied to its suppressor.

The grid of tube 1 of trigger A31 is coupled to the anode resistor of tube 2 of trigger A32, which is also normally OFF. The grid of tube 2 of trigger A32 is directly coupled to P24 cam contact through R1BU contact in the punch unit. With a card at the die card lever, when P24 makes at 11.5 on the punch index, a circuit is completed from the +40 volt line to the grid of $A32_2$, and trigger A32 is turned ON to initiate computing. The manner in which trigger A32 goes ON is exactly the same as described in connection with the read-in triggers.

When A32 goes ON, the potential at the $A32_2$ tube drops, and a negative pulse is transmitted to A31 trigger (OFF side) from a tap on the load resistor of $A32_2$. A31 is thus turned ON, and the grid of tube 2 rises to cathode potential as does the grid of the A25 switch. With the grid of A25 above cutoff, A25 will respond to any pulses applied to its suppressor. The suppressor of A25 is normally at −50 volts, which is sufficient to block conduction. However, the suppressor is also connected by a capacitor to the anode of A16, the source of the A pulses.

Each time the A pulse goes positive, A25 conducts, and the potential at its anode drops. Hence A25 inverts these A pulses to B pulses, which in turn are taken from a midpoint tap on the load resistor for A25 and fed to A26, the first stage trigger of the primary timer. As previously explained, the positive pulses applied to the primary timer are of insufficient amplitude to affect its status; only negative pulses will be recognized by the primary timer triggers.

Remember from Figure 107 that the cycle points represent negative shifts in the B pulses or positive shifts in the A pulses. A positive shift in the B pulses or negative shift in the A pulses occurs at half time, that is, 1.5, 2.5, etc.

The first positive A pulse applied to A25 after computing is initiated, produces a negative B pulse to advance the primary timer to 15 by turning A26 ON, as indicated in Figure 107. Since A27, A28, and A29 are already ON when computing starts, all triggers will be ON after the first B pulse. The second B pulse developed by A25 turns A26 OFF, and the potential at the $A26_1$ anode drops, producing a negative pulse. This negative pulse is taken from the midpoint of the load resistor for $A26_1$ and passes to A27 trigger, turning A27 OFF. As A27 turns OFF, its tube 1 develops a negative pulse which is applied to the third-stage trigger, A28, turning it OFF. Follower tube A20 starts conducting and a negative pulse appears at the anode of A20, which is passed on to A29 to turn it OFF. Therefore, after two B pulses are applied to the primary timer, all triggers are OFF and the timer is at 0.

The next negative pulse applied to A26 trips it

ON at 1 time of a computing cycle. As A26 turns on, tube A26 produces a positive pulse which has no effect on the next stage, A27. Another negative pulse is applied at 2 time to stage A26, returning it to OFF status. At this point a negative pulse from A26 is applied to A27 to turn it ON. Thus, each applied negative pulse reverses A26 but the next stage A27 is reversed only once for every two pulses applied to A26. Similarly, A28 is reversed once for every two tripping pulses applied to A27 while A29 is reversed once for every two tripping pulses received by A28. The combinational patterns of ON and OFF states of the stages of the primary timer are indicated in Figure 107. It is seen that there is a different pattern at each of the cycle points, 0 through 15, of the sixteen-point computing cycle.

The primary commutator will continue to function as long as trigger A31 remains ON. Trigger A31 is turned OFF, in a manner explained later, when the multiplication is completed. On the other hand, the trigger A32 is turned OFF by cancelling upon removal of negative potential from the −100 (cancel) line which occurs upon the opening of main cancel cam contact P10 in the punch unit.

If A32 were to control tube A25 directly instead of through trigger A31, then termination of computing operations would be timed by the restoration of A32 which is under control of a cam in the punch unit. It is necessary, however, to terminate computing operations under control of the computing circuits; for this reason, trigger A31 is introduced between A32 and A25, and means are provided in the computing section to turn A31 OFF at a predetermined point of a computing cycle after termination of the computing operations. It must be remembered that the entire computation only requires about 27 milliseconds, which is only 6 teeth of movement of the punch index. Consequently, it must be possible to stop computing, even though the compute start cam contact or manual control switch is still made. This is made possible by using two triggers. A31 can be turned OFF regardless of the status of A32.

> Note: The .0025 megohm resistor shown between post 48 (Section 23A) and ground has been removed and should be disconnected on any machines which have this resistor installed. The resistor was added to maintain a current flow through P24 at all times, but it was found that it upset the operation of the start trigger A32 occasionally. Instead, to insure more positive operation, the resistor has been removed and a silver point installed in P24.

### Secondary and Tertiary Timers

As previously mentioned, the secondary timer is a conventional ten-point counter just exactly as described under *Electronic Counters*. For this reason it is not necessary to repeat the principle of operation.

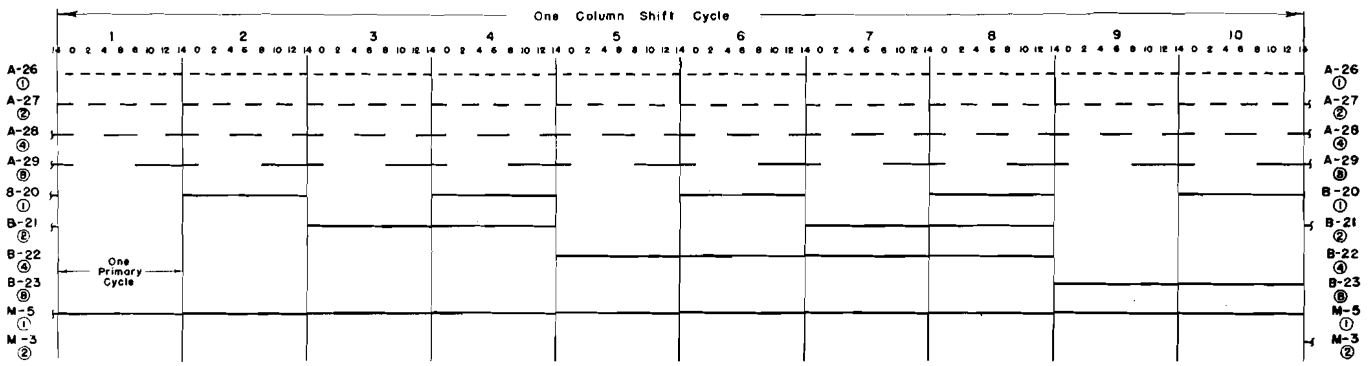


*Figure 108. Relationship Between Primary and Secondary Timers*

The secondary timer consists of triggers B20 through B23, blocking tube B27, and follower B24 shown in Section 29 of the circuit diagram. The indicator block in socket B18 indicates the status of the secondary timer. The follower B24 follows the OFF side of B23, the last stage of the secondary timer. It is used to avoid loading the trigger B23. A negative pulse appears at the anode of B24 and at the anode of $B23_1$ tube on the tenth pulse applied to the secondary timer. These negative pulses are the carry pulses and are used to advance the column shift (tertiary timer) and to turn OFF trigger B17.

The secondary timer is cancelled to 0 and advances 1 point at 14 of each primary cycle. The means of producing this −14 pulse will be discussed shortly. The tenth pulse from the primary timer to the secondary timer causes the secondary timer to advance from 9 to 0 and a carry is signalled. This is a signal to column shift and to start a new series of ten primary cycles. The timing relationship existing between the primary and secondary timers is shown in Figure 108. A careful study of this timing chart is essential to the proper understanding of the sequence of operations.

The tertiary timer is a three-stage binary counter which cancels to 1 so that the reading of the counter indicates the column shift position. The tertiary timer consists of triggers M2, M3, and M5 along with followers M1, M4, and M6. The circuits are shown in Section 51.

### Multiplier Advancing Pulses

From the section on Multiplying Principles it will be remembered that in order to determine how many times the multiplicand is to be added into the product counter, the multiplier counter must be "rolled" by adding 10 pulses to each position successively. One pulse is added during each adding cycle, and the column shift control determines which position of the multiplier receives the advancing pulses.

The block diagram and sequence chart in Figure 109 indicates how the primary timer controls the

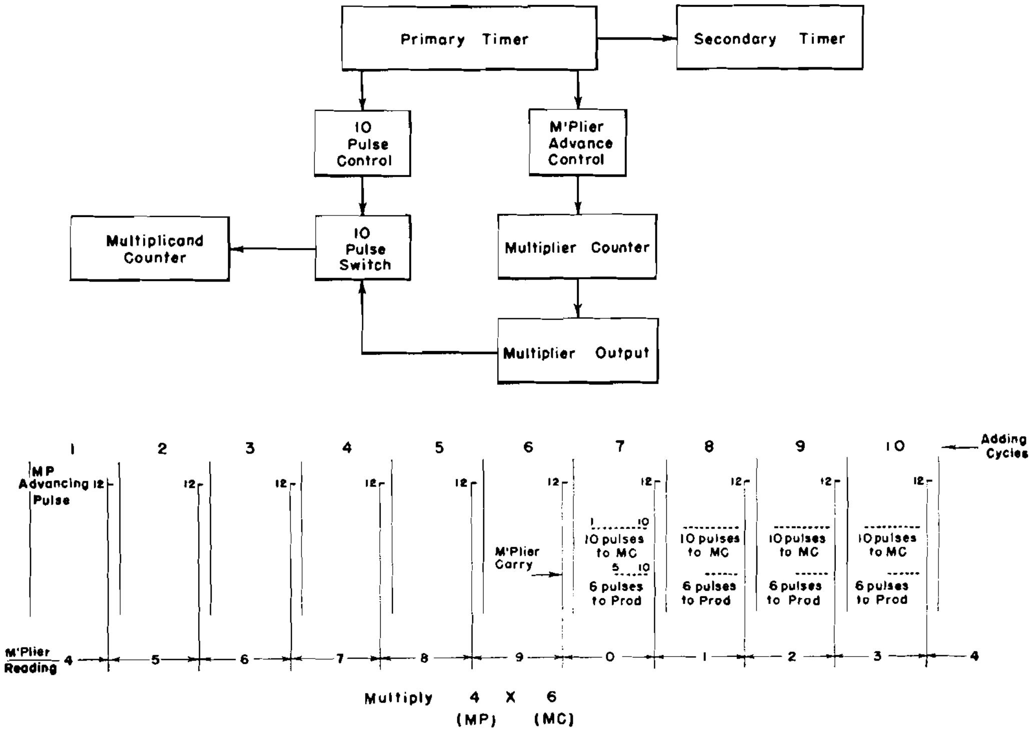


*Figure 109. Block Diagram of Multiplier Advancing*

number of times that the multiplicand counter is rolled. A group of 10 pulses to roll the multiplicand counter is fed to the 10-pulse switch each adding cycle, but the 10 pulses cannot enter the multiplicand counter until the 10-pulse switch is opened by the carry-over of the multiplier counter. The multiplier counter position by which multiplication is taking place receives an advancing pulse at 12 of each cycle, as indicated in the sequence chart in the lower section of Figure 109. Observe that no rolling pulses can ever enter the multiplicand counter during the first adding cycle of a column shift cycle, because the first multiplier advancing pulse does not come until 12 of the first adding cycle, and this is after the adding portion of the cycle. The first adding cycle is used for half-entry during the 6th column shift cycle.

The multiplier digit always advances from 9 to 0 in that adding cycle of the set of ten which is the tens complement of the controlling multiplier digit. Multiplicand entries start on the succeeding cycle, so that the number of multiplicand entries in any column shift cycle equals the value of the multiplier digit. As shown in Figure 109 at 12 of the sixth adding cycle, the multiplier position containing a 4 advances from 9 to 0. Consequently, during the 7th through 10th adding cycles, the multiplicand will receive 10 rolling pulses. However, only 6 of these pulses will reach the product counter during each adding cycle because of the 6 standing in the multiplicand counter. This part of the operation is explained later with reference to the multiplicand read-out.

Observe also from Figure 109 that the multiplier advancing pulse during the 10th primary cycle is used only to bring the multiplier reading back to its original reading. This is necessary when group multiplying, because the same multiplier is used for a group of cards.

The circuit for producing the multiplier advancing pulse at 12 is shown in the A chassis circuit (Section 24A) and consists of trigger A35 and power tube A36. Note that indicator light 7 in socket A13 shows the status of A35. Figure 110 shows the same circuit together with the timing chart for the operation. The pulse produced is used to control a switch, therefore, a positive pulse must be produced at 12 of each primary cycle. Trigger A35 is initially OFF by cancelling, hence, neither positive nor negative pulses applied to the ON side ($A35_2$) will have any effect until A35 is turned ON. A35 is turned ON by the first negative pulse applied to its OFF side ($A35_1$); positive pulses have no affect as has been pointed out previously. $A35_1$ receives a + pulse at 0 and a − pulse at 8 from A29, the fourth stage of the primary timer; consequently A35 goes ON at 8. Observe from the timing chart that $A35_2$ also receives a +8 pulse. This will not affect the operation. When A35 goes ON, a positive pulse is produced at the anode of $A35_1$ as the potential rises from about +40 volts to +140 volts. This pulse is transmitted to the grid of power tube A36 but it has no effect since A36 is normally conducting.

The next negative pulse to $A35_2$ from A28 (the third stage of the primary timer) comes at 12; consequently A35 goes back to its OFF status at 12. At this time the potential at the anode of $A35_1$ drops, and this negative pulse is transmitted to the grid of A36. A36 momentarily stops conducting, thus permitting the potential at its anode to rise to +150 volts and producing a positive pulse at 12 to pass on to the multiplier entry switches. A35 repeats this operation once for each primary cycle.

The multiplier input switches for controlling entries to the multiplier counter are located on the C chassis and consist of 6SK7 type switch tubes; C3, C6, C9, C12, C15, and C18 for the first through sixth positions of the multiplier counter respectively.

The read-in triggers and switches shown on the C chassis are exactly the same as the ones on the D chassis and have already been explained. Note that the multiply control switches utilize the same load resistors as the read-in switches. This is per-

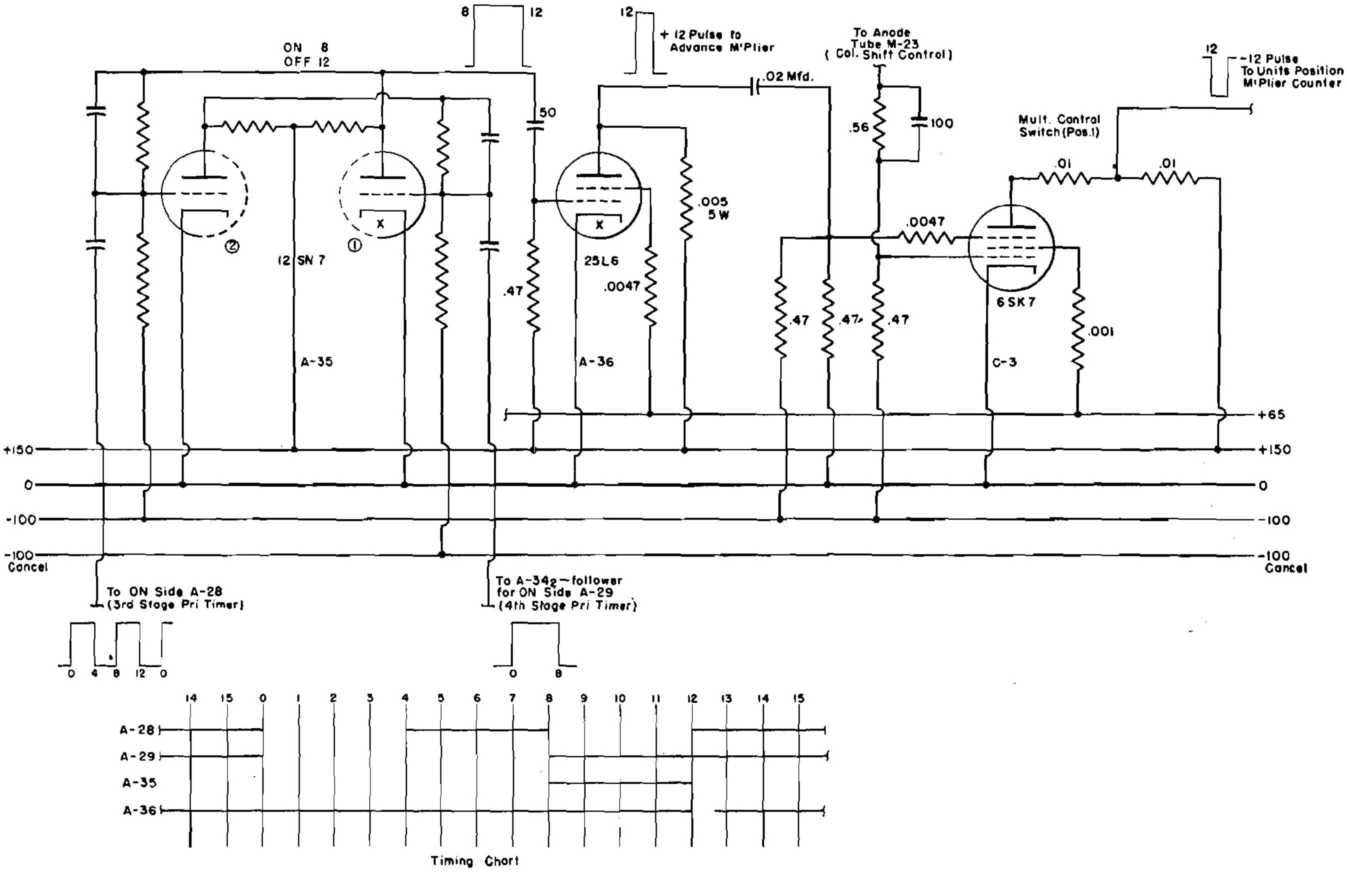


*Figure 110. Multiplier Advancing Pulses*

missible since the two switches never operate at the same time.

The grids of the multiply control switches are directly coupled to column shift control tubes in the M chassis. Each grid is controlled by a different tube in the M chassis, corresponding to the different column shift cycles. The sixth position of the multiplier counter is conditioned first and the first position last. As long as the column shift control tube in the M chassis is conducting, the corresponding multiply control switch is cut off since the potential at the grid will be approximately –30 volts. This is determined as follows: the top of the .56 megohm resistor is tied directly to the anode of the column shift control tube in the M chassis. The potential at this anode is less than +50 volts while this tube is conducting. The lower part of the .47 megohm resistor is tied to the –100 volt line. From the ratio of the resistances, the potential at the grid of the switch tube is found to be approximately –30 volts.

When the column shift control tube stops conducting, the potential at its anode rises to essentially +150 volts (ignoring the effect of its load resistor); then the grid of the corresponding multiply control switch rises above cutoff and the switch is conditioned to conduct, subject to the pulses applied to the suppressor. The grid of any one switch remains conditioned throughout a complete column shift cycle, i.e., 10 primary cycles. However, the suppressor will rise above cutoff only once (at 12) during each primary cycle, consequently the multiplier position in operation receives only one pulse per primary cycle.

The suppressors of all the multiply control switches are tied together to the voltage divider shown under switch C3 (Section 32A). This voltage divider consists of equal resistors between the −100 volt line and ground; consequently, all suppressors are normally at −50 volts which is well below cutoff for this element. All suppressors receive a +12 pulse through the .02mfd coupling capacitor, which transmits pulses from the multiplier advancing power tube A36. Each time A36 produces a positive pulse, all suppressors rise above cutoff. However, only the switch conditioned for operation during the given column shift cycle can conduct. This switch will then conduct for a brief instant at 12 and produce a −100 volt negative pulse at its anode. Since triggers are operated on −50 volt pulses, the output to the multiplier counter is taken from the midpoint of the load resistor for the multiplier input switch. From this it is evident that one position of the multiplier counter will advance 1 at 12 of each primary cycle, the particular position being determined by the column shift cycle.

The purpose of the 100 mmfd capacitor across the .56 megohm resistor in the grid circuit of the C18 tube shown in Figure 110 is to permit instantaneous changes at the grid by counteracting the effects of interelectrode capacitances. The 4700 ohm resistors in the suppressor circuit prevent parasitic oscillations.

The multiplier counter, which receives its entry pulses from the C chassis, consists of six standard electronic counter positions on chassis E, F, and G. The multiplier counter chassis are identical to the counters previously described. It might be mentioned that no provision is made for carry in the multiplier counter because there is no need for carrying in this counter or the multiplicand counter.

Figure 111 shows a block diagram of the multiplier advancing circuits, indicating all tubes involved as well as the operations. The section to the right shows how the multiplier output control determines the number of times the multiplicand receives rolling pulses. This operation is discussed in detail in the following paragraphs.

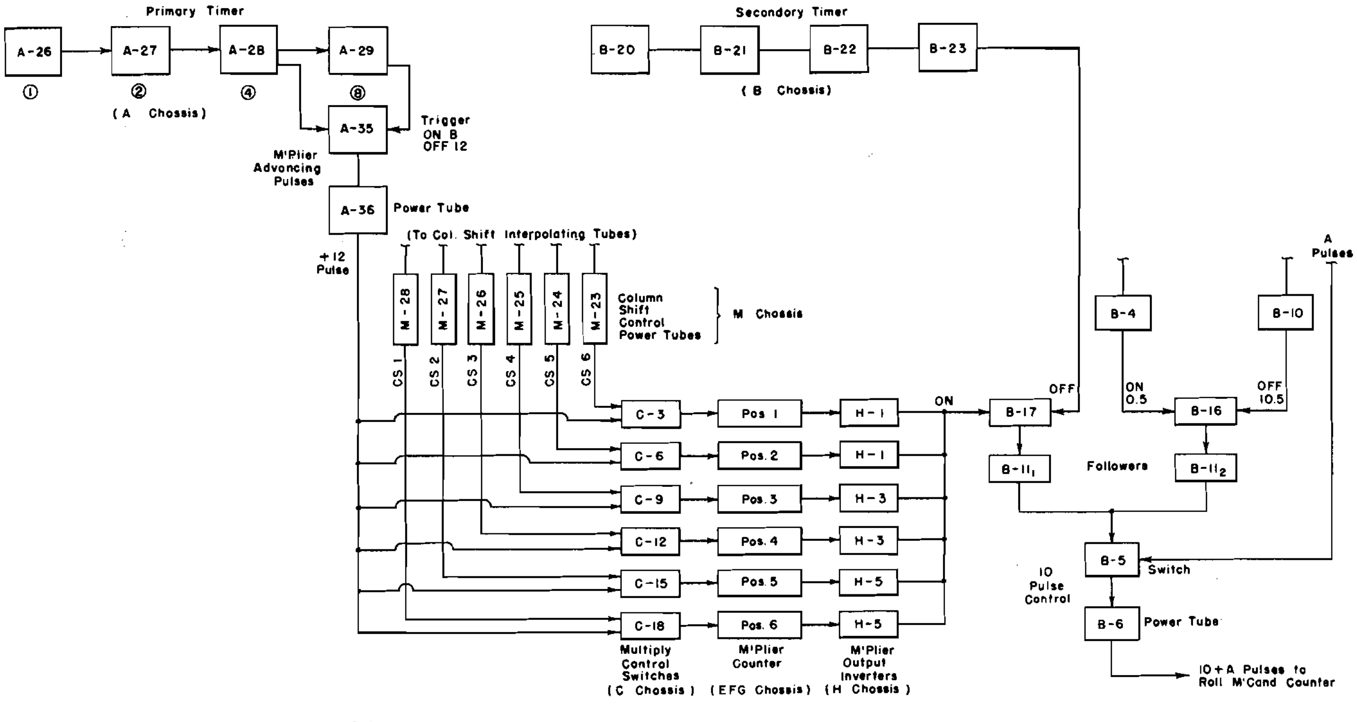


*Figure 111. Block Diagram of Multiplier Advancing Circuits*

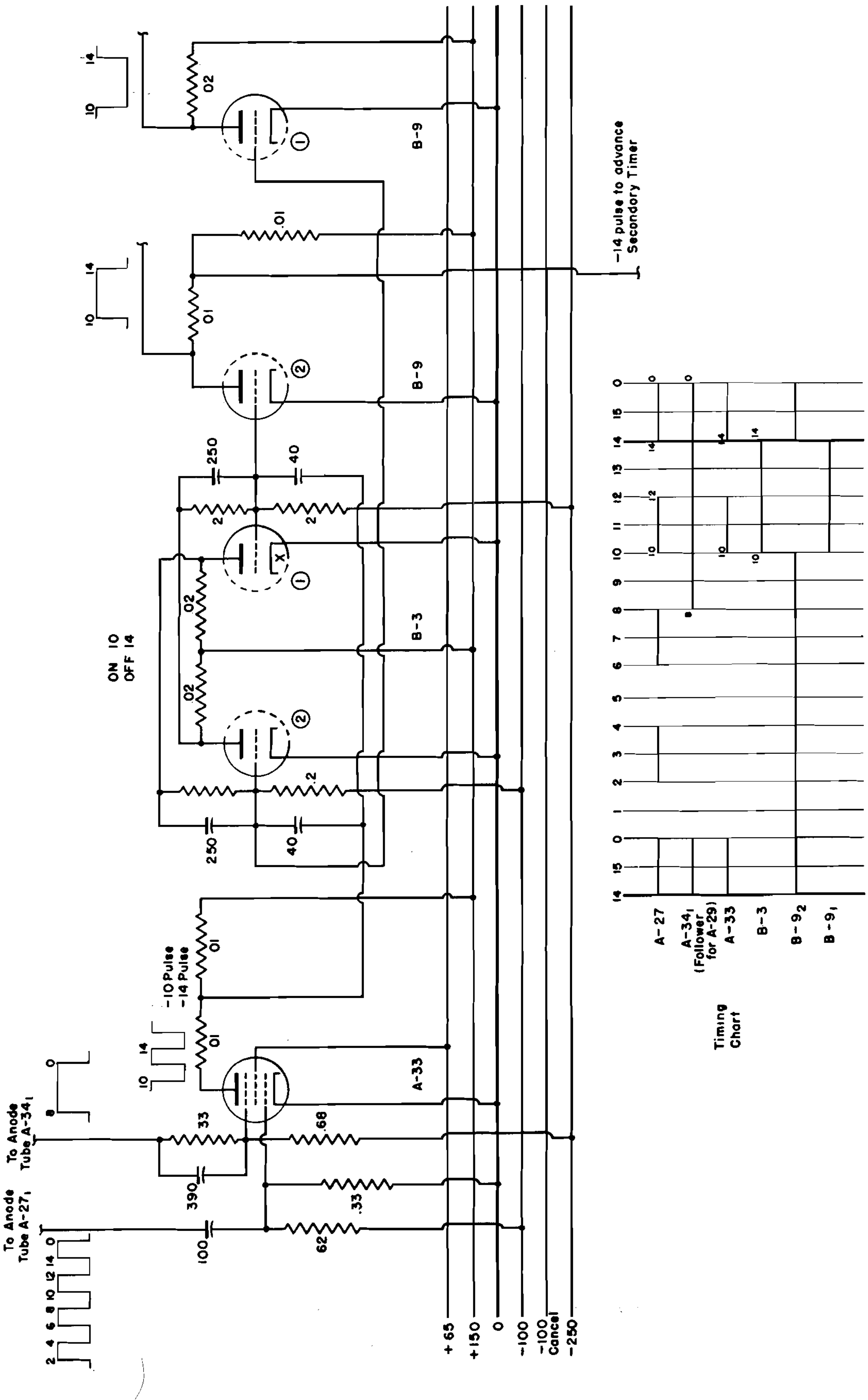


*Figure 112. Operation of B3 Control Triggers and Followers*