CYCLIC CIRCUIT SCHEMES OF FAST-ACTION PULSE-COUNTERS

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0.1 Electromechanical pulse counters, which are widely used in telephony, telemechanics, and automatics circuits, frequently fail to satisfy increasing requirements for high computation speeds. Where rapid action is required, electromechanical counters are being replaced by ionic and electronic circuits.

High-speed computation was first solved in connection with experimental nuclear physics. In the Cavendish laboratory in 1931, Wynn-Williams designed several special high-speed counting circuits using ionic and electronic tubes [1, 2]. At present, electronic and ionic devices are being used with Geiger counters in counting alpha-particles.

High counting speed are also needed in telephony, telemechanics, military engineering, photocontrol of industrial processes, quality electric welding, automatic defectoscopy, chronography, computers, etc.

Present electronic counting circuits can count up to a million pulses per second, which is more than 10,000 times the maximum speed of electromechanical counters.

0.2 There are a great many pulse counter circuits and designs, but the principle of construction is common to all. Relay, thyratron, and electronic counting circuits follow similar principles but differ only in the components and consequently in speed of operation.

A block diagram of a counting unit is shown in Figure 1. Any pulse counter may be considered as being made up of four types of elements:

1) a pulse shaper, which transforms input pulses of arbitrary shape into pulses of a definite shape for sharp operation of the entire counter;

2) a pulse reducer, which reduces the number of pulses by k times; that is, produces at the output a number of pulses which is k times less than the number of input pulses;

3) a remainder indicator, which determines the remainder by dividing the number of pulses on the input by the reduction factor k;

4) the coupling element, which couples the input of the following reducer with the output of the preceding reducer.

If m_0 pulses are applied to the input of the circuit, this number can be expressed through the readings of the remainder indicators n_1, $n_2, \dots, n_l$ as follows:

$$m_0 = n_1 + n_2 k + n_3 k^2 + \dots + n_l k^{l-1} + m_l k^l \quad [sic] \qquad (1)$$

Thus we see that the reduction factor k is the radix of our number system. Since the decimal system is now used, the counters should be set up for $k = 10$.

The ordinary decimal mechanical counter has as a pulse shaper a ratchet mechanism which transforms a pulse of arbitrary shape into a definite angle of deflection. A mechanical reducer with a gear ratio (reduction factor) of 10 is used as a reducer. The remainder indicator is a disk with ten divisions marked off on it, and the coupling element is a mechanical mesh which connects one reducer with another.

This breakdown into individual elements can also be applied to electronic, ionic, or relay counting units.

0.3 The main element of any pulse counter is the reducer. The pulse reducer system determines the requirements for the pulse shaper, coupling element, and remainder indicator.

One of the most widely used types of pulse reducers is the cyclic reducer, which consists of several "monotypical" elements (relays, thyratrons, or electron tubes). With each successive pulse, the state of these elements changes cyclically. The number of elements in the reducer circuit is directly proportional or even equal to the reduction factor of the circuit. If the total reduction factor ~~If the total reduction factor~~ of a counter is expressed as a function of the number of elements in reducers (A) and the reduction factor of one reducer (k) is

$$i = k^{l} = k^{A/k},$$

it can be shown that $\underline{i}$ is greatest when $\underline{k} = e \approx 2.7$, for constant A.

Thus, from the standpoint of cost of a counting unit, it is most efficient to construct two- and three- path pulse reducer circuits with $k = 2$ and $k = 3$. In this case, the counter uses a number system with radix 2 or 3 (instead of 10).

1.1 Relay circuits for two-path pulse reducers (Figure 2) were first used in telemetering and telemechanics. Such a circuit creates the rotating field for a synchronous motor of the pulse-frequency telemetering system used in the TsLEM (Central Electrical Assembly Laboratory) of the Mosenergo. Similar circuits are used to control the number of selective pulses in telemechanics units of the type VRT and PRT of the "Tsentroelektromontazh" (these circuits were proposed by the author and L. G. Rashkovskiy) and as the preliminary element of a relay counter in the telemechanics system RTU-7 (3).

The operational principle of the circuit is as follows: The line relay L transmits input pulses to relay pairs A and B, whose circuits are connected as in normal operation of a pulse-pair, ~~except~~

except that they are brought through relay contacts L/1 and L/2. Line relay L/3 and L/4 are also connected in the locking circuit of relays A and B. When a series of pulses are transmitted to the coil of line relay L, relays A and B are connected and disconnected with a frequency which is one-half the pulsation frequency of the line relay.

The opening and closing of the line relay contacts and the operation of relays A and B as a function of time are shown graphically in Figure 3. The unshaded rectangle shows the current through the relay coil, while the shaded rectangle shows the closed state of the normally-open and normally-closed relay contacts. The normally-open contacts are shown above the abscissa, and the normally-closed contacts below it.

Lines 2 and 3 show the operation of relays A and B for normal circuit operation when the following conditions are observed:

$$T_a < 2T_1 , \quad T_2 < t_1 , \quad T_2 < t_2$$

where T_a is the time required for reversing the normally-open and normally-closed contacts; T_1 and T_2 are the times of connection and disconnection of the relay; t_1 and t_2 are times of pulse and pause.

If the first condition is not observed (Figure 3, lines 4 and 5), relays A and B operate as repeaters of the line relay. If the second and third conditions are not observed, one relay sticks and the circuit ceases to operate (Figure 3, lines 6 and 7).

The times of pulses and pauses received by the circuit must be greater than both the time of connection and disconnection of each of the relays A and B. On the other hand, the time during which relays A and B are connected must be greater than the time required for transfer of the normally-opened and normally-closed contacts of the line relay. Since the time when the relay is connected is made up of the time required for the current in the coil to build up to actuate the relay and the time required for the relay armature to move, while the time required for transfer of the line relay's contacts is only part of the time required for movement of the relay armature, observance of the last condition is not difficult. Thus, the limiting frequency at the input of the circuit is defined as $1/2T_1$ or $1/2T_2$, depending upon which is the smaller.

For fast-acting telephone and coding relays, the time during which the relays are "in" or "out" may be of the order of 0.005 second; consequently, the circuit described is useful for counting pulses whose frequency does not exceed 100 cycles.

1.2 [This section describes the operation of the Wynn-Williams Scale-of-Two thyratron counter.]

1.3 Considerably greater operating speeds (in comparison with ionic circuits) are provided by electronic circuits. The first electronic circuit for a two-path pulse reducer was proposed by Eccles and Jordan (4, 5) in 1919. Later, a number of circuits were devised on this principle; these were known as symmetrical triggers and were used widely in various types of electronic counters (6-11). The Potter circuit (10), shown in Figure 4, is the simplest and most advanced.

The trigger is a two-stage d.c. amplifier, the output of which is shorted to the input. The external pulse is fed simultaneously to the grids of both electron tubes (resistance r_0). Two pulses fed to the input produce one pulse at the output.

The behavior of the circuit when pulses of various shapes are applied to its input can be best studied in a plane with coordinates U_1 and U_2 or i_1 and i_2, where U_1 and U_2 are the voltages on the grids and i_1 and i_2 are the plate currents of the electron tubes (12, 14, 15).

In Figure 5, the voltage U_1 on the grid of the first tube is plotted on the abscissa and the voltage U_2 on the grid of the second is on the ordinate. As was shown by A. A. Andronov and S. E. Khaykin (12), the absence of an external pulse corresponds to three equilibrium points A, B, C in coordinates U_1 and U_2.

Point C is always unstable, whereas points A and B correspond to a state of stable equilibrium (12) when one tube is conducting while the second is completely blocked.

The external pulse can be represented in the coordinates U_1 and U_2 as a displacement of a representative (phase) point. When the pulse magnitude increases, the speed of motion of the representative point increases and at a certain point reaches a value limited only by the distributed parameters of the circuit. This moment corresponds to a "jump" from a certain point a to a point a' or from b to b'. The points for the beginning and end of the "jump" will differ depending upon the voltage distribution on the tube grids. A study of this "jump" conditions made previously by the author (13, 14) revealed the geometric position (locus) of the points of the beginning and end of the "jump" in coordinates U_1 and U_2 (Figure 5a).

Two curves for the beginning of the "jump" can be drawn (G + P) depending upon whether or not driving capacitances C_1 are used. Curve G corresponds to $C_1 = 0$ while curve P corresponds to $C_1 \neq 0$. The geometric positions (locus) of the points of the end of the "jump" are shown by the curves G' and P' (Figure 5a).

Let us assume that at an initial moment the representative phase point is at B and the first tube is conducting while the second is blocked.

When a negative external pulse is fed to the input, the representative point will shift from point B toward b_1 or b_2. If the capacitance C_1 is zero, the representative point, passing point b_1 and reaching C_1, will be displaced along the straight line c_1-c_2 (Figure 5b) in proportion to the increase of the input pulse and independent of its sharpness. When the external pulse is removed, the points return on the segment c_2-c_1 along the same trajectory. From the point c_1, the representative point jumps into one of the equilibrium points A or B, depending upon where the asymmetry of the circuit is smaller. If the asymmetry is such that the point B is more stable, displacement will occur along the curve c_2-c_1-B and the representative point will go back to the point B. If point A is more stable, the representative point, having once passed into point A, will return there during every pulse (Figure 5b). Therefore, if there are no capacitances C_1, the circuit operates as an amplifier without producing any triggering effect and thus cannot be used as a pulse reducer.

The capacitance C_1 changes the picture completely. For a sloping pulse the representative point upon reaching the point b_1 on curve P jumps to the curve P' (the point e_1'), which is the geomtric locus of points of the end of the "jump" (Figure 5b). The representative point moves along the trajectory b_1'a_1 as circuit condensers charge. If the pulse is removed while the representative point is moving along b_1'a_1, the latter will go to A without going to a_1 and the trigger will be in the second state of stable equilibrium. Only the following pulse will return the representative point to B.

If the pulse width is greater than the length of the path b_1'a_1, the representative point, upon reaching a_1, will jump to a_1', from which it will move towards b_1 (the dotted curve in Figure 5c) as the condensers charge. The representative point may make several jumps, depending upon the pulse, width and land finally either at point A or B. When these conditions hold, the circuit operates as a multivibrator. In order to obtain sharp operation of the circuit as a pulse reducer, the pulse width must be less than the time required for the representative point to traverse the path b_1'a (the so-called resolving time of the circuit).

$$T_c = r_1 C_1 \cdot \frac{r_2 + R_a}{r_1 + r_2 + R_a} \ln \frac{\Delta U_3}{\Delta U_0 - \Delta U_0'} \qquad (2)$$

where r_1, r_2, R_a, C_1 are the circuit parameters shown in Figure 4; ΔU_3 is the greatest projection of the trajectory $b_1'a_1$ on the coordinate axes U_1 and U_2; ΔU_0 is the highest value of the input pulse; and $\Delta U_0'$ is the input pulse magnitude necessary to displace the representative point from B to b_1.

For a pulse with a steep front, the trajectory of the representative point changes slightly. Movement from the point B occurs along the curve Bb_2 (Figure 5d). From b_2, the representative point jumps into point b_1', from which it moves towards point a as the condensers charge.

Since the input pulse magnitude $\Delta U_0'$ required to reach the curve P is lower when the pulse has a sharp front, we can obtain reliable triggering operation independent of the pulse width by placing the pulse amplitude within the limits $\Delta U_0'' < \Delta U_0 < \Delta U_0'$. Actually, if this inequality holds, the representative point will not reach curve P after the condensers charge but will remain at some point <u>a</u> until the external pulse is removed, after which it will move into the point A (dotted line in Figure 5d).

Thus, sharp operation of the trigger can be obtained with restricted-amplitude pulses having a sharp front independent of pulse width. This circuit is more sensitive to negative than to positive pulses and can be made practically insensitive to positive pulses by proper selection of resistances. The capacitance C_3 must be selected so that it is known

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to be greater than the parasitic capacitances of the electron tubes to provide reliable operation of a trigger pulse reducer. Increase of the capacitance C_1, however, lengthens the resolving time of the circuit and thus reduces the maximum frequency of input pulses.

Electron tubes with low internal resistances and interelectrode capacitances must be selected in order to obtain fast-acting pulse reducers. If this is done, one can obtain reducers operating sharply with pulse frequencies reaching several hundred thousands per second.

Three-Way Circuits

Three-path circuits have much in common with two-path circuits in both construction and operation.

Their distinguishing feature is that three currents or voltages displaced 120 electrical degrees relative to each other are obtained at the output of three-path circuits, while currents or voltages displaced 90° (relay circuits) or 180° (electronic and thyratron circuits) are obtained at the output of two-path cyclic circuits.

A rotating electric or magnetic field can be easily obtained on the output, and thus three-path circuits are of special interest as final stages for counters which drive servomotors or electronic commutators.

2.1 A relay circuit for a three-path pulse reducer designed by the author for telemetering is shown in Figure 6.

The circuit is prepared for operation by pushing the push-button n. The relay A is connected, locks itself in contact A/2, and the coil circuit of B/6 is prepared by contact A/3.

When a pulse is fed to line relay L, the contact L/2 is closed and the coil circuit of B/6, which had been prepared by contact A/3, is connected. When the pulse ends, the contact L/2 opens and the contact L/1 closes. Current to both coils of relay A is cut off, and contact A/5 prepares the circuit for operating relay C. The following pulse actuates relay C, which opens relay B after the pulse is removed. With each successive pulse, the relays A, B, C are cyclically connected. The diagram of the operation of relays L, A, B, C is shown in Figure 7.

The requirements for the pulses fed to the line relay are similar to requirements for two-path circuits. The pulse width must at least equal the time during which the relay is connected and the length of the pause must be greater than the time during which the relay is disconnected. During instantaneous closure of the normally-open and normally-closed contacts of the line relay, there must not be time to have two relays of the cyclic system connected,

2.2 Circuits for thyratron three-path pulse reducers do not have any characteristics limiting their construction to three paths. A thyratron fires when the external pulse is supplied, and its extinction is a function of the firing of the following thyratron; thus, a circuit which provides in the firing of one thyratron, extinction of the preceding one, and preparation of the following one for firing is in principle applicable to any number of thyratrons.

Figure 8 shows a three-path cyclical circuit using cold-cathode thyratrons.

The operation of this circuit has much in common with the operation of the relay three-path pulse reducer shown in Figure 8. The role of the contacts A/3, B/3, C/3 is assumed by the voltage drop in the plate circuit of the preceding thyratron across the resistances R_a, R_b, R_c. This voltage prepares the circuit for operation of the following thyratron. The functions of the contacts A/5, B/5, C/5 are fulfilled by the condensers C_1, the capacitive current of which extinguishes the preceding thyratron after firing the following one.

The requirements for the shape of the input pulses for this circuit are the same as for the two-path circuit (Figure 4).

2.3 The electronic circuit (Figure 9) of a three-path pulse counter (the circuit was designed by the author-Certificate of Authorship according to Statement 1132/342041-III), while similar to the two-path circuit in its operation, has a number of real differences. Whereas the grid voltage of one tube under steady-state conditions was a function only of the voltage on the plate of the second tube in the two-path pulse reducer circuit, the grid voltage of a tube is a function of the plate voltages of the other two tubes in the three-path counter circuit.

The operating principle of the circuit is as follows: Normally one of the tubes is completely conducting, while the other two are cut off. When negative pulses are fed to the grids of the electronic tubes, the tube which is conducting is cut off. The current through this tube (for example A in Figure 11) drops rapidly, and the voltage on the grids of the other two tubes rises. This voltage rise is transmitted to tube B more rapidly than to tube C because of the effect of capacitor C_1. After the previously conducting tube is cut off, the following tube starts conducting and remains conducting. When a second negative pulse is supplied, the process is repeated (the conducting tube is cut off and the following one is made to conduct). The switching voltages for the tubes are fixed by the capacitors C_1. When a series of pulses are fed to the circuit input, the tubes A, B, C, etc. are cyclically switched.

The circuit is more sensitive to negative then to positive pulses. An excessively long pulse may cause the circuit to operate as a multivibrator and give a high indication to the following stage.

Three coordinates (Figure 12) must be used instead of two in order to analyse the displacement of the representative point, which characterizes the state of the circuit.

Let us suppose that at the initial moment that tube A is conducting while the other two are cut off (B and C). This state of the circuit in the coordinate axes U_a, U_b, U_c is characterized by the point 1. A pulse fed to the circuit forces the representative point to move along the trajectory 1a. From point a, the representative point jumps to a_1', from which it moves smoothly to point 2 as the condensers charge. The following pulse produces displacement along the trajectory 2bb'3 and, finally, the third pulse moves the representative point along the path 3cc'1. The circuit returns to the initial state.

In this circuit, the requirements for the pulse shape are the same as for the two-path pulse reducer. A five-path trigger can be made in the same way as a three-path trigger. In this case, there are five tubes and conductance of any of these blocks the remaining tubes.

A combination of a five-path with a two-path trigger gives a counting ring (decade) or a pulse reducer with a reduction factor of 10.

This type of circuit, although not the most economical in tubes, is still very convenient for reading results of calculation. Remainder indicators for ten-path pulse reducers give a direct reading of units, tens, hundreds, thousands, etc. of the total number of pulses fed to the circuit.

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Conclusions

1. Circuits for fast-acting pulse counters with cyclic reducers are based upon the same principles regardless of the elements (electronic, thyratron, relay) from which they are constructed.

2. When constructing circuits for pulse counters with reducers, the number of elements of which are directly proportional to the reduction factor, it is most efficient to use circuits with a reduction factor of 2 or 3.

3. The pulse shape is of great importance in electronic and thyratron circuits. The reducer may operate incorrectly when the pulses are long or have a sloping front. The pulse shape should be standardized with the help of a special circuit to give sharp operation of the reducer circuit.

4. Three-path pulse reducer circuits produce three voltages, all 120° out-of-phase with respect to each other, at the output. By using three-path circuits as the output stage, a rotating field can be created for an actuating mechanism.

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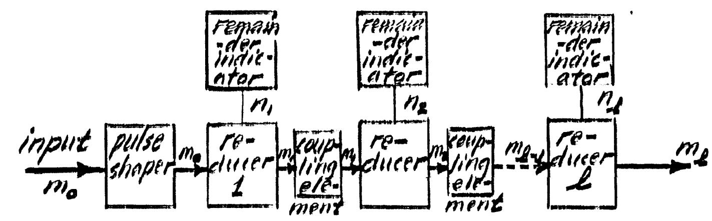

Figure 1 - Block Diagram of a Counter.

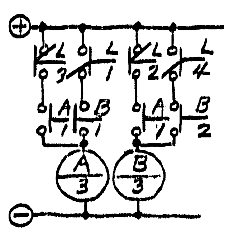

Figure 2 - Two-Path Relay Circuit.

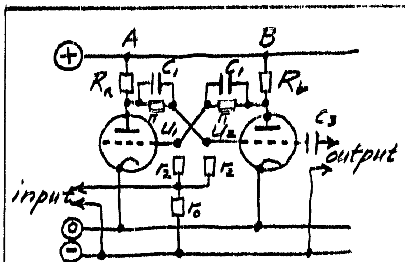

Figure 4 - Two-Path Electronic Trigger Circuit.

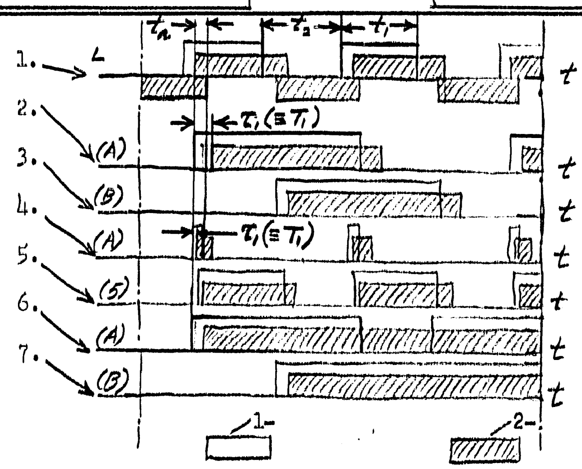

Figure 3

[Caption on page 16]

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Continued from the bottom of page 15.

[Diagram of Figure 3 is at the bottom of page 15.]

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Figure 3 - Diagram of Operation of Two-Path Relay Circuit: Lines 2 & 3 : Normal Operation; Lines 4 & 5 - $T_2 > T_1$; Lines 6 & 7: $T_a > 2T_1$; 1-Current in Coil; 2-Closing of Relay Contacts (T_1 and T_2 - Times of Operation and Release of Relay; t_1 and t_2 - Times of Pulse and Pause; T_a - Time for Transferring the Normally-Open and Normally-Closed Contacts of the Line Relay).

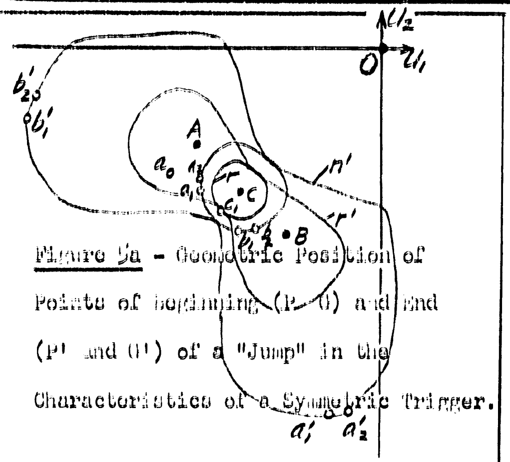

Figure 5a - Geometric Position of Points of Beginning (P and Q) and End (P' and Q') of a "Jump" in the Characteristics of a Symmetric Trigger.

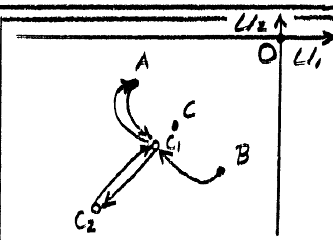

Figure 5b.- Trajectory of the Representative Point of a Two-Path Trigger With No Driving Capacitances.

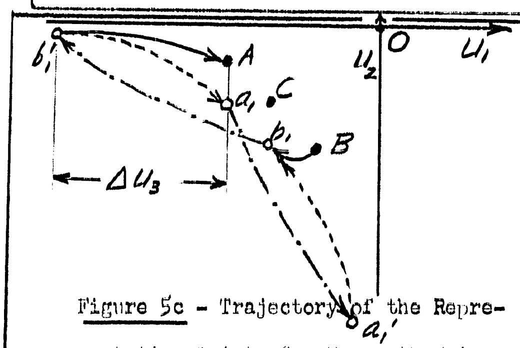

Figure 5c - Trajectory of the Representative Point of a Two-Path Trigger For a Pulse With a Sloping Front: Jump: Smoth Displacement For a Short Pulse; Smooth Displacement For a Long Pulse

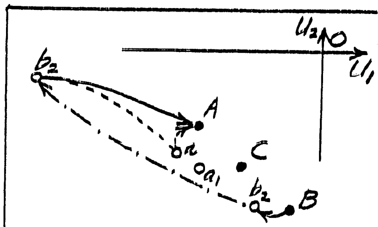

Figure 5d - Trajectory of the Representative Point For a Pulse With a Sharp Front: Jump: Smooth Displacement For Short Pulse, Smooth Displacement for a Long Pulse.

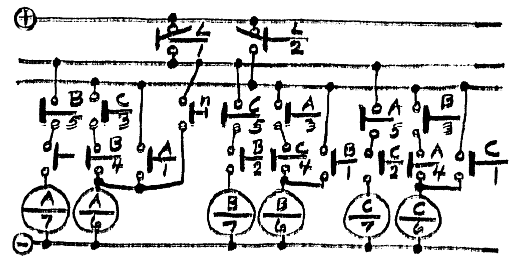

Figure 6 - Three-Path Relay Circuit With Two-Coil Relays (A, B, and C)

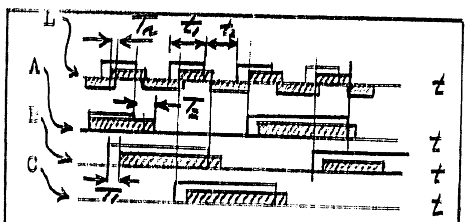

Figure 7 - Diagram of Operation of Three-Path Relay Circuit.

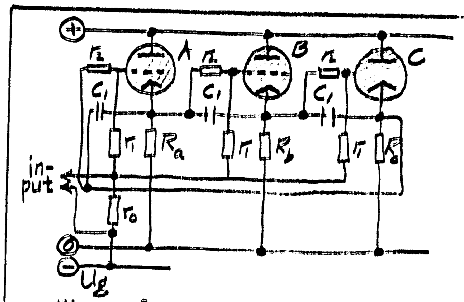

Figure 8 - Three-Path Thyratron Circuit.

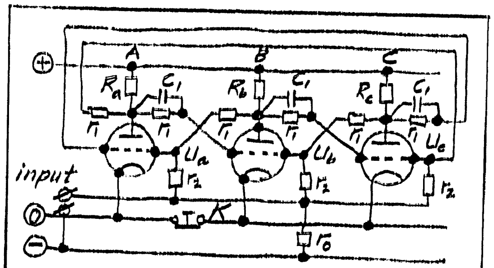

Figure 9 - Three-Path Electronic Trigger Circuit.

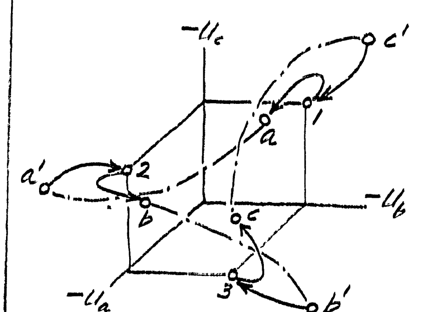

Figure 10 - Trajectory of the Representative Point of a Three-Path Trigger When Pulses are Fed to the Input:-.-.-.-.-Jump; ———— Smooth Displacement.

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