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By Ye. I. Mamonov and Yu. I. Sharapov

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# APPLICATION OF SEMICONDUCTOR DEVICES IN COMPUTER TECHNIQUE.

[Following is the translation of an article by Ye. I. Mamonov and Yu. I. Sharapov entitled Primeneniye Poluprovodnikovykh Priborov v Vychislitel'noy Tekhnike (English version above) in "Avtomaticheskoye Upravleniye i Vychislitel'naya Tekhnika" ("Automatic Control and Computer Technique"), Moscow, 1958, pp. 175-203.]

The reliability of the performance of an electronic digital computer containing thousands of tubes depends to a considerable degree on the sound performance of these tubes and is determined by the probability of tube failures in time. The reliability can be increased first of all by means of using durable parts.

Meanwhile, the useful life of heater-cathode tubes is comparatively short. The drawbacks of electron-tube elements are also a high energy consumption and large dimensions.

The useful life of semiconductor diodes and triodes is tens of times longer than that of tubes. Their use makes it possible to raise the reliability of the machine performance and to reduce the expenditure of machine time for preventive maintenance. The electric energy consumption is also reduced by tens of times.

So far the best results have been obtained through the use of germanium diodes which make it possible to reduce sharply the number of electron tubes in the machines and raise the dependability of the circuits. In the course of several years of continuous operation only a few of the 10 thousand of germanium diodes failed in the machine BESM [1].

Widespread introduction of semiconductor electronics and also of the printed circuits and other small-sized materials and parts is one of the most important trends in the development of computers. This makes it possible to broaden the area of the application of the new machines, especially in the small-sized and portable control devices and systems (aircraft, ship, automobile and other equipment).

Being considered in the present article are the principles of the application of germanium point-contact and junction triodes and diodes in the circuits of the automatic digital computers.

The use of point-contact triodes in the circuits of high-speed machines is based on two principles. One of them is based on the utilization of N-shaped characteristic of the triods for designing bistable trigger circuits, automatically oscillating and one-shot multivibrators and also logical circuits.

Designed according to a different principle are the dynamic circuits for which nonlinear characteristic with negative resistance is not obligatory [4], [5].

More widely used in the computer technique are germanium junction triodes characterized by high power and dependability and by a considerably smaller zero current.

The semiconductor diodes in the digital computers are utilised for the construction of logical circuits which realize the basic functions OR, AND, NO and in particular for the construction of a circuit designed for decoding and used for the automatic switching of the control signals. Diodes are also used for shaping the pulses by means of limiting and damping them and also for stabilizing the voltage levels.

Diodes are also used in one-way devices for the storage of constants, table values and other permanent information [2] which is collected beforehand and is only read at high speed in the process of solving a problem. They are also used in diode-capacitor devices for the storage of information [3]. The utilization of the passive nonlinearity of the diodes is characteristic for these purposes, most desirable being a sharp nonlinearity, i.e. high impedance in open circuits and low impedance if the circuits are closed.

Owing to the attenuation of signals in the circuits with passive elements it is often necessary to use amplifiers.

The recently discovered properties of crystal diodes which provide an opportunity of utilizing their active nonlinearities are of interest. This pertains to the germanium point-contact diodes with S-shaped characteristic deformed in the straight-line direction and to junction diodes under the conditions of the so-called delayed conductance.

The frequency of the electron-tube elements of the counting circuits in the fastest operating computers amounts at the present time to about 10 megacycles and the problem of increasing the rate of the computations still more is being raised. Therefore the semiconductor devices must operate at a higher frequency.

An essential feature of the principal circuits in digital computers is a comparatively high level of the electric signals. Part of these signals is used for the presentation of information in accordance with the program and the other part serves for control.

Another distinguishing characteristic of the latest machines is the use of tens of thousands of semiconductor elements. At the present time information is available on building machines in which all the basic circuits are made of semiconductor elements [4], [25], [26], [32], [33].

Of the other requirements demanded of the semiconductor devices one should mention the uniformity of the characteristics of the same type of devices which secures their interchangeability in the circuits. Another requirement is an adequate stability of the parameters in a wider temperature range. Obviously, as the result of the development of silicon devices the possibilites of improving the parameters will increase.

## The principles of the Structure of Trigger Circuits with Point-Contact Germanium Triodes.

NEGATIVE-RESISTANCE TRIGGERS. When a resistor is connected to the base circuit of a point-contact triode having a sufficient amplification factor $\alpha$, there is created a positive feedback between the emitter and collector circuits. The actual condition of the presence of negative characteristic regions in a circuit with triode indicates that the value of $\alpha$ should be as high as possible since in that case the operating conditions are lightened [6]:

$$\alpha > \left(1 + \frac{R_e}{r_e}\right)\left(1 + \frac{r_e + R_e}{r_b + R_b}\right), \quad (1)$$

where $r_e$, $r_b$ and $r_c$ are equivalent triode resistances;

$R_c$, $R_e$ and $R_b$ - the resistors in the collector, emitter and base circuits.

Proceeding from the condition (1), with a higher $\alpha$ the magnitudes $R_c$, $R_e$ and $R_b$ may be larger in the presence of the necessary and controllable circuit instability which is advantageous from the standpoint of lightening the electric operating conditions.

Circuit diagram shown in Figure 1 may be utilized for a characteristic of the operating conditions of a trigger with two stable states. In this process the curve $U_e = f_1(I_e)$ must be intersected by the load line at three points:

$$R_e < R_b \frac{R_k + r_k(1-\alpha)}{R_k + r_k + R_b}. \qquad (2)$$

Two of these points (b and v) are stable and the crossover from one point to the other is accomplished in avalanche-like fashion. The graph $I_c = f_2(I_e)$ shows the character of the gap. For the connection with the circuits of the computer arithmetic and other devices in the make-up of which there are bistable trigger cells, the collector circuit is usually utilized as being more powerful. It is necessary to send to the emitter pulses of alternating polarity. This is the drawback of the circuit. A pulse of positive polarity should be sent when the trigger is in position b, the amplitude of the pulse having to be larger than the magnitude bA counted off along axis $U_e$. If however, the trigger is in the position v, then a pulse of negative polarity is sent, this pulse having to be larger than the magnitude vD.

However, owing to instability (for example, owing to the temperature instability) and the spread of the triode characteristics such trigger circuit is of little applicability in practice. The basic method for the improvement of similar circuits is incorporation of diodes and resistors in the triode electrodes circuit. Thus, for example, the incorporation of a diode and transmission of positive bias voltage to the base circuits (dotted line) makes it possible to fix point A of the break of the N-type characteristic and improve at the same time the sensitivity of the trigger to starting. The position of this point is affected by the change in the magnitudes of $I_{ko}$ and $U_k$. The voltage $U_e$ at point A determined chiefly by the direct resistance of the diode, is reduced by several tens of times upon this change in the circuit and amounts to tenths of a volt. At the same time point D is sufficiently stable.

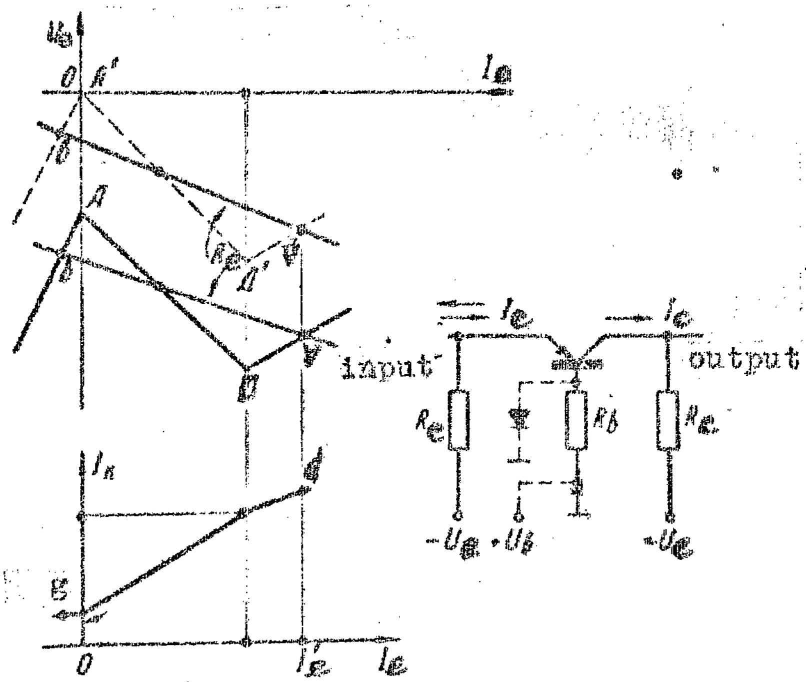



Figure 1. Characteristics $U_e=f_1(I_e)$ and $I_c=f_2(I_e)$ of a circuit with point-contact triode.

A large number of circuits with point-contact triodes are used in practice [6] - [12]. We shall consider below only some of these circuits.

The drawback of the trigger circuit shown in Figure is that in order to switch it from one balanced state to the other it is necessary to send pulses of different polarity. By means of dividing $R_e$ into two series-connected resistors and connecting the junction points between them to the base of the diode (the plus terminal - to the base) it is possible to achieve the starting of the circuit with single-polarity pulses.

In a number of devices, for example in adders and registers, for the control and for connection with other circuits it is necessary to pick up simultaneously from the trigger sufficiently powerful static signals corresponding to both states. For this purpose it is most convenient to utilize the collector circuits. In the circuit diagram shown in Figure 3, a low potential may be picked off from the collector of the left leg and a high potential - from the collector of the right leg. In the transition of the circuit from one state to the other the potentials of the legs are changed to opposite potentials and during this the switching has avalanche-type character as the result of the availability of the feedback. The switching rate is determined by the circuit parameters and the frequency characteristic of the triode when the signals are large. Single-polarity pulses may be utilized to accomplish the switching.

For quenching to zero or for setting up unity it is necessary to send pulses to the appropriate arm. Diodes $D_1$ and $D_2$ at the input

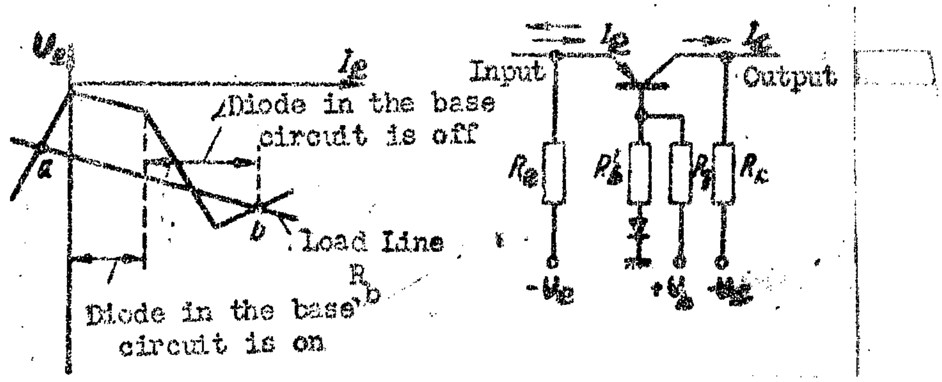



Figure 2. Characteristic $U_e$=f($I_e$) and trigger circuit with one point-contact triode.

of the circuit may have bias. Diodes $D_3$ and $D_4$ serve for stabilization of emitter characteristics and diodes $D_5$ and $D_6$ secure the divi-

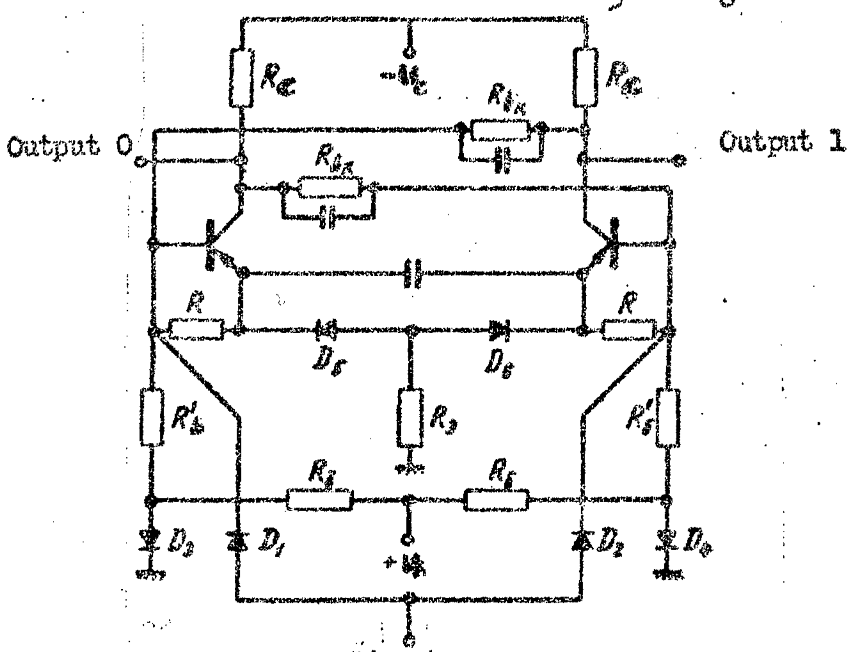



Figure 3. Circuit diagram of a one-digit binary adder with twopoint-contact triodes.

sion of the emitter circuits of the triodes. Resistors $R_b \approx 10\ R'_b$ comprise about 10 kilohms, $R_e$=1 ÷ 2 kilohms and $R_c$ - several kilohms. The voltage $U_c \approx -(40 \div 50)$ volts. Leakage resistance R=10 ÷ 20 kilohms. Capacitors bypassing resistors $R_{b_k}$=10 ÷ 20 kilohms are intended for speeding up the transmission of high-frequency signal components in the feedback circuit during the changing over of the circuit from one state to the other. The coupling capacitor between the emitters also serves for accelerating the transition process.

The trigger circuits considered were used as the foundation for the design of one-way and reversible adders and also for designing adders operating in serial and parallel fashion in which the binary number system is usually used.

By using N-type characteristics of the point-contact triodes there can also be easily constructed some logical circuits OR, NO, one-shot multivibrators designed for a temporary delay of a signal, regenerative amplifiers of pulse shaping and others. The circuit diagram shown in Figure 2 may be used as the foundation of these devices. For example, by sending to the emitter the voltage gap and a pulse instead of the bias magnitude $U_e$ it is possible to realize the logical function AND or NO for two input signals. The appearance of the output signals in these circuits depends on the combination of the input signals.

The maximum frequency of the circuits operating on this principle and used in practice amounts to about 100 kilocycles per second and the duration of the transition processes - to several tenths of a microsecond. First of all, these parameters depend on the design of the triod proper and on its characteristic in the region of high frequencies. One of the external methods of raising the operation frequency of the triodes in the circuits of computers is a decrease in the saturation depth and in the amount of charge accumulation in the base during the switched-on state. This is achieved by incorporating in the emitter and collector circuits diodes which limit the maximum values of the currents.

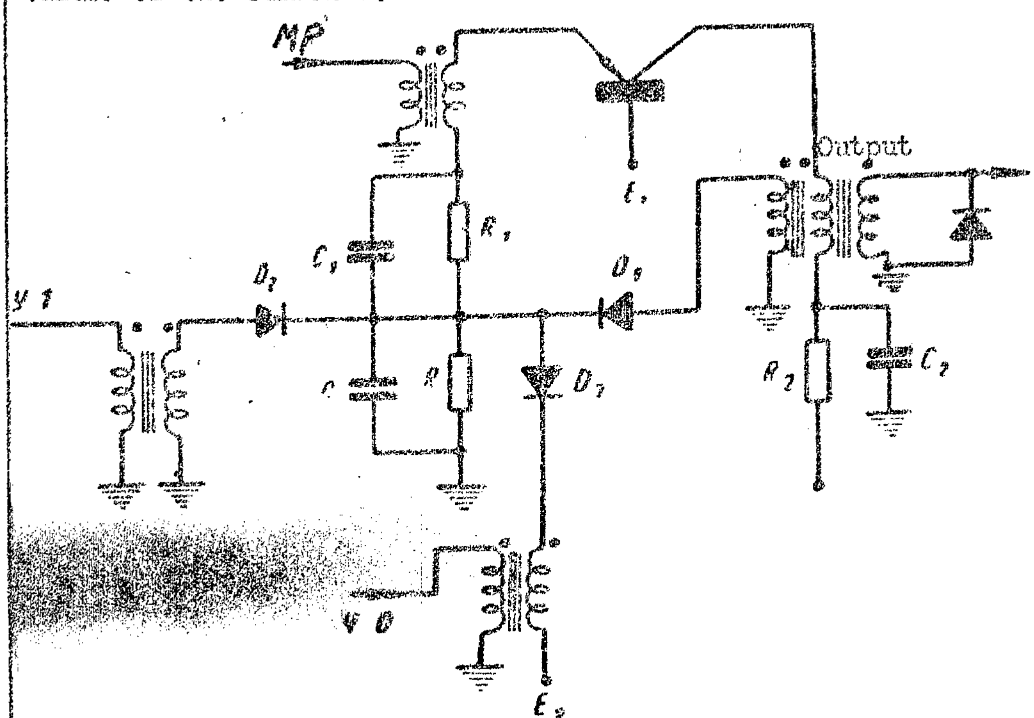



Figure 4. The basic diagram of a dynamic trigger.

DYNAMIC TRIGGERS. Dynamic trigger with point-contact triode is is based on the same principle as a similar tube circuit [13]. Like the static trigger it can have two states - 0 and 1. No signals arrive at the output in the state 0 and in the state 1 there are pulses of a definite fixed frequency at the output.

The basic element of the dynamic trigger circuit with point-contact triode developed at the Institute of Precision Mechanics and Computer Technique, Academy of Sciences USSR [14] is the pulse amplifier (Figure 4). On the input of the amplifier there is a rectifier on which arrive at a fixed rate and amplitude standard pulses called the main pulses (MP). From the amplifier output the pulses are sent to the memory capacitor C designed for the maintenance of a high potential on the rectifier control input in the interval between the pulses. In the amplifier circuit is used the point-contact triode C 1 D or C2B and a series-type rectifier. The signal voltage delivered on the amplifier represents the sum of the voltage on the capacitor C and the voltage of the pulse MP arriving from the transformer.

When there is zero potential on the memory capacitor, the rectifier is shut off, the pulses do not pass through and the trigger is in 0 state. Upon the arrival of the unity pulse a high potential is set up which keeps the rectifier on for some time. The first pulse MP passes through the amplifier and through the feedback circuit and charges the memory capacitor. This makes possible the passage of the next pulse MP and so forth. Upon the arrival of the zero-setting pulse the memory capacitor is discharged, the rectifier is shut off and stops the admission of the pulses MP.

Serving for the suppression of undesirable fluctuations which may arise upon the admission of pulses is resistor $R_1$ which is connected serially to the secondary winding of the transformer. In order to prevent frequency distortion this resistor is bypassed by the capacitor $C_1$=150 micromicrofarads. The memory capacitor is bypassed by the resistor R=100 kilohms which increases the stability of the time constant of the memory capacitor discharge. This reduces the dependence of the capacitor on the reverse resistance of the diodes $D_1$ and $D_2$ and of the triode. The time constant should be 5-10 times greater than the period of the pulse train. In addition, the constant voltage on the capacitor from the bias source $E_2$ in the zero setting circuit is reduced to a minimum since the magnitude of R is considerably less than the reverse resistance of the diode $D_3$. Constant positive bias is transmitted to the base of the triode connected in conformance with the grounded-base configuration. In the collector there is a pulse transformer one winding of which is utilized for sending the feedback signal through the diode $D_1$ to the capacitor C. Resistor $R_2$ and the capacitor $C_2$ form a filter in the feed circuit.

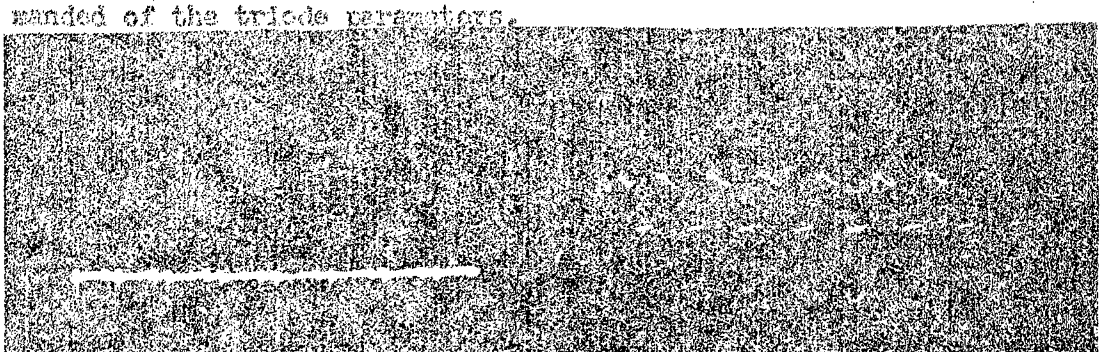
The circuit considered is characterized by adequate reliability and the circuit triodes operate relatively stably. Reliability may be estimated by the difference between the maximum value of the base bias $E_{1\ max}$ at which the unity state proves to be unstable and the minimum value of the base bias $E_{1\ min}$ at which the zero state is unstable:

$$\Delta E = E_{1\ max} - E_{1\ min}.$$

This difference called reliability margin is equal to 4-6 volts without load. The higher the $\alpha$, the larger the reliability margin of the circuit.

Forming on the output of such a trigger are pulses of 100 millivolt power and the potential on the capacitor makes it possible to achieve the feeding of 3-4 rectifiers of the type mentioned.

Dynamic trigger has the following advantages over the static trigger: only one triode and a small number of parts are necessary for its construction. The triode is used in the pulse-type mode of operation which makes the conditions of its operation easier and increases the economy of the circuit. No particularly rigid requirements are demanded of the triode parameters.



a) b)

Figure 5. An oscillogram of dynamic trigger performance upon arrival of zero-setting and unity-setting pulses every 4 microseconds.

An important advantage is also the quick operation of the circuit. The trigger operates at the main-pulse repetition rate of 500 kilocycles per second (Figure 5). The high rate of the trigger operation is possible owing to the circumstance that the point-contact triodes have good frequency characteristics in which respect they differ to advantage from the junction triodes. A dynamic trigger with junction triodes is constructed according to an analagous system with the exception that the triode is incorporated in accordance with the grounded-emitter configuration. However, owing to poor frequency properties of the existing junction triodes such a trigger is characterized by low frequency under the conditions of saturation. When operating with small signals, the power of such a trigger will be inadequate. Just the same, in many cases the junction triodes have advantages over the point-contact triodes.

## Trigger Circuits with Crystal Junction Triodes.

CHARACTERISTIC OF JUNCTION TRIODES OPERATING WITH LARGE SIGNALS. There are distinguished three regions of operation of the junction triodes: the region of the collector current cut-off, the region of linear dependence between the input and output signals and the regions of the collector current saturation [15]. In the saturation region the voltage between the emitter and collector comprises hundredths of a volt. If the arriving signals are small, the triode operates primarily in the region of linear dependence.

In the circuits of computers the junction triodes are used in an overwhelming majority of cases under the conditions of large signals, i.e. only in the cut-off region and in the region of current saturation, the most essential characteristic of the triodes being the switching time. In the switching devices the junction triodes are utilized chiefly according to the grounded-emitter configuration. This secures the highest amplification with respect to power, makes it possible to reduce the current for control and also to obtain an almost ideal changeover switch.

One of the most important parameters of a junction triode is amplification $\alpha'$ with respect to base current.

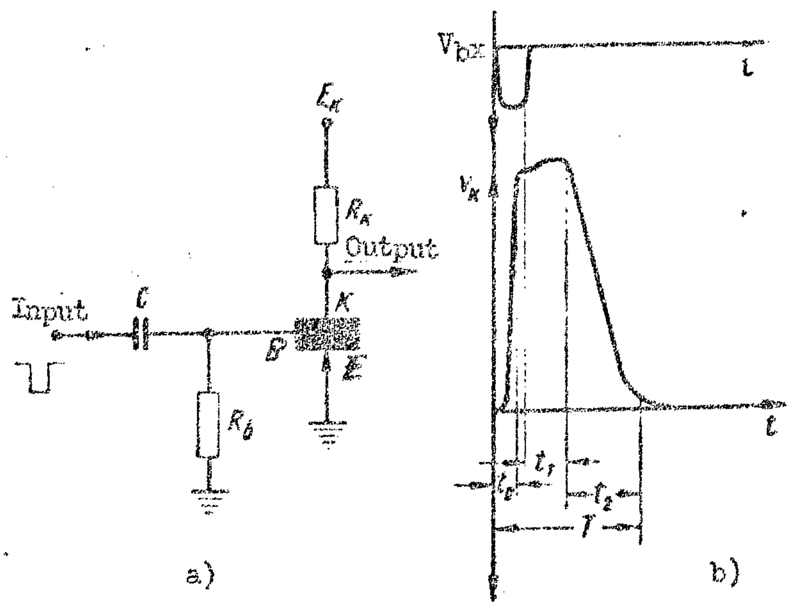



Figure 6. Diagram of the reading of pulse characteristics.

In the absence of input signal, the triode is normally cut off and passing through the collector is a small current which does not exceed a few tens microamperes in the normal operation of the triode (Figure 6). During this, the voltage on the collector is close to the voltage of the power supply $E_k$. When a negative signal arrives at the input the triode is triggered. The minimum magnitude of the negative voltage on the base required for this is called the base voltage of the collector current cut-off $v_{b.cut}$ and for the triodes P 1 E - P 1 I it amounts to about 0.15 volts. At a definite value of the base current the triode is saturated and the voltage on its collector $v_{k.sat}$ comprises 0.03-0.07 volts and the current $I_{kn}$ is determined by the load resistance $R_k$ and voltage $E_k$. The base current at the saturation threshold of the collector will be equal to

$$I_{bn} = \frac{1}{\alpha'_c} I_{\kappa n} = \frac{E_\kappa}{\alpha'_c R_\kappa},$$

where $\alpha'_c$ is the average value of $\alpha'$ corresponding to the amplitude of the collector current from the cut-off to saturation.

The collector current cannot increase upon further increase in in the base current. The voltage on the base is determined by the input characteristic of the triode (Figure 7). The voltage on the base $v_{b.sat}$ with a definite base current $I_{b.sat}$ may be taken as the parameter of the input circuit.

Let us consider the response of the amplifier to a short negative pulse having steep fronts (see Figure 6 b). Upon the delivery of such a pulse at the input, the voltage on the collector does not increase to zero at once but in the course of certain time $t_o$ which characterizes the duration of the forward pulse front on the output including the delay. After the sending of the input pulse is discontinued the voltage on the collector remains the same for some time and passing through the base and collector is the space-charging current. When the concentration of the holes near the collector junction reaches the equilibrium value [17], [18] the collector current begins to diminish slowly (time $t_2$). Time $t_1$ during which the collector current preserves constant magnitude during the spacing-charging, depends

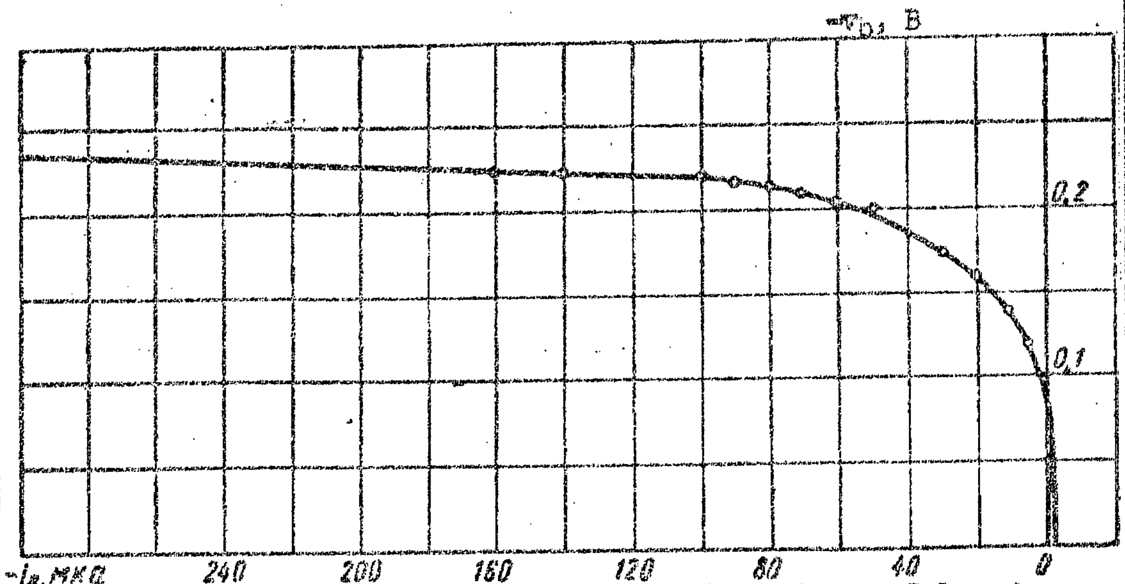


Figure 7. Input characteristic of the triode P 1 E when $E_k$=-10 volts and $R_k$=2 kilohms.

on the degree of the saturation of the triode and theoretically can be reduced zero. In this case the magnitude of the input signal corresponds to the threshold of saturation. Magnitudes $t_0$, $t_1$, $t_2$ depend both on the parameters of the triode and on its operating conditions determined by the parameters of the external circuit [16].

The amplification factor $\alpha'$ may be considered to be constant with respect to the base current only when operating with small signals. Its magnitude depends on the emitter current and is appreciably reduced when the currents are large [19]. This circumstance should be taken into consideration when operating with large signals.

The maximum permissible magnitudes characterizing the triode are $I_{k,per}$, $V_{k,per}$, $P_{k,per}$. Having a particularly important significance among other parameters is the dark current $I_{k0}$ passing through the collector and base in the positive direction when the value of the emitter current is zero. Also of an important significance is the magnitude of the zero current $I'_{k0}$, this magnitude being defined as the collector current when the base current is zero (i.e. for the case when the base circuit is broken). In the junction triodes, this current reaches several hundreds microamperes and in the case of poor triodes may be more than one milliampere. If the base of the triode is grounded through the resistor $R_b$, then in the absence of a signal the collector current will have the mean value between $I_{k0}$ and $I'_{k0}$. This value will be the smaller the smaller $R_b$ is. If $I_{k0}$ exceeds the maximum permissible value, then the value of $I'_{k0}$ is also large which is not permissible.

STATIC TRIGGER. There exist many variants of a circuit trigger circuit with junction triodes [20], [21]. The operating frequency of such triggers is usually low and as a rule does not exceed one hundred kilocycles per second. The appearance of new high-frequency surface-barrier triodes will raise the operating frequency above one megacycle per second.

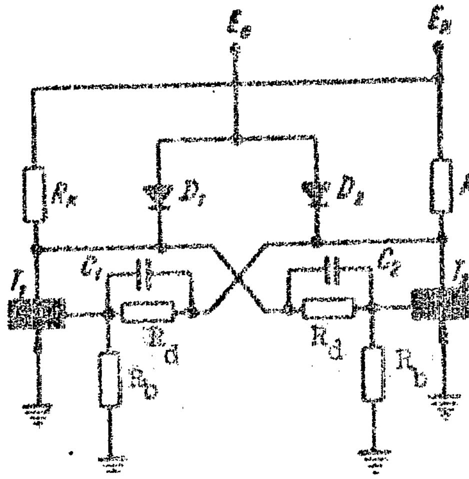



Figure 8. Trigger circuit in junction triodes.

At the Institute of Precision Mechanics and Computer Technique, Academy of Sciences USSR, there was investigated the possibility of constructing fast-operating switching circuits and first of all the basic memory element - a trigger with the use of junction triodes P 1 E - P 1 I (Figure 8), [23].

In the design it is taken that every triode can have two stable states: collector current saturation and cut-off. In the state of saturation, the potential on the collector is about the same for all triodes and amounts to $v_{k.sat} = -(0.03 \div 0.07)$ volts. In the cut-off state the collector potential is equal to the limiting voltage $E_0$.

When switching the trigger the duration of the transition process is determined by the space-charging time and, consequently, the elements of the circuit must be appropriate to the shortest space-charging time. The reduction in the duration of the rear front is also achieved by the introduction of the limiting voltage $E_o$.

In order to reduce the space-charging time the resistance $R_k$ must be as low as possible and its magnitude is determined by the permissible collector current $I_{k.per}$. Thus, if $I_{k.per}$ = -5 milliamperes and $E_k$= -10 volts, then $R_k = \frac{E_k}{I_{k.per}}$ =2 kilohms.

The conducting triode is kept in the saturated state at the expense of it's base current $i_b$ which must be larger than the current $I_{bn}$ and have a certain margin for higher reliability of the circuit. The total current passing through the resistance $R_d$ is equal to the sum of the current $i_b$ and the current passing through the leakage resistance $R_b$ and since the latter causes useless losses, its magnitude should not exceed 20-30% of the value of $i_b$.

The magnitude of

$$R_b = \frac{E_0'}{i_b + i_{R_b}}, \quad (1)$$

where $E'_o$ is equal to the difference between $E_o$ plus the voltage drop on the direct resistance of the diode $v_D$ and the voltage on the base of the triode ($v_{b.sat}$):

$$E_0' = E_0 + v_D - v_{b\,sat} \quad (2)$$

Let

$$E_0' = -5v,\ i_b + i_{R_b} = -0{,}5 \text{ milliamps}$$ 3

then

$$R_b = \frac{5v}{0{,}5\ ma} = 10 \text{ kilohms}$$ 4

The resistance $R_b$ must also be as low as possible in order to reduce the effect of the zero current, and its minimum magnitude is determined by the permissible losses of the net power. If it is taken that $i_{R_b}$ = 25% of $i_c$, then in the example cited $i_{R_b}$ = -0.1 milliamperes. Then $R_b = \frac{V_{b\ sat}}{i_{R_b}} \quad \frac{0.25 \text{ volts}}{0.1 \text{ milliamp.}} = 2.5$ kilohms.

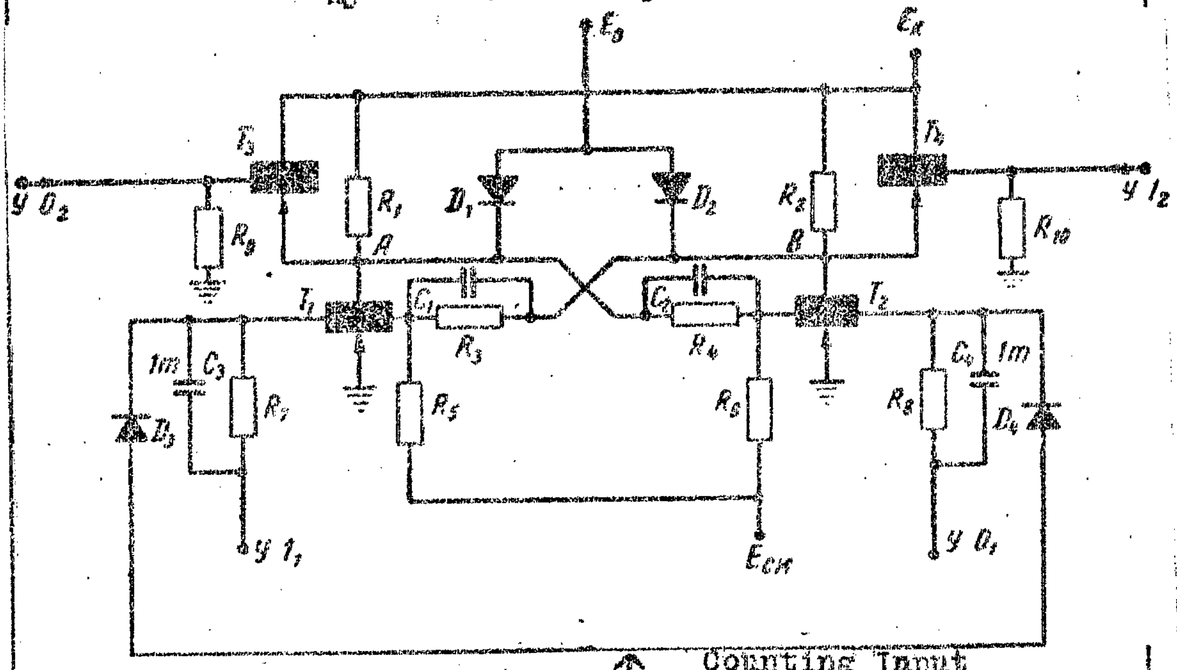



Figure 9. General-purpose trigger circuit.

A very responsible element of a trigger circuit is capacitor C designed not only for speeding-up of the voltage transmission, as in tube circuits, but also for the transmission of the trigger and space-charge currents to the triodes until the establishment of a stable state. If the capacitance is too small, then this hinders the triggering, and if it is too large, then a high saturation takes place during the time immediately after the changeover and this reduces the quick operation of the trigger.

The starting of the trigger can be accomplished both by the positive and negative pulses delivered to the collector or to the base. Altogether there exist eight different variants for starting, the best results being given by the variants shown in Figure 9. In this circuit, corresponding to the state "1" is the negative potential on the right triode. Separate triggering by the negative unity and zero setting pulses delivered to the base is the most economical one. The starting pulse acts on the triod and triggers it. The current required for this slightly exceeds $I_{bn}$ and the voltage on the base cannot exceed $v_{b\ sat} = 0.2 \div 0.3$ volts. The chains $C_3R_7$ and $C_4R_8$ increase the input resistance ($C_3$ and $C_4$ serve for the compensation of the input capacitances of the triodes). The maximum frequency of the trigger during this does not exceed 500 kilocycles per second since the rear front (the cut-off time) determined by the space-charging comprises about 2 microseconds.

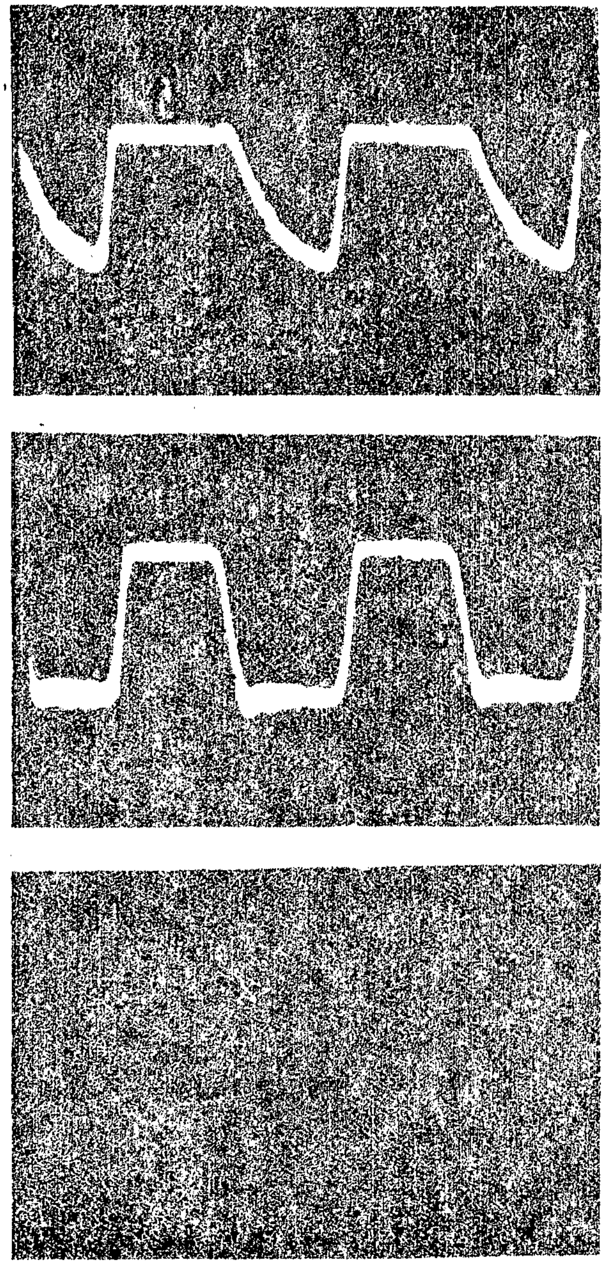
A considerably higher rate is secured by another method of separate starting called "accelerated triggering". With this method, there are sent to the collector circuit power pulses which are delivered on the unity and zero setting inputs of the emitter repeaters $T_3$ and $T_4$. For example, if the trigger is in the position "1" and a signal is delivered on the input of "0"$_2$, then the triode $T_3$ is triggered and since its output resistance decreases to about 10 ohms, the potential at point A is reduced to the negative level of $E_0$. If the amplitude of the input pulse exceeds $E_0$, then the potential is reduced still more. During this, the triode $T_2$ is quickly triggered (during the time of about 0.3-0.5 microseconds), the potential at point B increases, and the triode $T_1$ will be cut off. Its space-charge current does not pass through the resistor $R_1$ but through the triggered triode $T_3$ and the space charge occurs very quickly, in about 0.5 micorseconds. With the accelerated starting, the forward and rear fronts of the voltage gaps are equal to about 0.5 microseconds which secures reliable trigger operation at the frequency of 1 megacycle per second, with the power of the input pulses being about 50 millivolts.

The best variant of starting through the adder input is the transmission of positive pulses having a voltage of 1.5-2 volts through the diodes D3 and D4 (Figure 9). The sensitivity of the trigger with respect to the starting may be regulated by means of varying the positive bias $E_{cm}$ = 0.3 ÷ 0.5 volts. The maximum frequency during this depends to a considerable degree on the quality of the triodes. The larger the value of $\alpha'$, the higher the frequency. Frequency of 300 kilocycles per second may be considered normal but for some triodes P 1 E ($\alpha' = 60 \div 80$) and for triodes P 1 I, the frequency may amount to 500 kilocycles per second and higher (Figure 10).

TRIGGER WITH DIRECT COUPLINGS. Circuits with direct couplings began to be built after the discovery of surface-barrier triodes [24] which because of their parameters and characteristics proved to be the most suitables ones for the construction of such circuits [25], [26]. However, some junction triodes may also be used in these circuits.

Called direct coupling is such a coupling between the collector and the base which is achieved without any intermediate elements.

The chief advantage of such circuits is their simplicity and operating stability which is achieved through the absence of intermediate capacitors. Like the usual static trigger, a trigger with direct couplings (Figure 11) has two stable states of equilibrium. In each one of these states one triod is cut off and the other one is being saturated. The potential $V_{k\ sat}$ amounts to only 0.03-0.07 volts on the triode collector in the state of saturation. If this potential is less than the base cut-off voltage, i.e. if $|V_{k\ sat}| < V_{b\ cut}$, then the other triode the base of which is connected directly with the collector of the conducting triode will be cut off, the voltage on the collector of the cut-off triode being equal to the voltage on the base of the conducting triode $V_{b\ sat}$. In this case, passing through the load resistance of the cut-off triode is the base current of the conducting



a)

b)

c)

Figure 10. Oscillogram of Static Trigger Operation with the Flip-Flop Frequency of 500 kilocycles per second.

a - trigger started to the base; b - trigger with accelerated starting; c - trigger with counting input.

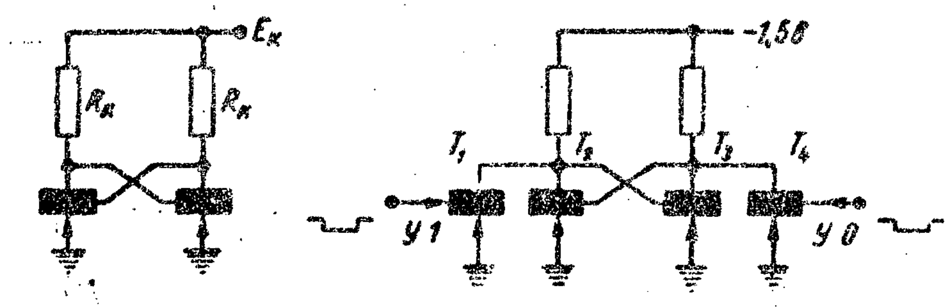
triode, this current securing the saturation state of the conducting triode and consequently, the stability of the overall state of the circuit. Upon the changeover of the trigger from one state to the other, the voltage difference on the collector is defined by the parameters of the triodes:

$$\Delta v = v_{b\ sat} - v_{k\ sat}. \qquad (4)$$

Shown in Figure 12 in a single coordinate system is a family of the collector and base characteristics of the triode P6B. The measurement points at which the triodes may be located are defined by the intersection of the load line AB with the characteristic curves of the triode. Determined at point 1b is the voltage on the base $v_{b\ sat}$ and and the base current $I_{b\ sat}$ of the conducting triode. The voltage and the collector current of this triode are determined at point 1k where the line AB is intersected by the corresponding collector characteristic. The intersection of the perpendicular dropped from the point 1k onto the axis of the abscissae with the base characteristic, defines the base current of the cut-off triode, the value of this current approaching zero. The collector of the cut-off triode is also small and is defined on the collector characteristic corresponding to the base voltage $v_b = v_{k\ sat}$.

It is efficient to achieve the starting of the trigger with the aid of auxiliary triodes (see Figure 11 b). The starting triodes $T_1$

and $T_4$ are energized with negative pulses to saturation and owing to



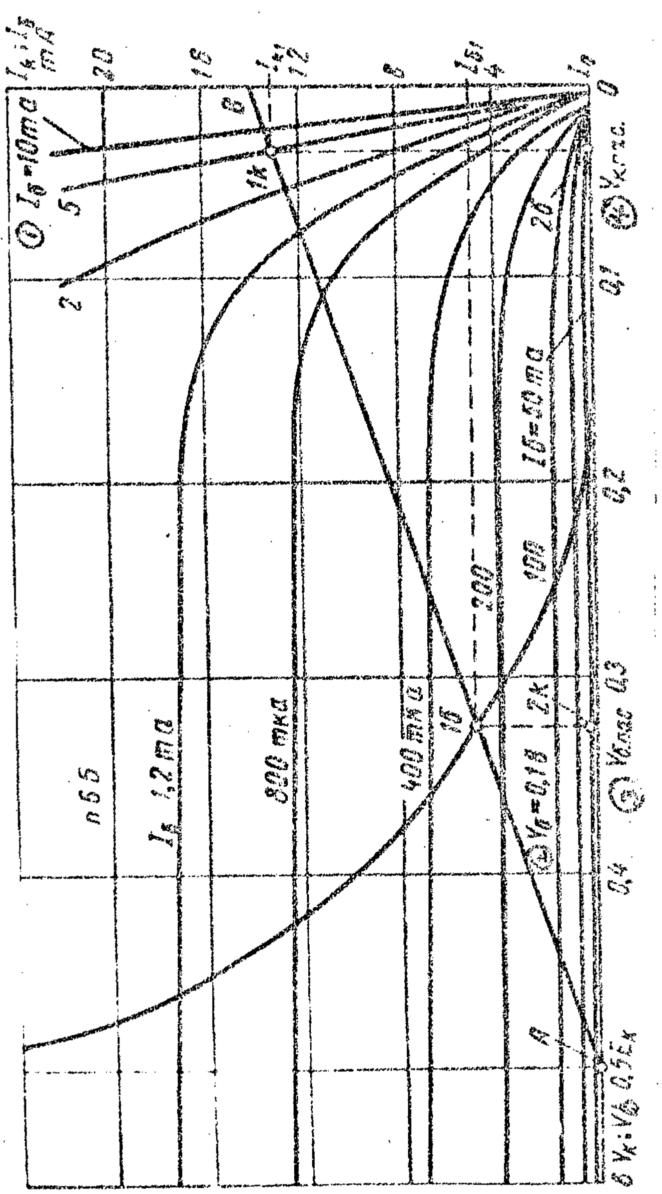

a)    b)

Figure 11. Direct-coupled trigger:

a - trigger circuit; b - trigger with triode starting.

this the voltage on the collector of the corresponding triode approaches zero. The starting triode must be in the state of saturation until the changeover process is completed, the duration of this process being determined by the space-charge time.

[See page 28b for Fig. 12.]



1) $I_b$=10 milliamperes 2) $V_b$=0.1 volts 3) $V_{b.sat}$ 4) $V_{k.sat}$

Figure 12. Combined characteristics for the calculation of direct-coupled circuits.

Figure 12.

In the case under consideration, the space-charge time is frequently very considerable when the usual junction triodes are used and only the surface-barrier triodes can secure the high rate of operation. With the junction triods P 1 I, these circuits can operate only if the frequency comprises several tens kilocycles per second with the feed voltages being 0.5 volts and higher. In order to reduce the degree of saturation in the direct-coupled trigger, triodes with a small value of $\alpha'$ are very adequate and secure a shorter flip-flop time.

## Diode Memory Elements.

JUNCTION-DIODE TRIGGER. The feasibility of creating such a trigger in principle is founded on the property of the junction diodes to operate as amplifiers of the power of the short-duration pulses [27], [28], [29]. This property is explained by the well-known phenomenon of the conservation of the minority carriers (holes) for

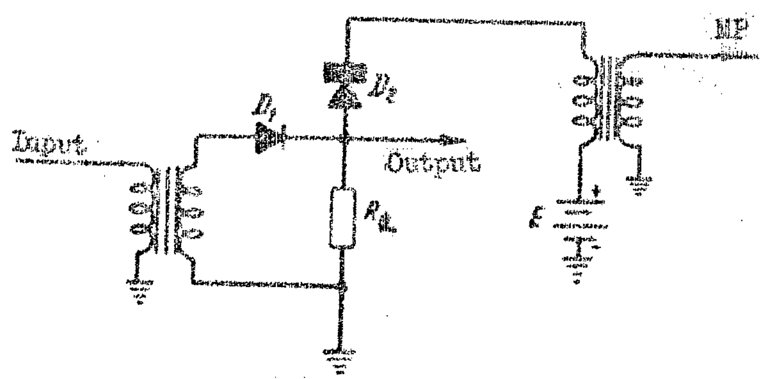



Figure 13. Junction-Diode Amplifier.

some time after the passage of the forward current. During this time and until the termination of the space-charging process, the junction diode has a high reverse conductance. Serving as the power supply source in the diode amplifier the circuit diagram of which is shown in Figure 13, is the generator of the main pulses MP. In the absence of an input signal the diode $D_2$ is off all the time.

In order that the diode not be triggered in the interval between the pulses, it is necessary to transmit the fixed bias E which is equal to the voltage amplitude of the main pulses divided by the ratio of the average pulse spacing to the average pulse duration. The pulse arriving at the amplifier input triggers the diode and forward current begins to flow through it, i.e. there occurs the so-called "ignition". During this, an increased concentration of holes develops in the semiconductor crystal. The high reverse conductance lasts until the concentration of the holes near the p - n junction is reduced to the equilibrium value. This period will be the longer the smaller the current flowing through the diode in reverse direction. If a pulse MP arrives at this time, it passes through the diode and the load $R_L$. The power of the output pulse is determined by the load resistance and by the amplitude of the pulses MP, and the power necessary for "igniting" the diode is not great and is expended on the direct resistance of the point-contact diode $D_1$, the direct resistance of the junction diode $D_2$ and on the internal resistance of the source of the main pulses. The most considerable power losses occur on the internal resistance and therefore it should be as low as possible.

Owing to the existence of a finite time for the space-charging of the holes, a junction diode can serve not only for pulse amplification but also as a memory element and can be used in a dynamic trigger circuit. If a signal from the amplifier output arrives at the input after some delay for the regeneration of the conduction state of the diode, then the pulses MP will be passing through continuously. The result is a trigger with two stable states and characterized by the absence or presence of the pulses on the output (Figure 14). The positive pulse from the amplifier output passes along the line and after being reflected from its open end returns with the same polarity and triggers the diode. The time between this pulse and the MP may be brief. The inconvenience of this circuit is that a comparatively bulky element, such as the delay line, has to be used for its construction.

Dynamic memory elements with junction diodes have so far been little investigated. However, already now it may be stated that they are of great interest owing to their simplicity.

POINT-CONTACT DIODE TRIGGER WITH A NEGATIVE REGION OF THE CHARACTERISTIC. The development of the method for obtaining point-contact diodes with S-type volt-ampere characteristic [30] made it possible to construct simple trigger circuits. Diodes consisting of silver contact springs with an admixture of arsenic and germanium n-type crystals were subjected to electrical forming. This was achieved by the short-duration gating of the current pulses of several amperes until the diode characteristic was transformed into S-type characteristic.

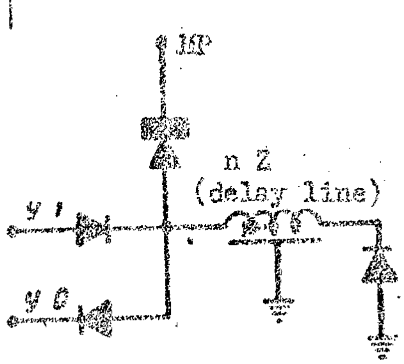



Figure 14. Dynamic trigger with junction diode (delay line is used for the transmission of the feedback signal).

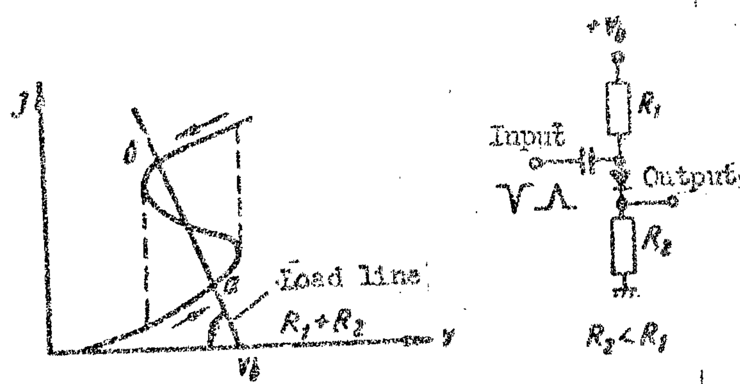



Figure 15. S-type characteristic of a point-contact diode and bistable trigger circuit on it.

Diodes having S-type characteristic may be utilized for the construction of a circuit with two stable states. For this, it is necessary to select properly the voltage $V_b$ and the load resistance R (Figure 15). Corresponding to one of the stable states is point a, and to the other - point b. With such diodes it is possible to design trigger memory cells, logical circuits without signal attenuation, different pulse generators and shapers. These circuits are simpler than the circuits with semiconductor triodes. The frequency of the control pulse train may amount to several megacycles per second, where-as in the circuits with triodes it does not exceed 200-300 kilocycles per second at the present time.

## Designs for the Elements and Subassemblies of a Computer Based on the Use of Dynamic Trigger with Point-Contact Triode.

RECTIFIER. Dynamic trigger with memory capacitor represents a combination of rectifier which is a necessary part of the machine, and of an amplifier. The series-type pulse-potential rectifier (Figure 16) operates on the quantitative principle. Therefore, in order to secure a clear and reliable performance of the rectifier, it is necessary to stabilize the level of the input pulse. The advantage of

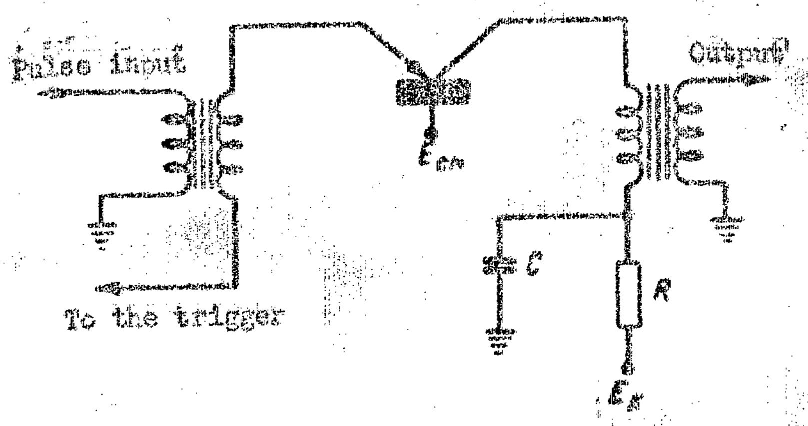



Figure 16. Rectifier on the Point-Contact Triode.

such a rectifier is the availability of the potential control and also that no synchronization of the input pulse is required for this. The rectifiers of a purely pulse type (in the majority of cases the diode rectifiers ) may be utilized in a number of subassemblies where the coincidence of the pulses is easily achieved [31].

In the circuit of a pulse-type parallel diode rectifer shown in Figure 17, the transformers are arranged on the input and the output signal is picked off from the resistor $R_1$. In the absence of signals, the current from the source passes through the resistor $R_1$ and through both diodes $D_1$ and $D_2$. In this case, the potential on the output approaches zero since it is equal to the magnitude of the voltage drop on the direct resistance of the diodes, or approximately 0.5 volts. Upon the arrival of the signal at one of the inputs, the corresponding diode is cut off. However, the potential on the output changes little since the current continues to flow through the second diode. If however, two signals arrive simultaneously, then both diodes are cut off at the same time and the current heads through the resistor $R_1$ into the load resistance $R_L$. The magnitude of false signals in such a rectifier depends on the ratio of the resistance $R_1$ and the transformer impedances. The suppression of false signals is achieved to a considerable degree by the introduction of a small positive voltage $E_3$ through the diode $D_3$.

ADDER. In the computers, the adder is utilized chiefly in the control devices for the addition of the series pulses, code storage for unlimited time and for the presentation of the code on the decoder after every addition of unity. All the digits of the adder can be set at any time at zero. The frequency of the pulse arrival in high-speed computers is very high while the setting process of all digits must be completed in the time less than the period of the pulse series. The more digits in the adder, the more difficult it is to carry out this requirement and therefore the high-speed devices are provided with a rectifier circuit for a through transfer, this circuit assuring a fast passage of the pulse along the adder. With this method of coupling it is possible to dispense with the counter input in the trigger.

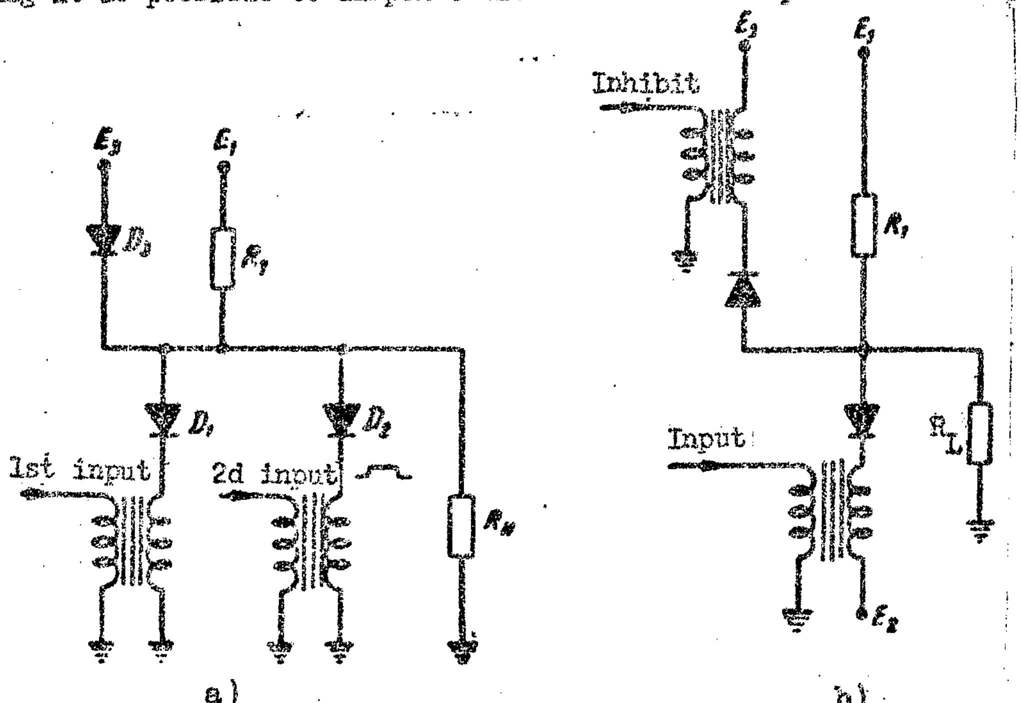



Figure 17. Diode pulse rectifiers:

a - coincidence rectifier; b - non-coincidence(inhibit) rectifier.

An adder with dynamic triggers (Figure 18) is arrangement in the following manner. Located on the input is the pulse synchronizer PS differing from the trigger in that in it a negative feedback is used instead of a positive feedback. A pulse arriving at any arbitrary instant charges the capacitor and creates the conditions for the passage of the first pulse MP which discharges the capacitor through the feedback circuit as the result of which the next pulses MP already do not pass through. The synchronizer is intended for the coincidence of the beginning of addition with the beginning of the pulse arrival MP and for securing thereby the completion of the changeover process before the arrival of the new puls MP.

After the synchronizer, the pulse heads directly to the rectifier of the transfer circuit and also through the delay line DL of the first digit. If there is already unity in the first digit place, then the transfer rectifier $B_1$ is cut in and the pulse passes to the next digit place until it finds a digit place with the zero code on which unity is then set.

A delay in the unity setting circuit is necessary in order that the rectifiers are not cut-in before the input pulse ends, i.e. the magnitude of the delay should be equal approximately to the width of the pulse (0.5 ÷ 0.6 microseconds). In those digit places where there is unity, the zero setting is accomplished by the pulse passing through the rectifier and the delay line in the zero setting circuit. The magnitude of this delay must be greater than the delay in the unity setting circuit by one more pulse width (1 ÷ 1.2 microseconds).

Key to Figure 18; See page 37b

(1) To the 3d digit

$DL_2$ (2)

$DL_1$ (3)

$DL_0$ (4)

Input (5)

MP (6)

2d digit (7)

1st digit (8)

a)

(9) 150 micro-microfarads

(6) MP

(10) 1 kilohm

(11) 470 ohms

(12) 470 ohms

(13) To the 2d digit

$DL_0$ (18)

(19) 470 ohms

(11) 470 ohms

(15) Output

(6) MP

(3) $DL_1$

(16) To the 2d digit

(21) 250 micro-microfarads

(20) 100 kilohms

b)

(17) 430 micro-microfarads

Figure 18. Adder with dynamic triggers:

a - structural diagram; b - the basic circuit diagram of one digit.

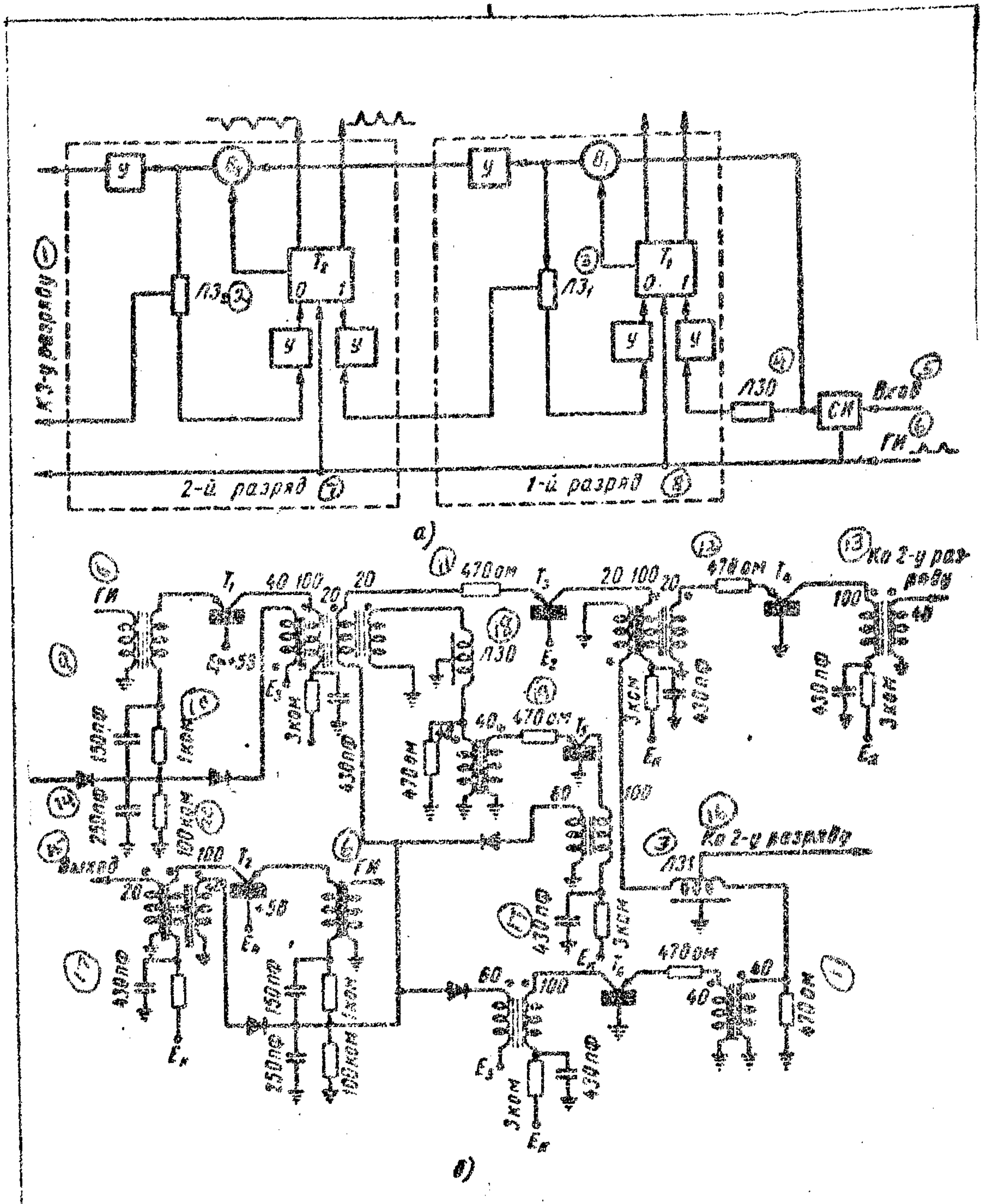

2-й разряд
1-й разряд
СИ
ЛЗ0
Вход
ГИ
a)
470 ом
Ко 2-у разряду
Выход
3 ком
430 пФ
100 ком
150 пФ
250 пФ
б)

Figure 18.

The number of digits in an adder depends on the frequency and the duration of the pulse delay in the rectifier and in the transfer circuit amplifier, the delay comprising about 0.15 microsseconds per cascade.

DECODER. The purpose of the decoder consists of sending the signal to the bus which corresponds to the number set in the adder.

A three-digit binary register can store eight different binary numbers. Corresponding to this, a three-digit decoder (Figure 19) has eight output buses. Each bus is connected by one terminal through the resistor to the source of negative voltage E. A low level of the po-

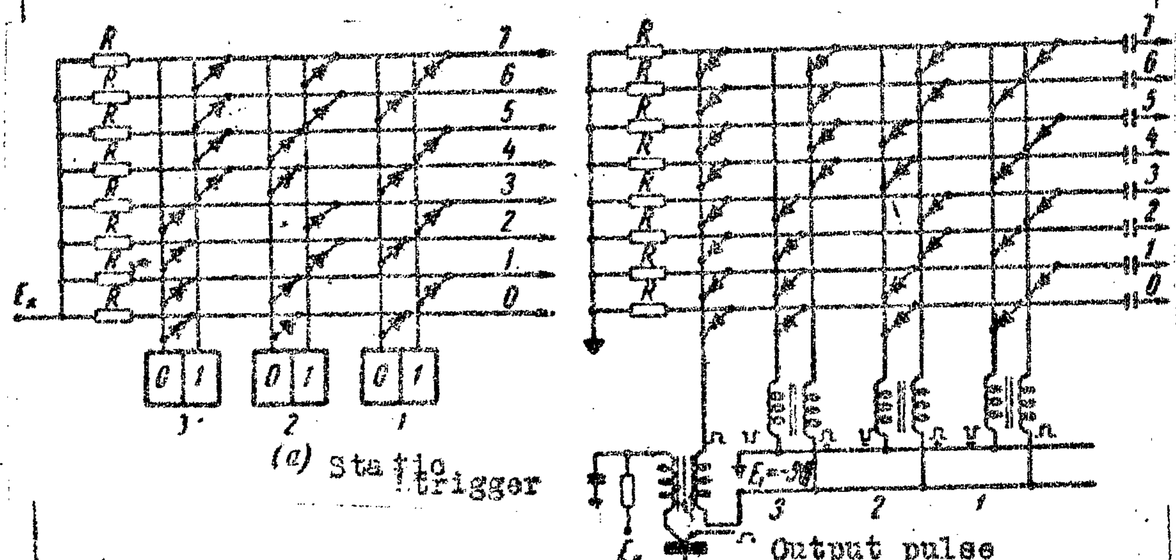



Figure 19. Circuit Decoder

tential on any bus can occur only when all diodes appropriate to a bus are cut off. For example, on bus 5, a low potential will occur when there is unity on the first trigger, zero - on the second and unity -

on the third which corresponds to number 5 in the binary system. During this, the level of the potential will be approaching zero on all of the remaining buses.

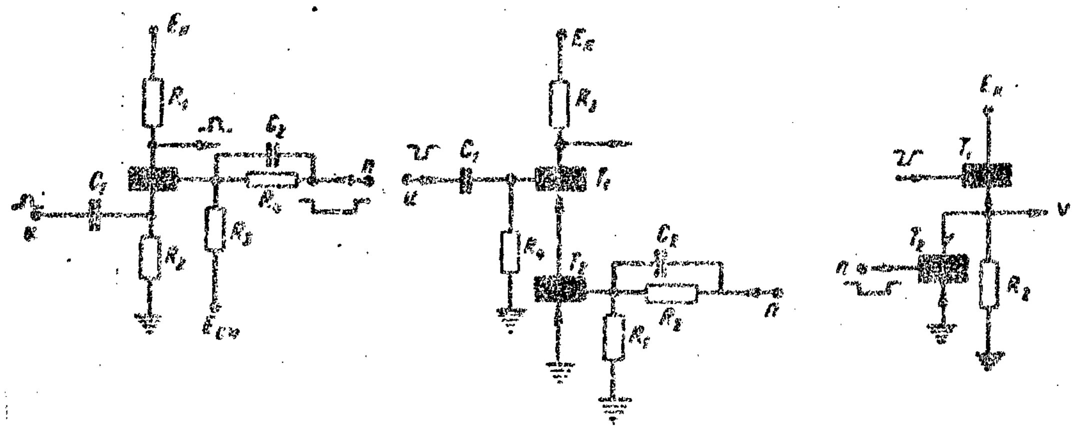
When using dynamic triggers for the decoder control, an output of positive and negative pulses must be secured from each trigger. In this case, the diode matrix consists both of the coincidence rectifiers and the non-coincidence rectifiers. Each bus is connected by the rectifiers to the digits forming the number code. Arriving at these rectifiers are the positive pulses from the transformer coils the lower terminals of which are connected to the negative voltage $E_1$. With all of the remaining digits, this bus is connected by non-coincidence (inhibit) rectifiers.

Upon the arrival of a negative pulse at even only one of these digits, the corresponding diode is triggered which prevents the appearance of a positive pulse on the output. For the selection of the code from the decoder, a pulse is sent through an auxiliary coincidence rectifier to each bus from the synchronous pulse source controlled by the output rectifier.

### Principles of the Construction of the Elements and Subassemblies of a Computer Based on the Use of Static Trigger with Junction Triodes.

POTENTIAL-PULSE RECTIFIERS. When using a static trigger as the basic memory element, utilized in the majority of cases are the potential-pulse-type rectifiers which can be constructed both with the diodes and junction triodes.

The diagram represented in Figure 20 a, shows a rectifier with one triode. The control potential is transmitted to the triode base



a) b) c)

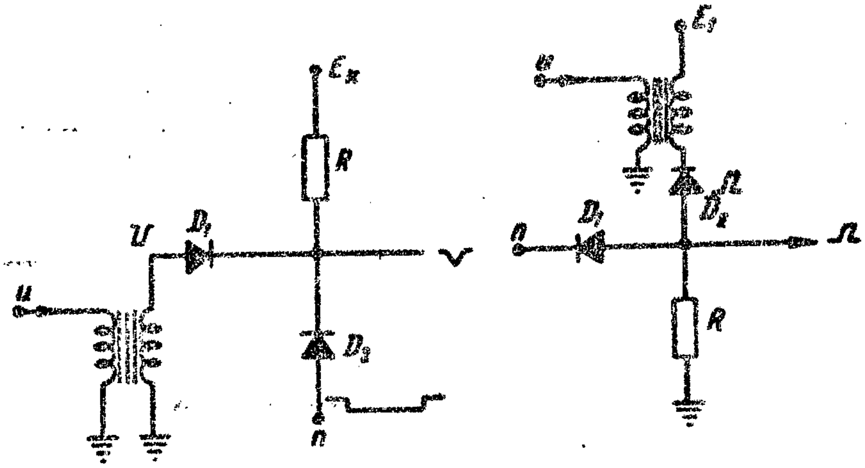
Figure 20. Junction triode rectifiers.

from the trigger arm, the input pulse arrives at the emitter and the output pulse is picked off from the collector load. Such rectifier operates on the quantitative principle which is associated with the necessity for the stabilization of the input signal level. The rectifier represented in the Figure 20 b, operates on the qualitative principle. The signal is delivered on the output only when both triodes are triggered. Such a rectifier may have several inputs and in this case a larger number of triodes are cut into a series circuit.

The drawback of both of these circuits is the large magnitude of the output pulse delay which comprises about 0.5 microseconds. Another drawback is the increase in the pulse width due to the long space-charge time.

The drawbacks mentioned above have been eliminated in the rectifier shown in Figure 20 c. In this case the signal arrives at the emitter repeater which reproduces the pulse almost without distortions. For cutting off the rectifier, the output circuit is short-circuited by another triode. However, this circuit is not free from shortcomings either. If the rectifier is cut off, the signal power is wasted, and the input of the circuit for which the rectifier is operating, proves to be short-circuited to the ground for the signals arriving from the other circuits. The use of one or two triodes for each rectifier is inefficient, especially if there is a large number of rectifiers in the circuit. Therefore, for the majority of circuits it is more expedient to use diode rectifiers which are characterized by simplicity, small magnitude of the delay and a slight distortion of the pulse. Most suitable for work with a static trigger are the parallel diode rectifiers operating on the purely qualitative principle (Figure 21). The potential input of these circuits is connected directly to the collector of the trigger cell triode. When there is zero potential on the trigger control arm, i.e. when the triode is conducting, the rectifier controlled by negative signals is cut off. However, when this triode is cut off, there will be a negative voltage level $E_0$

on its collector, and the appearance of a negative pulse on the pulse input of the rectifier will result in cutting off the second diode and



a)

b)

Figure 21. Diode rectifiers:

a - the circuit is controlled by negative signals;
b - the circuit is controlled by positive signals.

the appearance of a negative signal on the output, the magnitude of this signal being limited by the level $E_0$. Thus, the rectifier shown in Figure 21a, is a load for the conducting triode of the trigger, and the rectifier represented in Figure 21 B, forms a load for the cut-off triode of the trigger.

The advantage of the rectifiers considered, is that their output can be connected directly to the base of the amplifier or of the emitter repeater. A small negative bias of about 0.5-1 volts should be applied to the emitter for the elimination of false signals. The drawback of the diode rectifiers is the low power on the output which causes the necessity for the amplifying cascade.

ADDER. Used in the adder circuit shown in Figure 22 is the counting input of a trigger with the starting by positive pulses. In addition to the trigger, there are in every digit place two amplifiers which shape the pulse for starting the trigger and also a diode rectifier and emitter repeater E in the through-transfer circuit which secure the maximum high-speed operation of the adder. Distorting the pulse negligibly, the emitter repeater makes it possible to obtain a sufficient power amplification to compensate for the losses in the rectifier and for the transmission of the signal to the starting circuit. The necessary delay due to the pulse width in the starting circuit is the result of natural delay in two amplification cascades.

For starting the trigger it is necessary to send a positive pulse having a voltage of 1.5-2 volts and the width of which should not exceed 0.5 microseconds. If the width should be greater, then owing to the presence of diodes in the starting circuit the undesirable direct current will appear which disturbs the conditions of trigger operation at high frequencies. It is impossible to obtain a pulse of such duration and stable amplitude directly from the amplifier on a junction triode because of the poor frequency properties of the existing triodes and because of the large spread of the magnitude $\alpha'$.

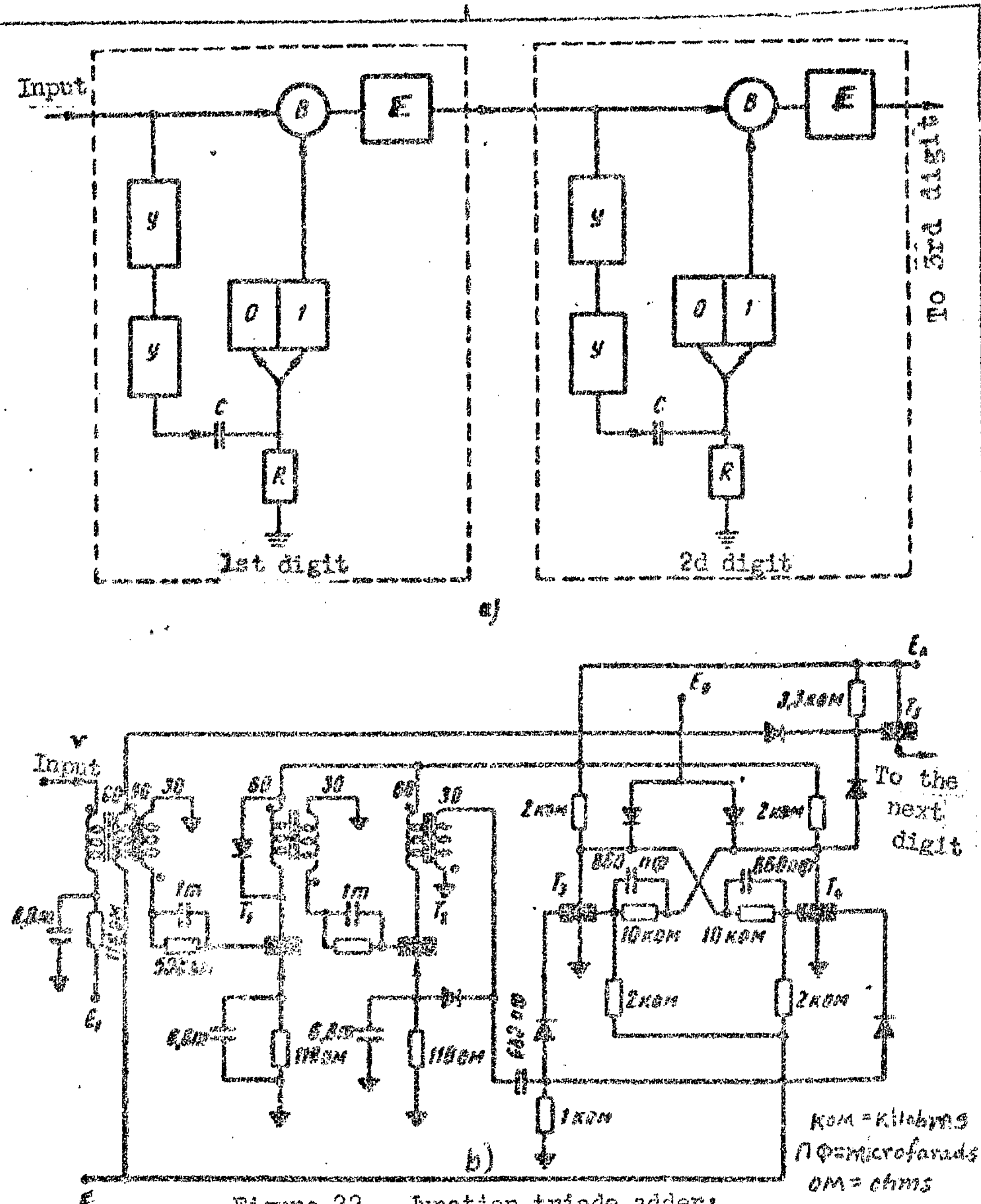



Figure 22. Junction triode adder:

a) structural diagram of the adder; b – basic circuit diagram of one digit.

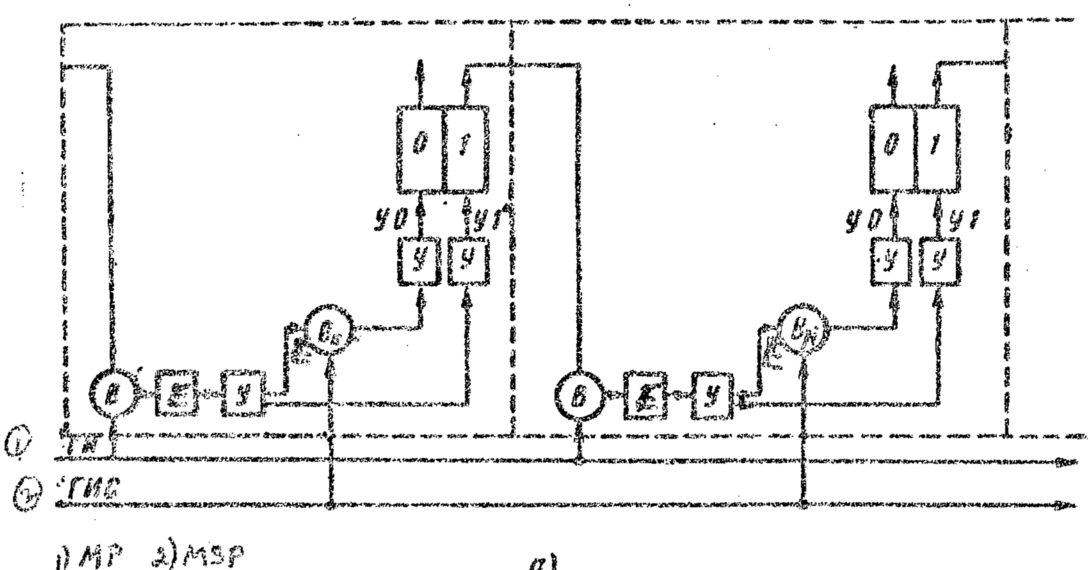
Therefore, a rectangular pulse with steep fronts forms on the output of the second amplification cascade. The pulse required for starting is formed by means of the differentiation of the forward front which is approximately the same for different triodes. By this method, the dependence of the circuit operation on the spread of the triode parameters is eliminated to a considerable degree. Placed in the emitter circuit of all amplifier triodes are resistors of 110 ohms intended for the prevention of accidental build-up of the collector current which may cause a breakdown. In order to eliminate the passage of false signals in the transfer rectifier, a negative bias $E_1$ of about 1 volt is applied to the emitter of the repeater $T_5$. The positive bias of the base in the trigger comprises 0.1 ÷ 0.35 volts depending on the magnitude of the starting pulse and the general conditions of the power supply. For the triode P 1 E $E_k = -12$ volts; $E_o = -5$ volts; $E_1 = -1$ volt; $E_2 = +0.25$ volts. These conditions may vary within a very wide range with corresponding changes in all voltages.

The maximum frequency of the circuit operation depends on the type of the triodes used. When using triodes P 1 E and P 1 I, the operating frequency of the adder comprises 250 ÷ 30 kilocycles per second and the number of the cascades amounts to 6-8. At the same time the delay of the signal in the transfer link does not exceed 1-1.5 microseconds for the entire circuit. Basically, the operating rate is limited by the duration of the rear front in the trigger proper. The use of higher-quality triodes, for example P6G makes it possible to raise the frequency to 500 kilocycles per second.

SHIFT REGISTER. Arising frequently in the arithmetic device of a computer is the necessity of shifting a number by one or several digit places to the right or to the left. This operation is performed with the aid of a special shifting circuit (Figure 23).

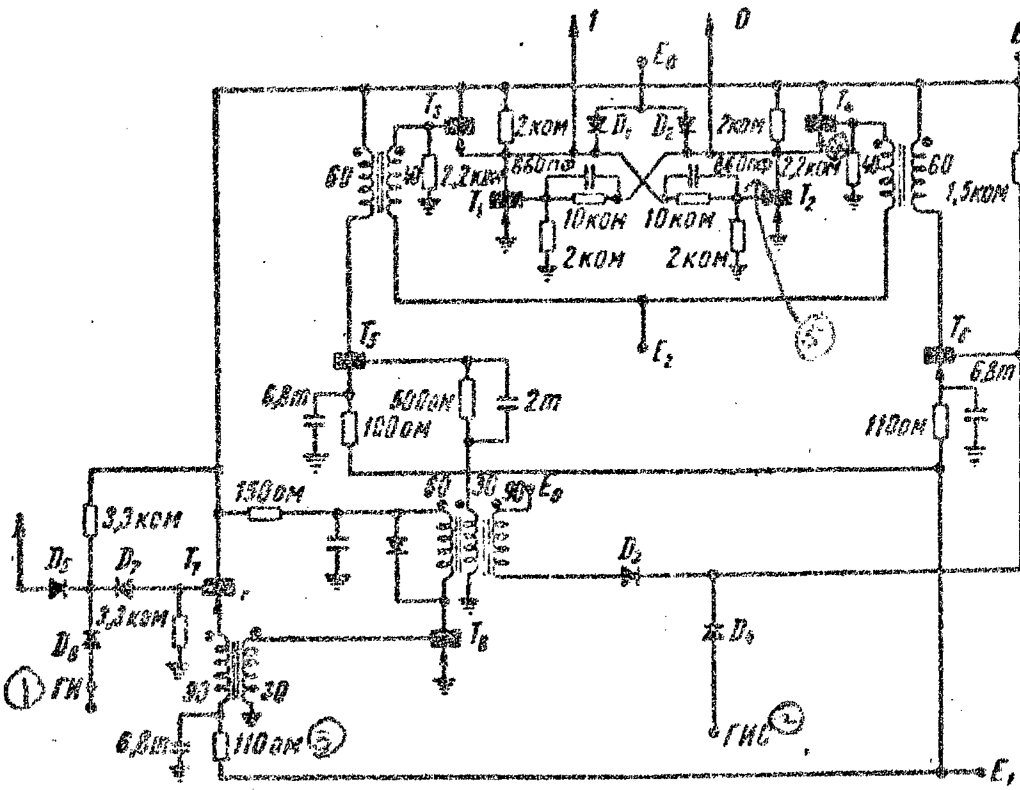
The main pulse of the shift is applied to the rectifier B in the unity setting circuit of each digit. This rectifier is controlled from output 1 of the adjacent digit. If unity is standing in the adjoining digit place, then the rectifier is cut in and the shift pulse sets unity in a given digit place irrespective of the preceding code. The main shift pulse MSP is sent through the non-coincidence rectifier $B_n$ to the zero setting circuit with a slight delay relative to the main shift pulse MP. Arriving at the inhibit input of the rectifier $B_n$ is the pulse from the unity setting circuit. In this case the pulse does not pass through into the zero setting circuit. If however, zero is set in the adjoining digit place, then the pulse does not enter the unity setting circuit, the rectifier $B_n$ will be cut in, and the pulse MPS will set zero in this digit place. The delay of the pulses MSP relative to MP must be equal to the delay in the amplifier circuit of the pulse arriving at the inhibit input of $B_n$ and comprises 0.3-0.4 microseconds.

No preliminary setting of the digits into zero position is required in this circuit, and the shift accomplished in the period of a tipping-over of the triggers. This is of substantial value for raising the rate of the operation, especially in the case of circuits based on junction triodes. The necessity for the presence of amplifiers in the zero-setting and unity-setting circuits is explained by the accelerated starting of the triggers which requires considerable signal power. The signal arriving at the inhibit rectifier also requires amplification. Emitter repeater E and an amplifier are used for this purpose.




a)

Figure 23 a.



b)

1)MP 2)MSP 3)ohms 4)kilohms 5)micromicrofarads

Figure 23. Shift register:

a - structural diagram; b - the basic circuit diagram of one digit.

## Direct-Coupled Circuits.

Based on the utilization of direct couplings, there can be constructed a large number of circuits which may be used in the building of all the principal subassemblies of a computer. These circuits

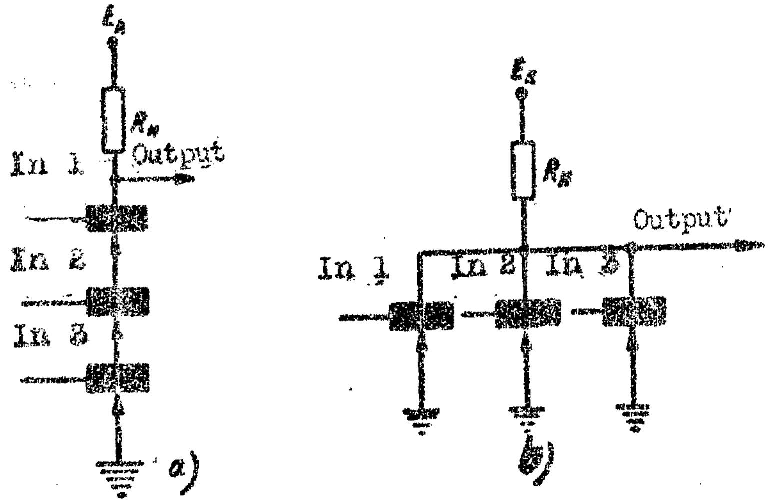



Figure 24. Circuits based on direct-coupled triodes.

a - circuit AND; b - circuit OR

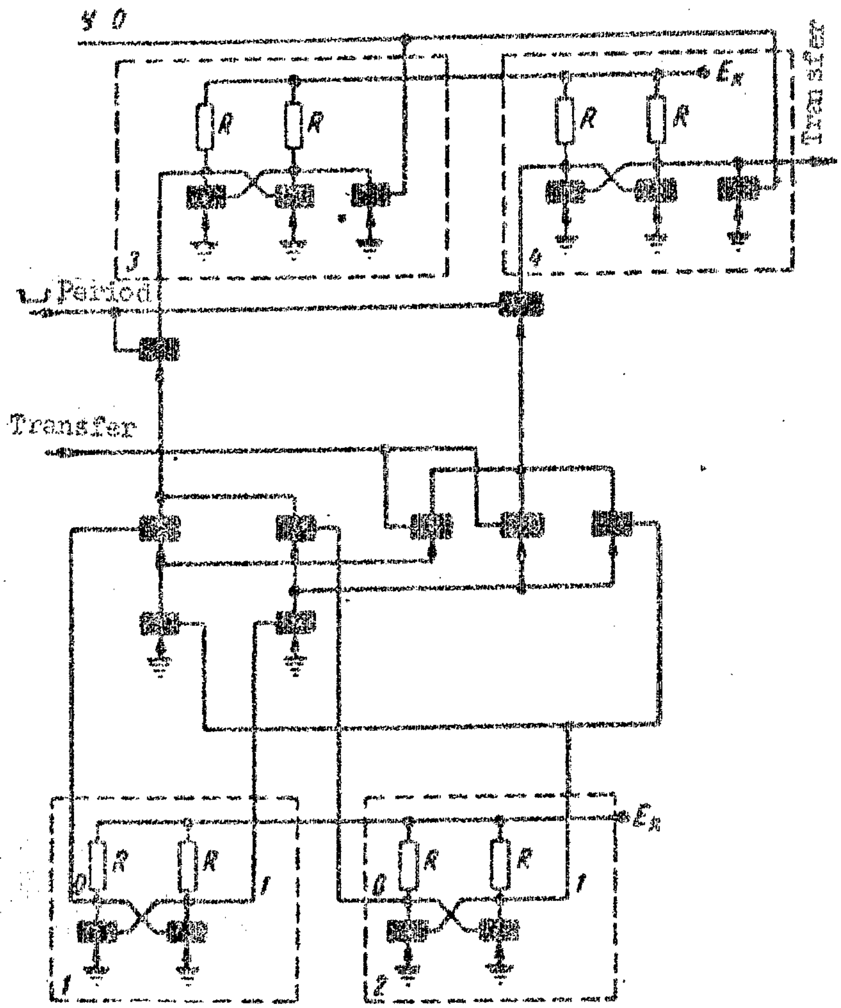



Figure 25. Direct-coupled triode half adder.

are extremely simple and therefore hold large promise in the computer technique. The advantages of the direct-coupled circuits can be realized to full extent only through the use of surface-barrier triodes possessing good frequency properties and which are most suitable for the construction of such circuits by parameters.

Serving as the basic elements for the creation of direct-coupled logical circuits are circuits AND or OR (Figure 24). Circuit AND emits a signal only if there is a negative potential on all of its inputs (in this case on three inputs). During this, all the triodes are triggered, and the potential on the output (the magnitude of this potential being equal to the sum of residual voltages on the triodes cut-in in the link) approaches zero. This potential must be sufficient for the cutoff of the other triode connected to the circuit AND.

If the control is accomplished from the triggers, then up to five triodes can be connected to such a chain.

The circuit OR is designed for the division of circuits operating for a single load. The signal will appear on the output if there will be a negative potential even on only one input.

In Figure 25 is represented the diagram of one digit of a half-adder, this diagram illustrating the use of the circuits AND and OR in the combination of one with the other. Stored in the trigger cells 1 and 2 are the codes of the first and second numbers. Upon sending a periodic pulse, a partial sum is set in cell 3 and in cell 4 - the transfer code to the next digit.

In the sum cell, unity is set only in the combination of 0 and 1 or 1 and 0. In the transfer cell, unity is set in the combination of 1 and 1.

The output of the logical circuit has the load resistance in common with the trigger triode and the changeover of the trigger occurs as the result of grounding the collector of this triode through some branch of the circuit.

* *
*

Up to the present time there is no ultimate principle for the design of semiconductor circuits of digital computers. This is explained first of all by the imperfection of the existing crystal devices and by the insufficient accumulated experience. With every day the semiconductor devices are being improved. This applies especially to the junction triodes. Recently there have appeared the surface-barrier, diffusion, silicon, pnip-type and other triodes, tetrodes, indium-coated and silicon diodes, and also diodes with the descending regions of volt-ampere characteristics.

The adoption and mass production of high-quality semiconductor devices have at the present time a particularly importance significance for the development of computer technique.

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