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THE HIGHLY STABLE DIODE 4Ts1M IN AUTOMATIC AND REGULATING CIRCUITS

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/Figures are appended_7

The 4Ts1M electron tube produced by Soviet industry can be used extensively in various regulators and automatic circuits. Many devices and instruments can be improved through its use. Some of these instruments are described below.

The 4Ts1M tube is an ordinary diode with a wolfram cathode.

The parameters of the tube are as follows: filament voltage, 4v; filament current, 1.6-1.9 amp; plate current, 10 ma; saturation transconductance, 0.03 ma/v; plate voltage, 250 v; life, 3,000 hr.

The wolfram cathode gives stable emission and a pronounced saturation effect. Emission current is roughly proportional to the seventh power of the filament voltage. These features make the tube very useful for the measuring devices of various voltage and current regulators and also for relays.

Its long life, which is even longer when the tube operates in normal circuits where the filament is underheated, makes it very reliable. Its drawbacks are the relatively high time constant (due to the thick filament, which prolongs the life) and the relatively high filament current, which limits its use in low-power dc circuits. The tube must be preaged for 24 hr under rated conditions before putting it into service to obtain absolutely constant emission because the wolfram filament contains some traces of thorium immediately after manufacture which are evaporated in preaging.

A number of circuits utilizing the 4Ts1M diode are described below.

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Measuring Element in AC Voltage Regulators

The schematic diagram of a measuring element for ac voltage regulators is shown in Figure 1. Line resistors are connected into three bridge arms; the 4Ts1M diode, the filament of which is supplied from the voltage to be regulated, is used as the fourth arm. The bridge is supplied by dc voltage. When a certain voltage is applied to the diode filament, its internal resistance will be equal to the line resistors and the voltage in the bridge diagonal will be zero. When the voltage applied to the diode filament fluctuates, dc voltage appears at the bridge output, the polarity of which is determined by the direction of fluctuation of the filament voltage with respect to the filament voltage corresponding to bridge balance.

Figure 2 shows the response of the measuring bridge. Since the diode operates at saturation, this measuring element is characterized by considerable variations of the voltage in the diagonal when the filament voltage fluctuates with respect to bridge-balance voltage.

When the bridge is supplied from a secondary source, the voltage corresponding to bridge balance will to some extent depend on voltage fluctuations from this source even when the filament (line) voltage remains constant because of nonlinearity of the bridge element.

When the bridge is supplied by rectified line voltage, this additional parameter affecting the operation of the measuring element is eliminated, and the circuit of the measuring element takes the form shown in Figure 3. The voltage to be regulated is rectified using a voltage-doubler circuit. The 4Ts1M diode filament is supplied from a special transformer whose primary is connected to the line (regulated) voltage through a rheostat; the rheostat is used to change the voltage corresponding to bridge balance. To regulate voltages of about 220 v, the rectifying part is reconnected into the ordinary half-wave rectification circuit; the primary winding of the transformer T1 is also reconnected. When the measuring element is supplied from the line, the output voltage drops to zero when the line voltage drops to zero.

When the filament voltage increases considerably, while the bridge resistors remain the same, the diode operates in the linear part of the curve (Figure 2) and the voltage in the diagonal will be proportional to the plate voltage.

The measuring element circuit described is very stable. The balance voltage fluctuates about 2% during initial heating of the measuring element (~0.5 hr) and then remains practically constant. Ambient temperature changes have almost no effect on the diode characteristics. For example, for an ambient temperature change from minus 15 to plus 90 deg C, no voltage variation was observed in the measuring element's balance. The current drawn by the measuring element is ~0.07 amp at 220 v and ~0.15 amp at 120 v.

Since the voltage variation at the measuring element output is determined mainly by changes in filament temperature, which, in turn, is determined by the effective value of the filament current, it is really the effective value which is regulated by this measuring element.

Inertia is the greatest drawback of the measuring element. Its time constant is about 0.08-0.1 sec.

A graphical method of calculating a measuring element with a 4Ts1M diode is appended. This method with modifications can be extended to the other circuits listed which make use of this diode.

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Measuring Element for dc Voltage Regulators

Figure 4 gives a simple measuring element circuit for dc voltage regulators. In this case, use of the 4TsIM diode is recommended only in regulators designed for generators with relatively low rated voltage and high currents. For 110 and 220 v generators there will be considerable power loss in the resistors R_2 and R_3 because of the high 4TsIM filament current. Therefore, the measuring element circuit shown in Figure 4 should be used for generators with rated voltages of 24 and 48 v.

The amplification of the measuring element in Figure 4 at the operating point of the characteristic is ~5 v per 1 v change at the input. Sometimes this may prove insufficient to ensure the desired accuracy in the operation of the regular as a whole. If so, a measuring element circuit with an additional tube, as shown in Figure 5, can be used. The amplification for this measuring element is 70 v per 1 v change at the input.

The left half of the tube L_2 operates as a cathode follower. The cathode potential (point b) follows the potential of point a. The right half operates as an ordinary amplifier. The plate circuit resistance R_2 must be considerably larger than the cathode resistance R_3 to avoid a considerable decrease in the amplification factor because of negative feedback.

Measuring Element for an Amplidyne Voltage Regulator

An amplidyne may be employed as a control element of a voltage regulator for large ac generators. It can either be used as an auxiliary exciter or can be connected in series with the exciter winding to increase reliability of operation. In the latter case, the exciter current corresponding to the nominal operation of the generator is provided by self-excitation. Figure 6 shows a schematic diagram of a measuring element with a 4TsIM diode for an amplidyne voltage regulator.

For small changes of the regulated voltages, the plate current in the left half of the tube L_2 varies greatly. This current flows through one of the control windings of the amplidyne. The current in the second control winding flows in the opposite direction and is proportional to the regulated voltage. Figure 7 shows the current variations in the control windings with respect to variations in the regulated voltage.

In Soviet-produced amplidynes, the rated voltage (at rated power) is supplied when the difference in the control winding currents is ~8 ma.

The advantage of amplidyne voltage regulators is the possibility they offer for operating a generator with a very low or even negative exciting current. This is very important for synchronous condensers or generators operating on long lines.

Vibrating Voltage Regulators for Low-Voltage DC Generators

A 4TsIM diode in a vibrating voltage regulator circuit may be very advantageous as compared with the ordinary type of regulator. As is known, an electromagnetic relay acts as a measuring element in the ordinary types of vibrating regulators for low-voltage dc generators. Therefore, such regulators cannot maintain a sufficiently stable voltage. Their operation is seriously affected by temperature variations, changes in the distance between relay contacts, and by the drop-out lag factor /presumably based upon ratio of drop-out to pick-up currents through relay coil/.

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Use of a 4TslM diode in a vibrating regulator system can greatly improve its operation. Figure 8 shows the regulator circuit. One of the windings of a sensitive polarized relay ($R = 13,000$ ohms, pick-up current 0.1 ma) is connected in the plate of the 4TslM. The relationship between the relay winding current and the voltage at the regulator input is shown in Figure 9, curve 1. The current in relay winding II is directed so that its mmf opposes the mmf in winding I. The current flowing through this winding is shown by the straight line 2 in Figure 9. The slope of this straight line with respect to the abscissa is determined by the resistance R_2.

The contacts of the polarized relay R_1 are closed and opened at voltage changes of ± 0.17 v ($\pm 0.7\%$) with respect to the voltage corresponding to the point O.

The contacts of relay P_1 close the circuit of the fast-acting relay P_2, the contacts of which alternately shunt and insert resistance in the exciter circuit of the generator.

The polarized relay P_1 has another winding III, which is connected, in series with the capacitor C_1, across the line. This winding provides flexible feedback and increases the vibration frequency, thus decreasing the fluctuations of the regulated voltage. For a 1.5 kw, 24 v generator, the vibration frequency is $\sim$15 cps with the regulator parameters specified. In an additional 6N7 tube is introduced, as in the circuit of Figure 5, satisfactory regulator operation can be obtained with a much less sensitive polarized relay. A similar circuit can be used to regulate the voltage of an ac generator with an exciter voltage of 24 v. In this case the 4TslM filament voltage is taken from the generator voltage through a transformer.

AC Voltage Relay With a High Drop-Out Lag Factor

Many protective and automatic circuits require ac voltage relays with a high drop-out lag factor. Voltage relays used in many protective circuits have drop-out lag factors on only 0.85-0.9.

Use of the 4TslM makes it possible to obtain a voltage relay with a considerably higher drop-out lag factor (0.97-0.98) than ordinary electromagnetic relays.

An ac voltage relay circuit is shown in Figure 10. Like the previous circuits, the left half of tube L_2 operates as a cathode follower and the right half as an amplifier. A code relay coil (coil wound with 45,000 turns of PE wire, $d = 0.08$ mm, $R = 10,000$ ohms) is connected in the plate circuit of the right half of L_2. The rectifying section is the same as that used for the ac measuring element. A standard code relay with a rewound coil and improved insulation of the working contacts was used. Depending on the contacts used, a minimum or maximum voltage relay can be obtained. The drop-out lag factor is $\sim$0.975; it can be varied by adjusting the sliding contact of the potentiometer R_4. This makes it possible to regulate the amplitude of the plate current changes for a given ac voltage change. The voltage at which the relay operates can be regulated by a rheostat ($R_1 = 300$ ohms); the rheostat permits one to regulate the operating voltage between $\sim$95 and 135 v for 120 v and between 190 and 210 v for 220 v. The relay draws ac power of $\sim$20 va. The oscillogram shown in Figure 11 demonstrates the fast action of the relay. The oscillogram corresponds to the time required for relay operation for an instantaneous change in the voltage at the terminals of from 90 to 110 percent (and vice versa) of the operating voltage.

Two-way Electronic Voltage Relay

Many circuits for automatic regulation (for example, in rough voltage regulation with the help of an autotransformer) and relay protection require a two-way ac voltage relay. One pair of contacts in this type of relay closes when the voltage applied to the relay measuring device increases to a certain value. When the voltage drops, this pair opens and the other pair closes. The alternate closing of the pairs of contacts takes place at voltage fluctuations of $\pm$ 1.5-2% of the specified value

Figure 12 shows the schematic diagram of an electronic two-way ac relay which differs from the one discussed in the preceding section in that the plate current of the right half of the tube L_2 flows across the two coils of the two relays P_1 and P_2. Code relays with rewound coils were also used here. Each relay has two windings: the main winding has 45,000 turns of PE wire, d= 0.07 mm, R = 12,000 ohms, and the auxiliary winding has 15,000 turns, of PE and d = 0.08 mm

With these parameters and two pairs of contacts, each relay operates when the current in the main winding is 4.8 ma and drops out when the current is 1.8-2.2 ma. The current i_2 flows through the auxiliary winding of the relay P_2 in a direction such that its mmf opposes the mmf created by the current i_1 in the main winding.

The value of the current i_2 is set, using the resistor R_5, so that the mmf created by it is greater than that required for relay operation. In general, the auxiliary winding is not used. The relationship between the plate current of tube L_2 (right half) and input voltage fluctuations (for 120 v) is shown in Figure 8. As in the previous case, the slope of this curve and thus the relay's insensitive zone depends upon the position of the sliding contact of the potentiometer R_4 (curves II and III). When the voltage is less than 119.7 v (for the characteristic curve I), the mmf created by the current i_1 is sufficient to seat the P_2 armature. When the voltage rises above 120.8 v, the current i_1, flowing opposite to i_2 and determined by curve 1, increases so greatly that the resulting mmf becomes less than the mmf corresponding to release of the P_2 armature and, consequently, the P_2 contacts are opened. When the voltage rises to 121.1 v, the current i_1 becomes strong enough for relay P_1 to operate. For a considerable increase in voltage, the mmf in P_2 may be reversed in sign but it cannot reach a magnitude sufficient for P_2 to operate again, since the upper part of the curve in Figure 13 is almost parallel to the abscissa.

When the voltage drops to 120.1 v, the current i_1 decreases so greatly that the armature of relay P_1 drops out. If the voltage drops to 119.7 v, the resultant mmf of P_2 becomes sufficient for it to operate and its contacts close. This is the manner in which a two-way relay operates. The voltage fluctuation corresponding to closing of the P_1 and P_2 contacts is equal to $\Delta U = 121.1 - 119.7 = 1.4$ v or approximately 1.2%.

As mentioned above, the insensitive zone depends upon the position of the sliding contact of the potentiometer R_4. The oscillogram in Figure 14 shows the high-speed operation of the relay. The oscillogram shows the time required for the relay contacts to switch-over for an instantaneous $\pm$10% variation of the normal relay voltage.

The relay is mounted in a cover from an EP 231 control relay and can be used for 110 or 220 v. The power drawn is ~25 va.

AC Voltmeter With an Expanded Scale

Whenever it is important to observe relatively small voltage deviations from a definite value, it is very desirable to use instruments with an expanded scale in the given range. An incandescent lamp connected in series with the instrument is sometimes used for this purpose. The 4Ts1M diode makes it comparatively simple to obtain such an instrument using an ordinary dc instrument for this purpose.

Figure 15 shows the circuit for this instrument. Additional parts are arranged behind the instrument so that the overall size is only slightly increased. An ac ammeter can be constructed on the same principles.

APPENDIX. GRAPHICAL METHOD OF CALCULATING A BRIDGE WITH A 4Ts1M DIODE

Figure 16 shows the va characteristic curve of the 4Ts1M for several filament voltage values.

Let us first consider the case corresponding to a constant bridge supply voltage. Let the line resistances in the bridge arms be equal; for a variation from U_f^o to $U_f^o + \Delta U_f$ in the filament voltage, a voltage of ΔU_1 will appear in the bridge diagonal (Figure 17). The straight line iR is drawn from the point corresponding to the supply voltage and ctg α is numerically equal to the plate resistance.

Figure 18 shows an expanded view of these characteristic curves. The voltampere characteristics are idealized and drawn parallel to the x-axis through the points where the real va characteristics cross a vertical line drawn through the point U_{a_2}. Thus, it is assumed that the ac plate resistance of the diode operating under saturation conditions is infinite. When the filament voltage changes by ΔU_f and there is no output load, the voltage on the bridge output ΔU_f will be equal to the segment ab (Figure 18) or

$$\Delta U_1 = ab = ac \cdot ctg\, \alpha = \Delta i_a \cdot R,$$

where R is the plate resistance. For a 1% change in the filament voltage, the voltage at the output of the measuring element will be

$$\mu_{01} = \frac{\Delta U_1}{\frac{\Delta U_f}{\Delta U_f^o} \cdot 100} = 0.01 \frac{\Delta i_a}{\Delta U_f} \cdot U_f \cdot R$$

or, passing to the limit,

$$\mu_{01} = 0.01 \cdot U_f^o \cdot R \frac{\partial i_a}{\partial U_f},$$

where U_f^o is the filament voltage for which the bridge is balanced.

In the actual circuit, the bridge supply voltage also varies simultaneously with the filament voltage; for a small filament voltage change with respect to the balance voltage, this relationship will be linear. Consequently, when changing to a new voltampere characteristic, corresponding to another filament voltage, the straight line 1' of load resistance will be drawn parallel to line 1 from the point corresponding to the new supply voltage. According to Figure 18, the voltage at the measuring element output ΔU_2 will equal:

$$\Delta U_2 = \Delta U_1 - \overline{cm} + \overline{oo'},$$

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where CO^1 is the change of the balance potential equaling $\frac{\Delta U_a}{2}$,

$$\Delta U_2 = \Delta U_1 - \Delta U_a + \frac{\Delta U_a}{2} = \Delta U_1 - \frac{\Delta U_a}{2} .$$

The voltage in the diagonal for a 1% voltage variation at the measuring element input in this case will equal

$$\mu_{02} = \mu_{01} - \frac{\Delta U_a}{2 - \frac{\Delta U_f}{U_f} \cdot 100} ,$$

but since

$$\frac{\Delta U_f}{U_f^\circ} = \frac{\Delta U_a}{U_a} ,$$

then

$$\mu_{02} = \mu_{01} - \frac{U_a}{200} .$$

Hence, the voltage at the measuring element output is less than it would be if the bridge were supplied from an independent source.

Let us also consider the influence of the ac plate resistance of the tube: r_i = arc ctn β.

Figure 18 shows the case of independent bridge supply, where the triangle cde is shown in the upper right-hand corner on an enlarged scale. It is obvious that

$$\Delta U_3 = \Delta U_1 - h .$$

in the triangle cde:

$$m = h \tan \alpha$$
$$n = h \tan \beta$$
$$m + n = h(\tan \alpha + \tan \beta)$$

On the other hand,

$$m + n = \Delta U_1 \cdot \tan \beta ,$$
$$h = U_1 \frac{\cot \alpha}{\cot \alpha + \cot \beta} = \Delta U_1 \frac{R}{R + r_i} ,$$
$$U_3 = \Delta U_1 \frac{1}{1 + \frac{R}{r_i}}$$

The voltage at the measuring bridge output for a filament voltage variation of 1% with respect to bridge balance voltage is:

$$\mu_{03} = \mu_{01} \frac{1}{1 + \frac{R}{r_i}} ,$$

that is, the ac plate resistance of the tube accounts for the decrease in voltage at the measuring element output. After taking all factors into consideration, the relative voltage at the measuring element output equals:

$$\mu_0 = 0.01 \cdot U_f^\circ \cdot R \frac{\partial i_a}{\partial U_f} \left(\frac{1}{1 + \frac{R}{r_i}} \right) - \frac{U_a}{200} .$$

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The curve $i_a = f(U_n)$ in Figure 19 was constructed to determine the most advantageous diode filament voltage for bridge balance, and, consequently, the resistance in the bridge arms.

In plotting this curve (from the curves in Figure 16), the ac plate resistance of the diode was assumed to be infinite, that is, the sloping lines were replaced by horizontal lines drawn through the points where the real characteristic cross the vertical line corresponding to a voltage $\frac{V_a}{2}$ ($V_a = 200$v).

Figure 19 also shows the dependence of the line resistances R_M in the bridge arms upon the voltage corresponding to bridge balance provided that the resistance in the arms of the bridge are equal. This curve permits one to determine the values of the resistances R_M which should be used in the bridge arms to balance the bridge for various filament voltages of the 4Ts1M diode.

Figure 19 also shows the curve $\frac{\partial i_a}{\partial U_f}$ and the curves for μ_{01} and μ_{02}. The dependence of ac plate resistance variations upon filament voltage must be known to plot the curve for μ_{03}. This relationship is shown in Figure 20. This figure also shows $1 - \frac{R}{r_i}$ as a function of U_f. The curve for μ_{03} has a maximum corresponding to the diode filament voltage at balance of $U_f \approx 3.4$ v and resistances $R_M = 45$ kilohms in the bridge arms. In reality, the bridge arms are 50 kilohms each. For this resistance value, μ_{03} is ~11.5 v/%. When the bridge is loaded, the amplification factor decreases. It can be approximately assumed that

$$\mu_{no\text{-}load} = \mu_0 \frac{R}{R + r_e},$$

where r_e is the equivalent bridge resistance across the terminals of the diagonal.

[Appended figures follow.]

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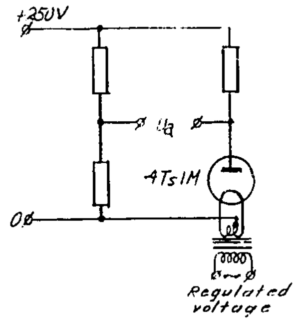

Figure 1

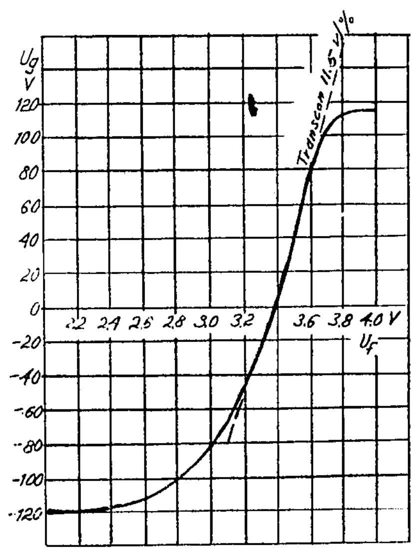

Figure 2

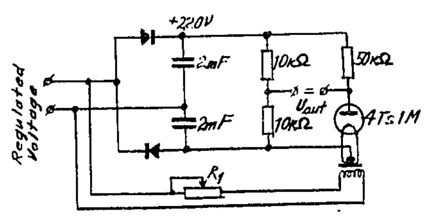

Figure 3

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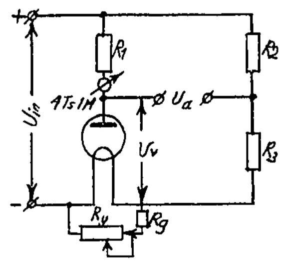

Figure 4

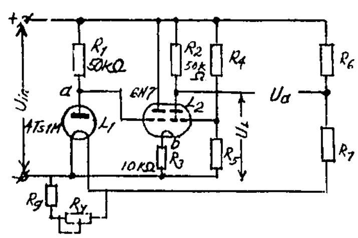

Figure 5

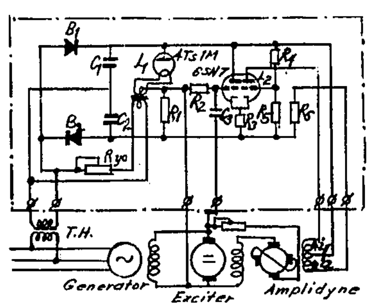

Figure 6

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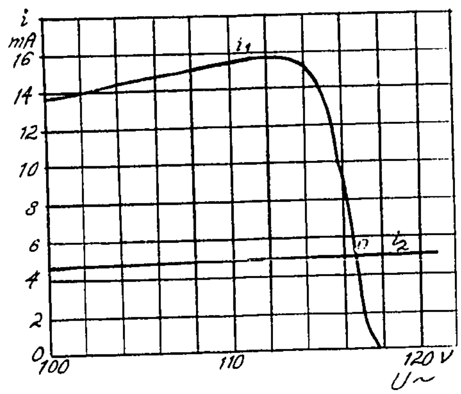

Figure 7

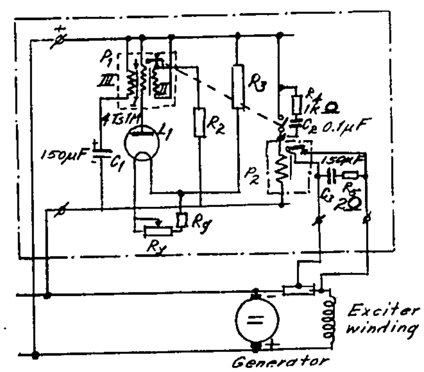

Figure 8

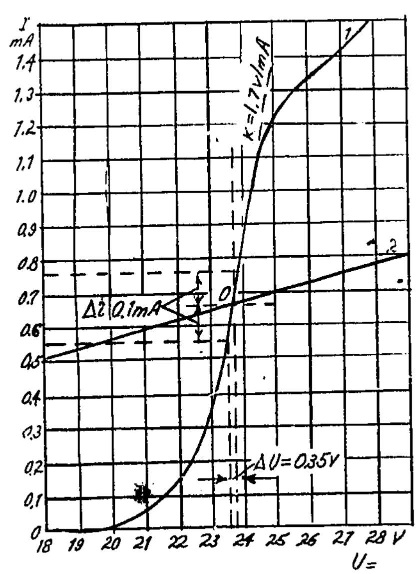

Figure 9

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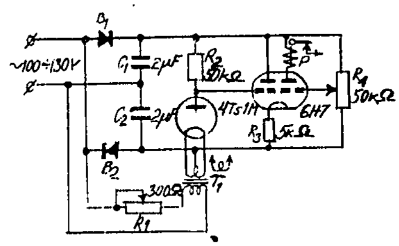

Figure 10

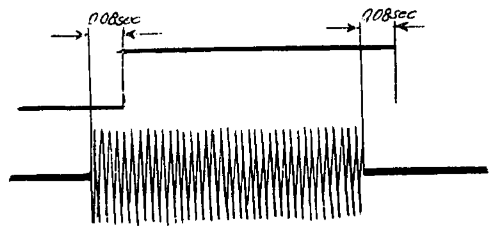

Figure 11

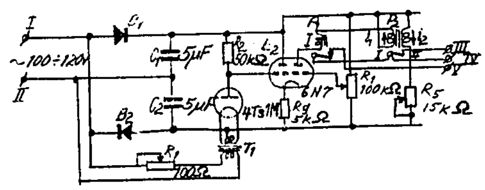

Figure 12

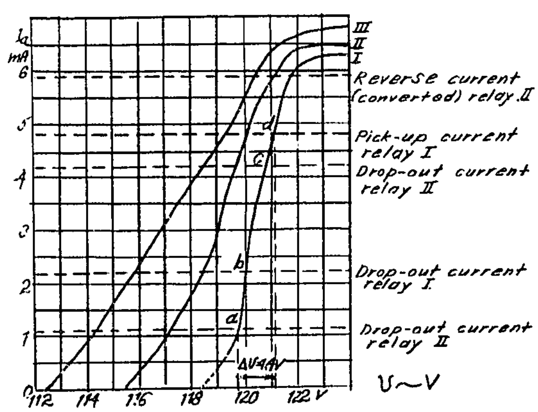

Figure 13

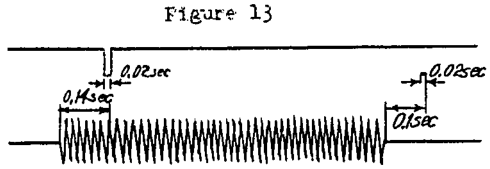

Figure 14

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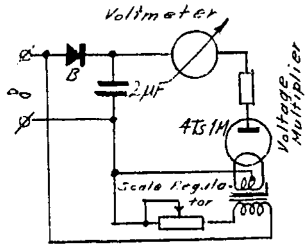

Figure 15

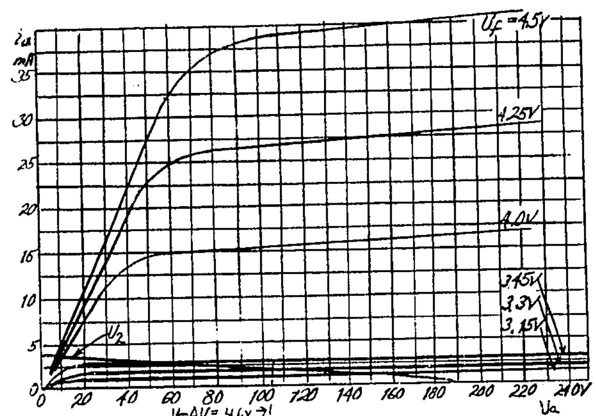

Figure 16

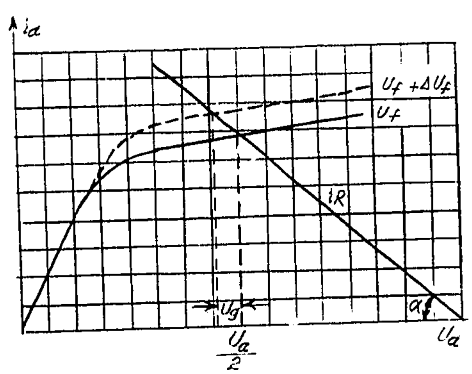

Figure 17

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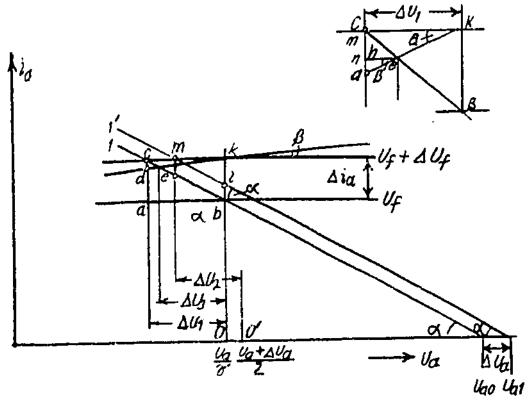

Figure 18

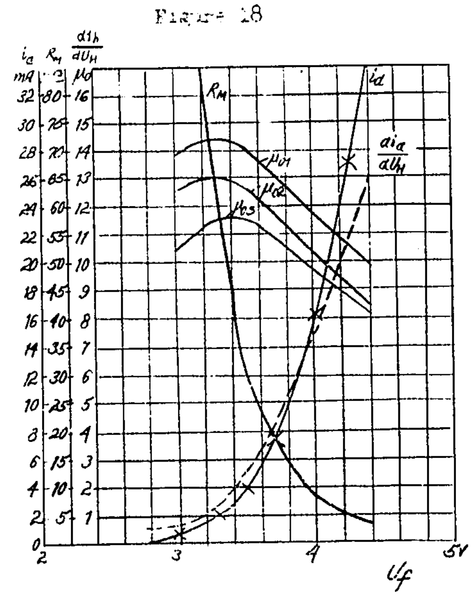

Figure 19

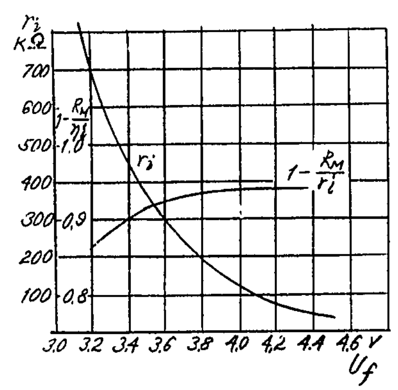

Figure 20

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