EEP 1 (EE 1) Secondary-emission valve

The EEP 1 is an amplifier with secondary-emission cathode. Although originally designed for wide-band amplification in television receivers, it is now recommended for use exclusively as a driver valve for radio receivers and amplifiers with a balanced output stage. The use of this valve not only saves the expense of the transformer normally required to produce the two alternating voltages of opposite phase, but it also provides a very high degree of amplification. In amplifiers especially, this tends to reduce the total number of valves required and also allows the use of negative feed-back, without losing too much of the gain.

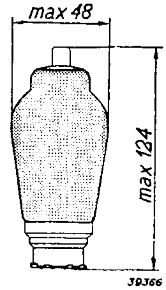


Fig. 1
Dimensions in mm.

Secondary emission and construction of the valve

When electrons strike a metal surface at a certain velocity a small number of them are thrown back, whilst the majority of them penetrate the superficial layer and there liberate electrons from the local atoms. Due to the impact of the primary electrons on the metallic surface, considerable velocity is imparted to the liberated electrons and if their direction of movement is favourable they are able to leave the surface. These electrons liberated from the surface of the metal by the primary electrons are known as secondary electrons. The capacity for emitting secondary electrons is expressed by the "secondary-emission factor" δ, which is the average number of secondary electrons liberated by the primaries. The number of secondary electrons and the path which they follow depend on the construction of the valve, on the potential at the various electrodes and on the physical properties of the bombarded surface. A nickel surface, for instance, gives a secondary emission factor of only 0.94 at a potential difference of 150 V, so the number of secondaries will not be greater than the number of primaries; in other words there will be no multiplication of electrons. The latter can take place only when the factor is greater than 1. Fig 3 shows the principle of the secondary-emission valve, and its action as applicable to the EEP 1 is briefly as follows. Electrons are drawn away from a primary, indirectly-heated cathode by a secondary-emission cathode at a positive potential (150 V). A screen and grid are mounted between the cathode proper and the secondary cathode and each electron reaching the latter liberates a large number of secondary electrons from it, these being attracted by the anode which is at a high potential (250 V).

It will be clear that every variation in the current flowing to the secondary-emission cathode, atten-

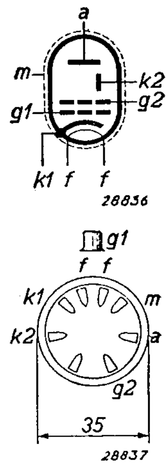


Fig. 2
Arrangement of electrodes and base connections.

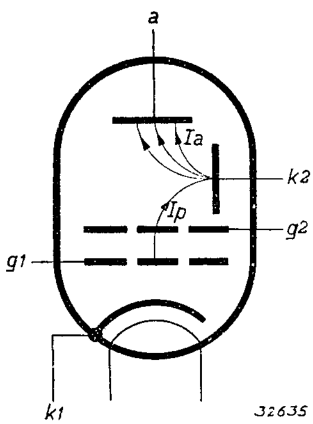


Fig. 3
Diagram of the system employed in the secondary-emission valve. Primary electrons, leaving the cathode k_1, are deflected towards the secondary-emission cathode k_2 and the secondary electrons liberated from the latter pass to the anode. The direction followed by the electrons is shown by means of arrows and it is just the opposite to that of the stream in an ordinary receiving valve.

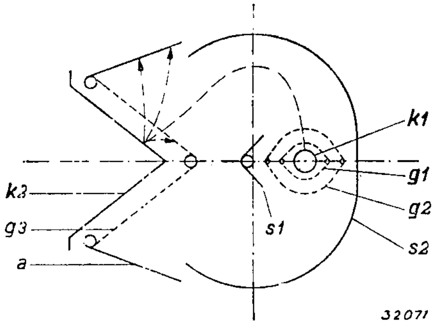


Fig. 4
Cross-section through secondary-emission valve, showing the path of the primary electrons and also that of the secondary electrons liberated from the cathode k_2.

k_1 = primary cathode
g_1 = control grid
g_2 = screen grid (150 V)
s_1 = screen for protection of secondary cathode (0 V) from deposits caused by evaporation of the cathode
s_2 = deflector screen (0 V)
k_3 = secondary-emission cathode (150 V)
$a + g_3$ = anode (250 V).

dant upon changes of voltage on the grid g_1, must produce a much greater variation in the current flowing from the secondary cathode to the anode, thus imparting steep-slope characteristics to the secondary emission, without necessitating an abnormally large cathode or an extremely small space between cathode and grid. If a comparison be made between two valves having similar cathodes, control grids and anodes, one of these valves employing the secondary-emission principle whilst the other does not, it will be found that the mutual conductance of the former is very much the greater.

For the same anode current, the mutual conductance of the secondary-emission valve is $\delta^{1/k}$ times greater than that of the ordinary valve, k being a factor related to both the design of the valve and the anode voltage. If the primary cathode current is not too low the value of the factor k will be constant at about 1.6, the mutual conductance in that case being $\delta^{0.6}$ times greater. Suppose that $\delta = 5$, then $\delta^{0.6}$ will be 2.6.

If the primary cathode (indirectly-heated, with oxide layer) and the secondary-emission area were provided inside the valve without any precautions to avoid this, the secondary emission area would in time become covered with a deposit of material produced by evaporation of the cathode (e.g., barium and barium oxide) and the stability of the secondary emission would thus be seriously affected; the use of an electron-optical device, coupled with a careful arrangement of the paths for the electron streams, however, prevents the deposition of any material on the secondary cathode. In the EEP 1 this difficulty, namely the tendency of the primary cathode to produce deposits, is overcome by employing an electron deflector. It is assumed that the molecules liberated from the primary cathode move virtually in a straight line and an appropriate arrangement of the electrodes in the valve makes the secondary-emission cathode accessible to electrons from the primary cathode, but not to material thrown off by this cathode. The action of the secondary-emission valve can best be explained in relation to Fig. 4 [1]), which shows a section through the system of electrodes in the EEP 1. The primary cathode k_1 (indirectly-heated oxide cathode), the control grid g_1, concentric with

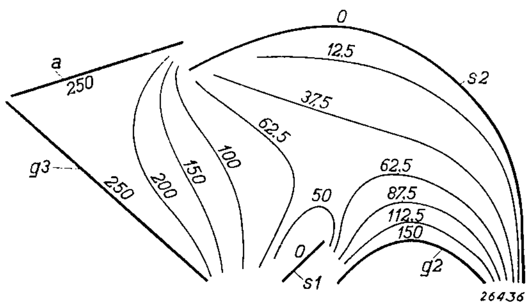


Fig. 5
Equipotential areas in the secondary-emission valve. For designation of the electrodes see Fig. 4.

*) The diagram shows the construction of the original model of the EEP 1, but in later models the anode plate a is omitted to ensure satisfactory operation of the valve as a pre-amplifier and phase-nverter in balanced output stages, thus leaving only the anode-"grid" g_3 as virtual anode.

the latter, and the screen grid g_2 (at a potential of about 150 V with respect to k_1) together constitute the first three electrodes of a normal screen-grid valve; k_2 is the secondary-emission cathode, which is usually also given a potential of 150 V. Between the system of three electrodes already mentioned and the secondary cathode a screen plate s_1 is provided to prevent the deposition of material from the primary cathode upon the secondary; this screen is connected internally to the cathode. A second screen s_2 is fitted about the electrode system, this being also at cathode potential and suitably shaped for correct deflection of the electrons. Finally, the valve contains an anode-grid g_3, stretched parallel to the emission cathode and connected to the anode plates a. The shape of the screen s_2 is such that the field produced between the primary and secondary cathodes causes the electrons to follow curved paths around the screen s_1 towards the secondary cathode k_2 (see Fig. 4). Fig 5 shows the equipotential areas in one half of the valve. Between the screen grid g_2 and the secondary cathode the electrons travel through two concentrating fields, deflection taking place in the low-potential area formed by screen s_2, and Fig. 5 clearly illustrates the so-called focusing arrangement. An electron arriving at the secondary-emission cathode liberates a number of secondary electrons (sec. emission factor $\delta = 5$) which are collected by the anode-grid g_3, mounted at about 1.5 mm distance from it and operating at a voltage of some 100 V higher than that of the secondary cathode.

It is worthy of note that the electrons released from the secondary cathode set up a negative current to this cathode; whereas normally the external current flows towards the positive electrode, the current in this case passes away from the secondary cathode and follows a path through the source of voltage to the primary cathode. Simultaneously, however, the positive current flows to the secondary cathode, so that the emission current must be diminished by the value of this primary current.

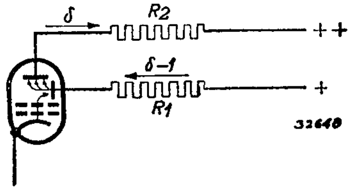


Fig. 6
Schematic arrangement showing the action of the secondary-emission valve employed as driver valve. The arrows indicate the direction followed by the electrons. The normal current flow is in the opposite direction to that of the arrows.

The secondary-emission valve as pre-amplifier in balanced output stages without transformer.

When balanced output stages are driven by means of the secondary-emission valve EEP 1, use is made of the fact that the secondary-emission current (in a positive sense) passes externally to the anode and is taken away at the secondary cathode. It must then be remembered that the current from the latter cathode is reduced to the extent of the primary electrons flowing in the opposite direction. The phases of the currents passing to the two electrodes are therefore 180° opposed and, if these currents be passed to or from the electrodes across resistors, voltages will be obtained which will also be 180° out of phase (see also Fig. 6).

These two alternating voltages of opposite phase may be applied through coupling capacitors with grid leaks to the grids of two output valves in a balanced circuit, and the values of the resistors in both anode and secondary-cathode circuit should naturally be such that the two opposed alternating voltages are exactly equal.

As already stated, the action of the valve depends upon the fact that for every electron reaching the secondary cathode δ electrons arrive at the anode; the number of electrons at the secondary cathode is therefore augmented by (δ—1) electrons passing through R_1 [1]) to the secondary cathode, whilst δ electrons leave the anode through R_2 in respect of these.

[1]) In Fig. 16 R_1 is made up of R_2 and R_3 in parallel.

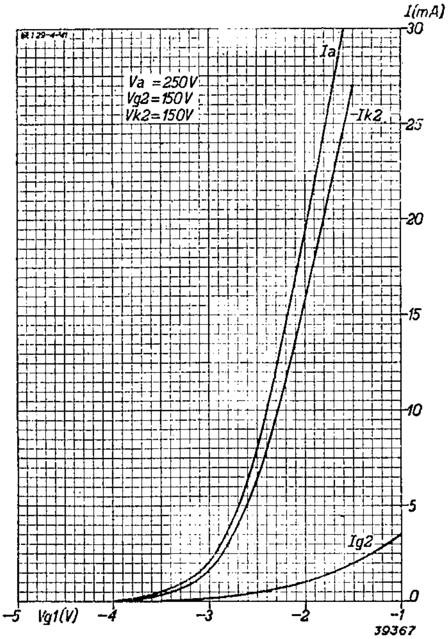


Fig. 7
Anode current, screen-grid current and secondary-cathode current as a function of the grid bias.

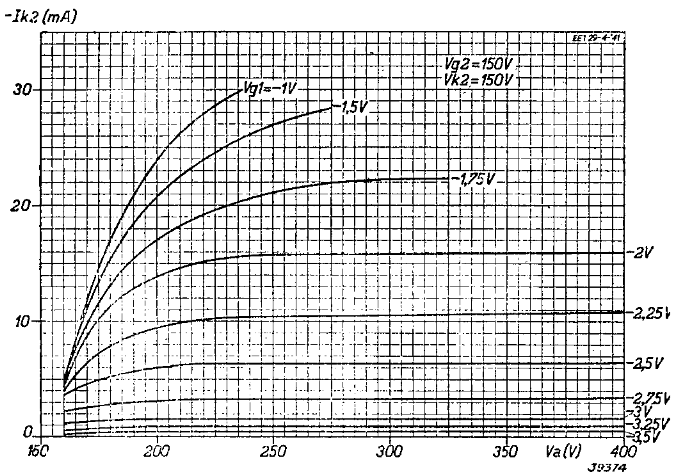


Fig. 8
Anode current plotted against anode voltage at different values of grid bias.

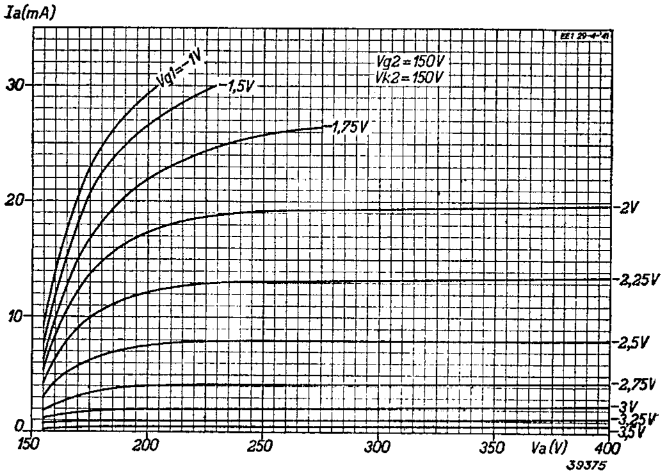


Fig. 9
Secondary-emission cathode current as a function of the anode voltage, for different values of grid bias.

If the effect of the secondary cathode on the anode current is ignored, equal voltages will depend on the following expression:

$$(\delta - 1)\ R_1 = \delta\ R_2,\ \text{or}\ R_2 = \frac{\delta - 1}{\delta}\ R_1$$

In practice R_2 will have to be slightly less than this value, in view of the fact that the alternating voltage at the secondary cathode also contributes to the anode current. Fig. 16 shows the theoretical circuit diagram of the EEP 1 driving a balanced output circuit. Since the factor δ is governed by the negative potential of the grid of the EEP 1, a method of stabilizing the grid bias is employed; the cathode is given a potential of about 23 V positive with respect to the earth line or negative H.T. line, whilst the first grid and screen grid are fed from a potential divider. In this way the first grid receives a positive potential of about 20 V.

Negative feed-back may be included in the cathode circuit as shown in Fig. 17.

A potential divider, R_9, R_8, is connected across the loudspeaker; resistor R_8 is simultaneously included in the cathode circuit of the EEP 1 and the speech voltage across R_8 therefore occurs between the cathode and the grid of this valve. The sum of the resistances of R_7 and R_8 should correspond to the value of the cathode resistor as specified for this valve (the value of R_7 in Fig. 16; see also the following data).

HEATER RATINGS

Heating: indirect, A.C. or D.C. parallel supply.

Heater voltage	V_f = 6.3 V
Heater current	I_f = 0.6 A

CAPACITANCES

$C_{ag1} < 0.006\ \mu\mu F$ $\qquad$ $C_{g1k2} < 0.001\ \mu\mu F$

STATIC RATINGS

Anode voltage	V_a	= 250 V
Screen-grid voltage	V_{g2}	= 150 V
Secondary-cathode voltage	V_{k2}	= 150 V
Grid bias	V_{g1}	= —2.5 V
Anode current	I_a	= 8 mA
Screen-grid current	I_{g2}	= 0.45 mA
Current to secondary cathode	I_{k2}	= —6.5 mA
Mutual conductance	S	= 17 mA/V
Internal resistance	R_i	= 50,000 ohms

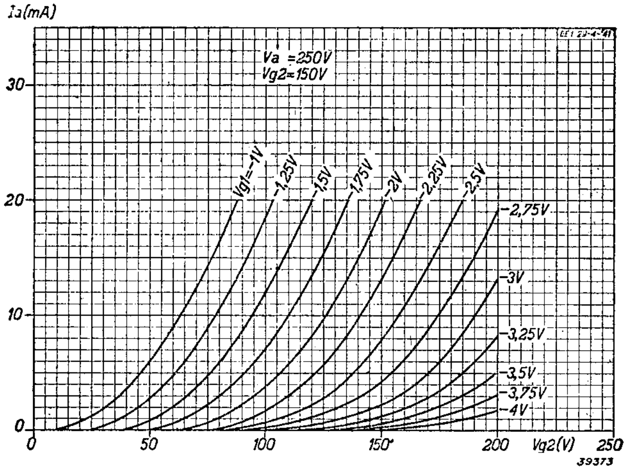


Fig. 10
Anode current as a function of the screen-grid voltage, for different values of grid bias.

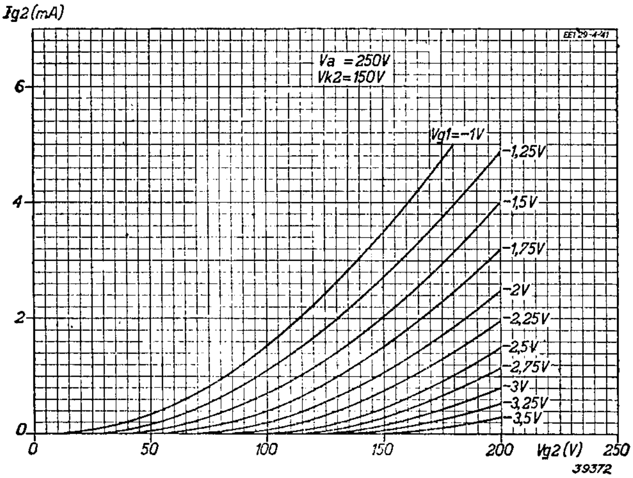


Fig. 11
Screen-grid current as a function of the screen voltage for different values of grid bias.

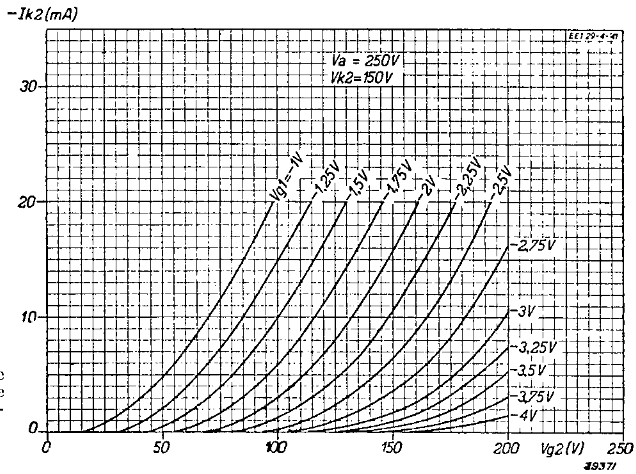
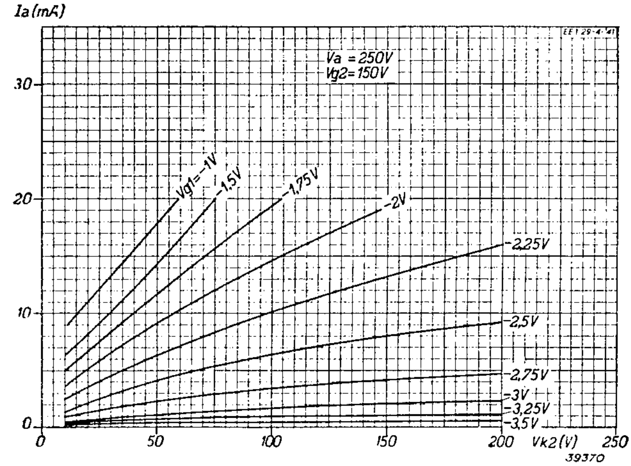
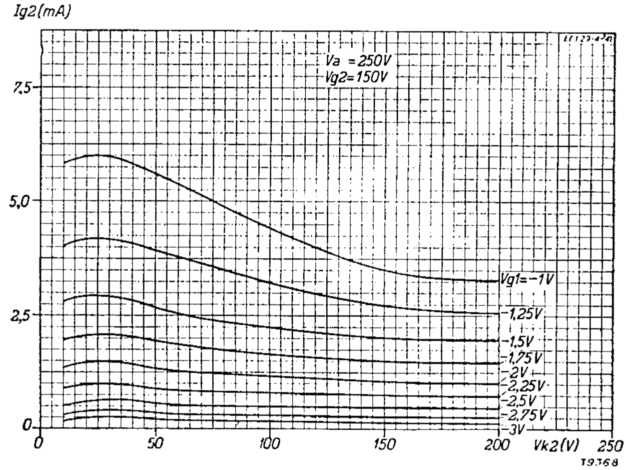


Fig. 12
Secondary-emission cathode current as a function of the screen-grid voltage, for different values of grid bias.



Anode current as a function of the secondary cathode potential at different values of grid bias.



g. 14
Screen-grid current as a function of the secondary cathode voltage at different values of grid bias.

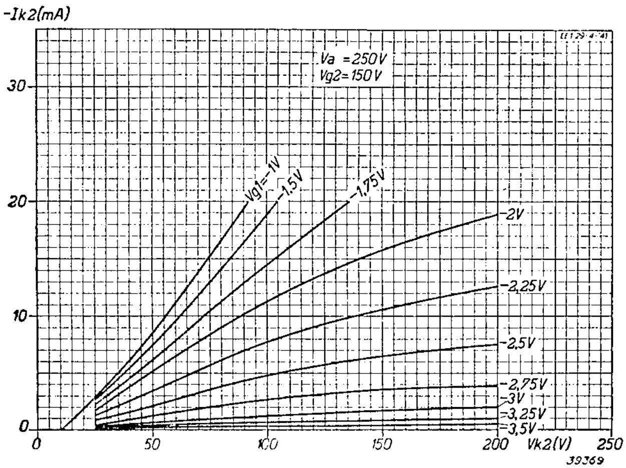


Fig. 15
Current flowing to the secondary cathode as a function of that potential of that cathode, for different values of grid bias.

OPERATING DATA: EEP 1 employed as pre-amplifier and phase-inverter in balanced ouput stages

(For resistance, current and voltage references see circuit, Fig. 16)

Supply voltage	V_b =	400 V	500 V
Resistor	R_1 =	26,000 ohms	26,000 ohms
Resistor	R_2 =	208,000 ohms	208,000 ohms
Resistor	R_3 =	29,000 ohms	29,000 ohms
Resistor	R_4 =	85,000 ohms	105,000 ohms
Resistor	R_5 =	30,000 ohms	30,000 ohms
Resistor	R_6 =	9,000 ohms	9,000 ohms
Cathode resistor	R_7 =	6,900 ohms	6,000 ohms
Alternating output voltage per grid in output stage	V_o =	10 30	10 30 V_{eff}
Alternating input voltage	V_i =	34 114	31 96 mV_{eff}
Gain between grid of EEP 1 and grid of output stage	V_o/V_i =	300 265	325 315
Total distortion	d_{tot} =	1.4 4.6	0.9 3.2 %

MAXIMUM RATINGS

Anode voltage in cold condition	V_{ao} =	max. 700 V
Anode voltage	V_a =	max. 400 V
Anode dissipation	W_a =	max. 2 W
Screen-grid voltage in cold condition	V_{g2o} =	max. 400 V
Screen-grid voltage	V_{g2} =	max. 150 V
Screen-grid dissipation	W_{g2} =	max. 0.1 W
Voltage on sec. emission cathode in cold condition	V_{k2o} =	max. 400 V
Voltage on sec. emission cathode	V_{k2} =	max. 200 V
Dissipation of sec. cathode	W_{k2} =	max. 2 W
Primary-cathode current	I_{k1} =	max. 10 mA
Grid voltage at grid current start (I_{g1} = + 0.3 μA)	V_{g1} =	max. —1.3 V
Resistance between grid and cathode	R_{g1k} =	max. 0.7 M ohm
Resistance between filament and cathode	R_{fk} =	max. 20,000 ohms
Voltage between filament and cathode (direct voltage or effective value of alternating voltage)	V_{fk} =	max. 50 V

APPLICATIONS

In connection with the foregoing the following points should also be noted. The EEP 1 must be allowed to work only with automatic grid bias; normally the bias is obtained from a resistor connected to the cathode and the value of this resistor should be such that the potential difference corresponds exactly to the required bias. The working point A will then lie just on the point of intersection of the line OA with the characteristic (see Fig. 18). A slight displacement of the curve would, in the case of normal valves, produce only a small increase or decrease in the anode current. In the EEP 1, however, a very much greater variation in anode current results and, since the normal cathode resistor is of a fairly low value and offers only a small degree of compensation, special precautions have to be taken. Better automatic control of the cathode current is possible if the slope of the line OA in Fig. 18 is reduced and this effect can be obtained by using a higher resistance, due to the fact that the slope of the line in question is determined by the quotient of the cathode potential and the cathode

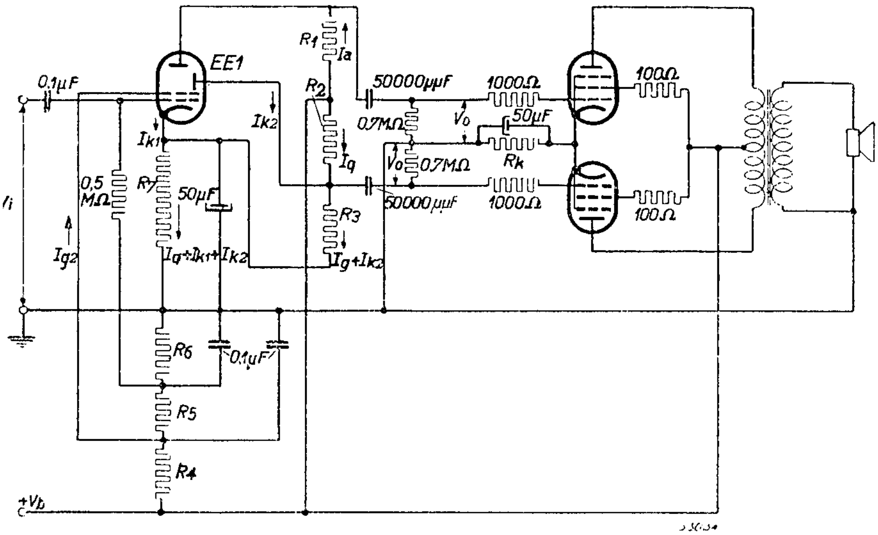


Fig. 16
Theoretical circuit diagram showing the EEP 1 used as driver valve without negative feed-back. The values of resistors R_1 to R_7 may be obtained from the operating data.

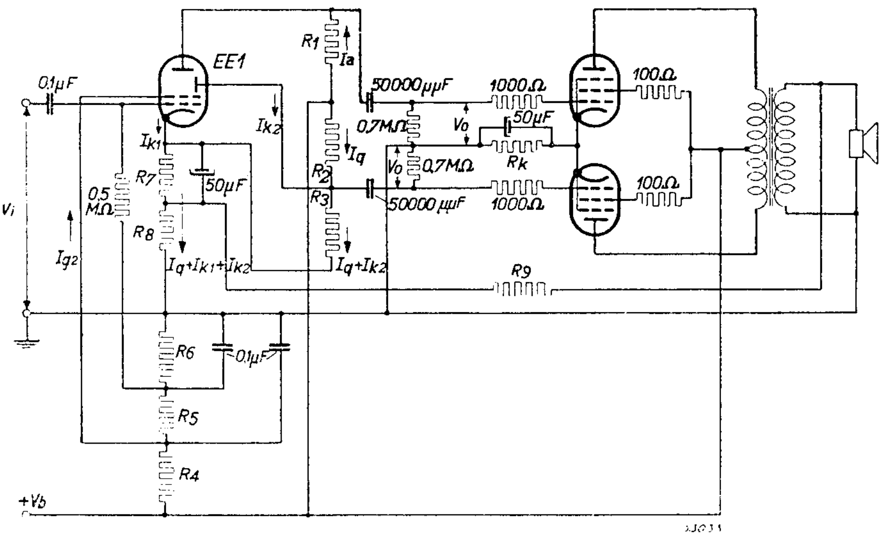


Fig. 17
The EEP 1 employed as driver, with negative feed-back. The circuit is the same as that of Fig. 16, with the exception of R_7 and R_8 of which the values depend on the required feedback; the sum of the values of R_7 and R_8 should correspond to the value of resistor R_7 in Fig. 16.

current. This, however, would make the grid bias too high, so that a positive potential has to be applied to the grid. In Fig. 18 this potential is represented by OB. From the point B the new line is drawn and the total grid bias as a function of the cathode current is then restored. It will be seen that the cathode current, regulated in this manner and indicated by the point of intersection with the curve, does not vary to any extent from the average value.

When the EEP 1 is employed as driver valve in a balanced circuit it is recommended that a supply voltage *Vb* of not less than 275 V be employed; otherwise the results will not be satisfactory.

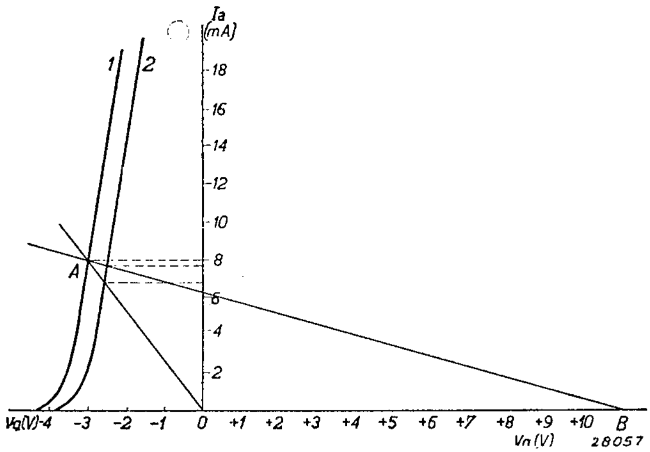


Fig. 18
Simplified diagram showing the effect of the cathode resistor on the constancy of the cathode current. The automatic control of the current is better according as the resistance line becomes flatter.