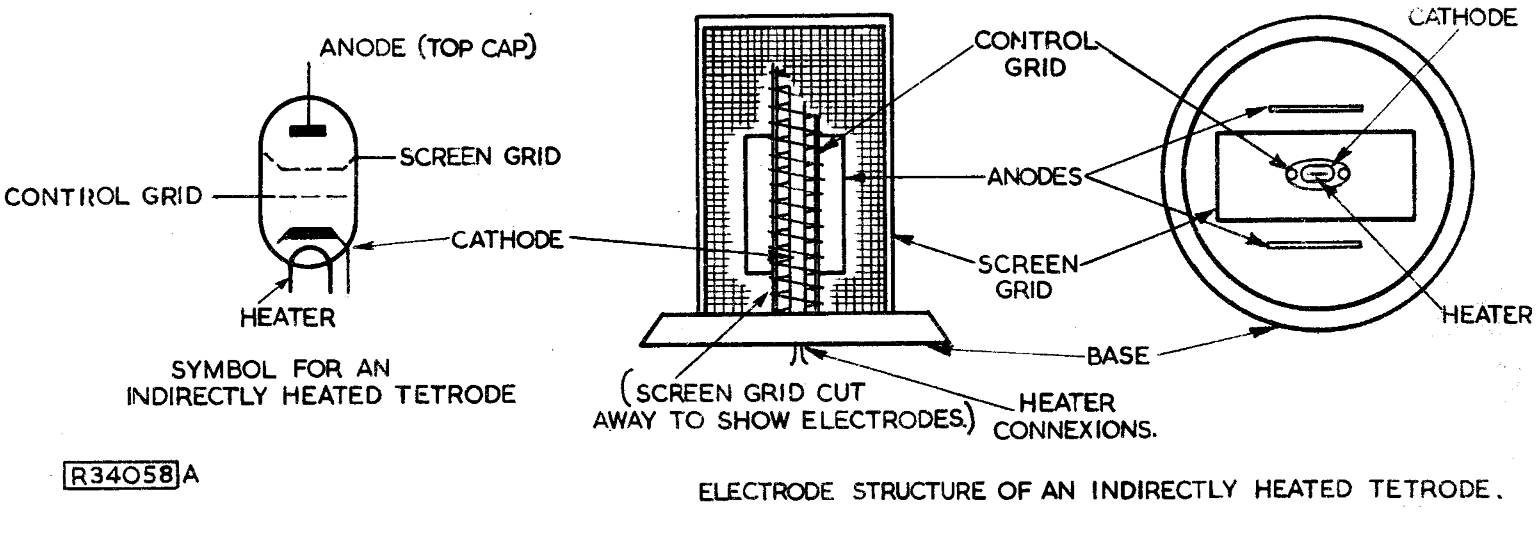
MULTI-ELECTRODE VALVES

CONTENTS

THE TETRODE

The inter-electrode capacitance between the grid and anode of a triode valve is of the order of 2 to 10 pF. Although this capacitance is quite small there is considerable capacitive coupling between the grid and anode circuits when the valve is used at radio frequencies. This coupling may produce instability, the effects of which are discussed in the pamphlet dealing with amplifiers.

The tetrode valve was developed to reduce the capacitive coupling to a minimum by the introduction of a metal screen between the anode and grid. Fig. 1(a) shows the symbol for an indirectly heated tetrode and Fig. 1(b) the electrode structure.



(a) (b)

Fig. 1

The valve shown has a grid near the cathode and, as in the triode, this grid is known as the control grid because the voltage applied to it controls the anode current. Completely surrounding the control grid is the screen grid which is a cage of fine wire mesh. The screen grid in Fig. 1(b) is partly cut away to show the other electrodes. The anode consists of two rectangular plates connected electrically and mounted one on each side external to the screen grid. The anode connexion is brought out to a top cap on the valve envelope.

The function of the screen grid may be understood by considering the lines of force between the electrodes. If the screen-grid were a sheet of metal instead of a mesh or grid, all the lines of force from the control grid and cathode would end on the screen-grid and there would be no capacitance between the control grid and the anode. With the screen-grid of open mesh construction and nearly at the same potential as the anode, practically all the lines of force from the grid and cathode end on the screen. When the potential of the screen-grid is below that of the anode there is a field between them, and a few lines also join the grid and anode, i.e. there is a slight residual grid-anode capacitance. Although the majority of the lines of force from the grid end on the screen-grid, most of the electrons travelling towards the screen-grid from the vicinity of the control grid are projected by their momentum through the spaces of the mesh and so come under the screen-grid anode field and are collected by the anode. Thus the screen-grid valve can function in a similar manner to a triode though its characteristics are somewhat different.

In commercial types of screen-grid valves, the residual grid-anode capacitances are from 0.001 pF to 0.02 pF; the screening effect of the fourth electrode is therefore very pronounced.

It will be noticed in Fig. 1 that there is also a circular screen extension plate, the purpose of which is to screen the grid and anode connexion leads which enter the structure from the bottom and top respectively.

Tetrode Parameters

Small changes in anode voltage will have practically no effect on the intensity of the electric field between the control-grid and the screen-grid, which is responsible for the electron flow across this region. In other words the anode a.c. resistance of the valve is very high. The influence of the control-grid however is nearly the same as if the screen and anode together formed a collecting anode as in a triode; in fact the mutual conductance is of the same order as for a triode. The mutual characteristics of the screen-grid valve are similar in shape to those of the triode but the anode characteristics are very different.

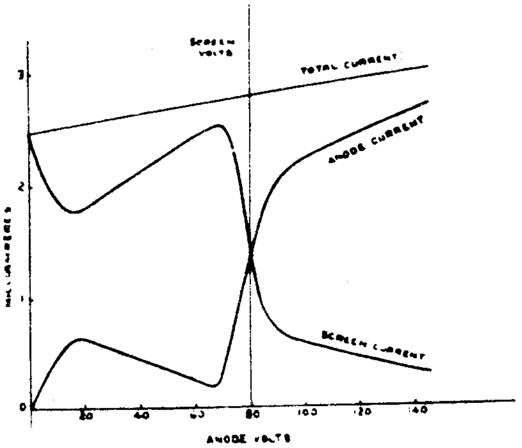
Fig. 2 shows the anode and screen current of a tetrode valve plotted against anode voltage.

If the screen voltage is maintained constant at about 80 volts and the anode voltage is raised steadily from zero, the anode current increases steadily until the anode voltage reaches about 15 volts, the anode current then reaches a maximum value and commences to fall. This fall is caused by the emission of secondary electrons from the anode due to the impact of primary electrons from the cathode. As the screen is at a high potential with respect to the anode, the screen attracts the secondary electrons, with the result that the screen current rises. Under these conditions the number of secondary electrons emitted from the anode is greater than the number of primary electrons hitting it and the net result is a reduction in anode current.

The reduction in anode current continues until the potential of the anode is sufficiently high, compared with the screen potential to re-attract the secondary electrons. After this potential is reached the anode current rises with increase of anode voltage and the screen current decreases. This occurs when the anode voltage is increased above 65 volts, as shown in Fig. 2.

The valve is said to exhibit a negative resistance characteristic during the period when the voltage applied to the anode is increasing and the anode current is decreasing. This property of a tetrode is used to advantage in some circuits but is usually a disadvantage.

Fig. 3 shows a family of anode characteristics of a screen grid valve.



Screen Volts = 80
Grid Volts = 0
Anode and Screen Currents plotted against Anode Voltage.

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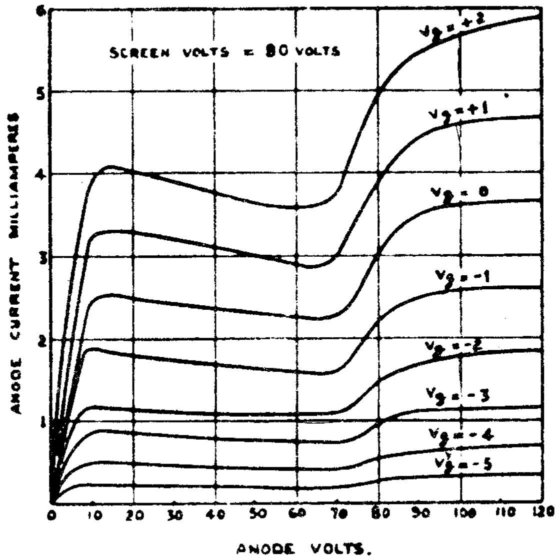
Fig. 2



Anode Characteristics of a Screen Grid Valve.

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Fig. 3

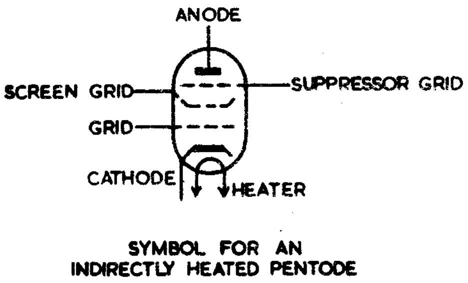
When the valve is in use as a voltage amplifier the effects of secondary emission from the anode must be avoided as the change produced by this in the anode characteristic results in distortion of the amplified signal. This is avoided by maintaining the screen grid potential at approximately half that of the anode. In general the screen grid valve is no longer used as an amplifier and is mainly regarded as a stage in the development of the modern pentode.

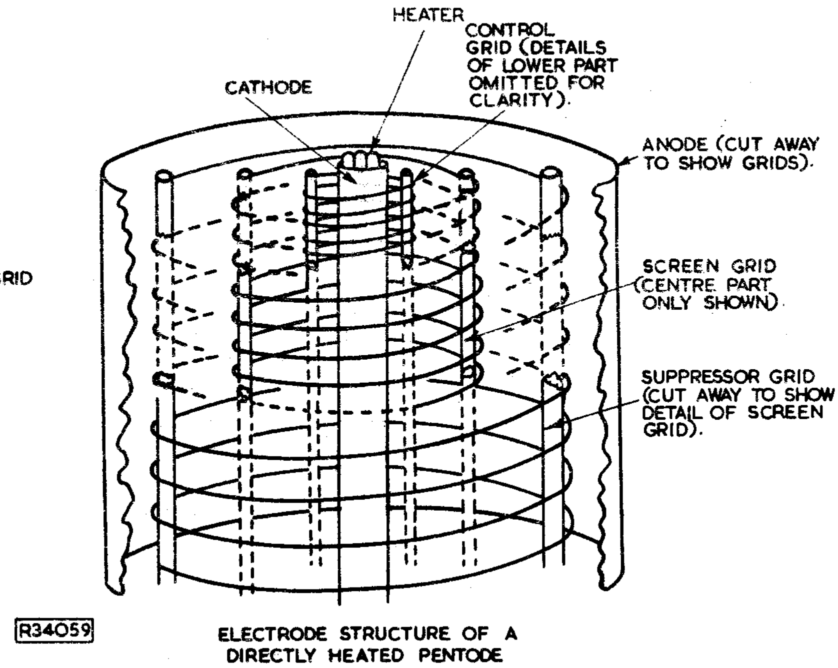
THE PENTODE

Broadly speaking a pentode is a screen-grid valve with a third grid, known as the suppressor, introduced between the screen-grid and anode and biased to prevent the interchange of secondary emission electrons between the screen-grid and the anode. This results in a pentode having a high r_a and high μ, somewhat similar to a screen-grid valve but it has no negative resistance or unstable properties due to secondary emission.

Fig. 4(a) shows the symbol for an indirectly heated pentode, and Fig. 4(b) shows the electrode structure.

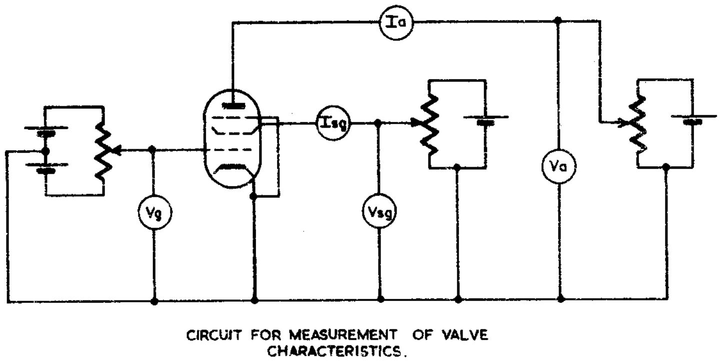
The suppressor grid is sometimes brought out to a separate pin but is usually connected internally to the cathode electrode, or, in the case of a directly heated pentode, to the centre or one side of the filament.

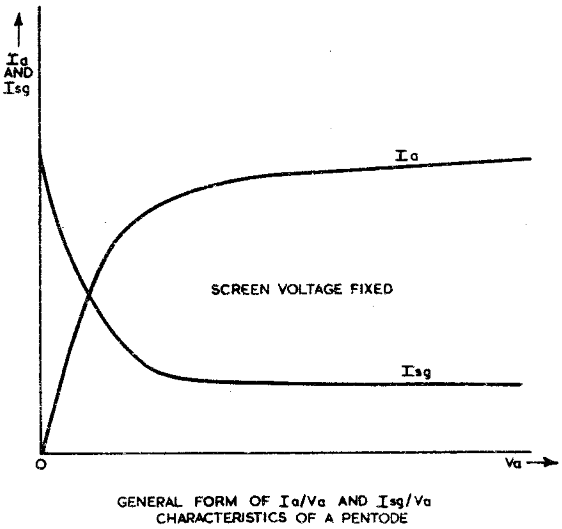




(c) (b)

Fig. 4





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(a) (b)

Fig. 5

Fig. 5(a) shows a method of measuring the various static characteristics of a pentode with fixed heater voltage, and the suppressor grid connected to the cathode. The Ia/Vg characteristic is very similar to that of a triode, but the Ia/Va characteristic is quite different. Fig. 5(b) shows the general shape of an Ia/Va characteristic of a pentode; an Isg/Va characteristic is also shown on the same graph.

When the anode voltage is zero, the screen current is maximum, as all the electrons which pass through the control grid are attracted to the screen. As the anode voltage is increased the anode current increases and the screen current decreases. This occurs because electrons pass through the screen and suppressor grids and are attracted to the anode which is now positive. At a certain anode voltage, the increase in anode current for a given voltage increase becomes less, until a point is reached when the anode current does not change, or only changes a very small amount, despite large changes in anode voltage.

Over a large range of voltage, the anode current is independent of anode voltage and the pentode can be regarded as a constant current device because of this.

Fig. 6 shows a typical family of Ia/Vg characteristics for a pentode CV 138. This pentode is widely used as an r.f. amplifier valve, as an oscillator, and as a frequency multiplier. It will function satisfactorily up to about 160 Mc/s. Note that these characteristics are for various values of screen grid voltage with fixed anode volts. The reason for this is that as the anode voltage has very little control over the current flowing through the valve, a mutual characteristic plotted at an anode potential of, say, 200 volts would be almost identical to a mutual characteristic at an anode potential of 250 volts. The difference in anode current due to the increase of 50 volts at the anode is so small that the two characteristics would be superimposed upon one another if an attempt were made to draw them.

The screen grid, however, is much closer to the cathode and exercises considerable control over the current flowing through the valve. By altering the screen potential for each characteristic, and keeping the anode voltage constant, a set of characteristics similar in shape to the mutual characteristics of a triode may be obtained.

Fig. 7 shows a typical family of Ia/Va and Ia/Vsg characteristics for a CV 138. The heater voltage and screen voltage are constant; the anode current is plotted for varying anode voltages at fixed values of grid voltage.

PENTODE PARAMETERS

Anode a.c. Resistance

The anode a.c. resistance is given by:-

$$r_a = \frac{\delta Va}{\delta Ia} \text{ (Vg constant)}$$

Considering the curves shown in Fig. 7 for the CV 138; when Vg = -3 volts and Va = 250 volts a small change in anode volts causes no change in anode current. Thus suppose δVa = 1 volt then:-

$$r_a = \frac{1}{0} = \infty$$

At other values of grid volts and anode volts r_a is finite but very large, and in practice pentodes similar to the CV 138 are treated as constant current generators i.e. r_a is considered to be practically infinite.

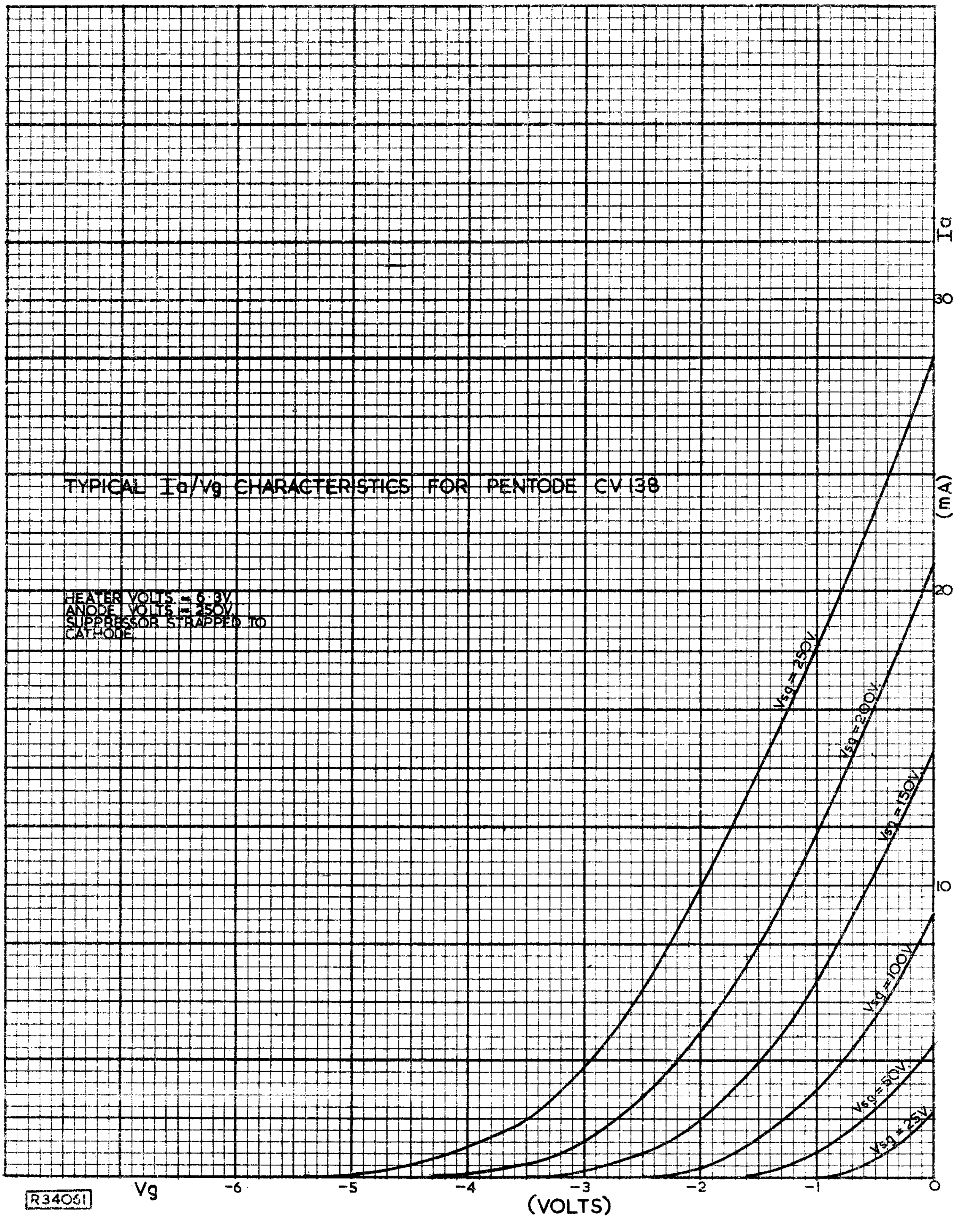
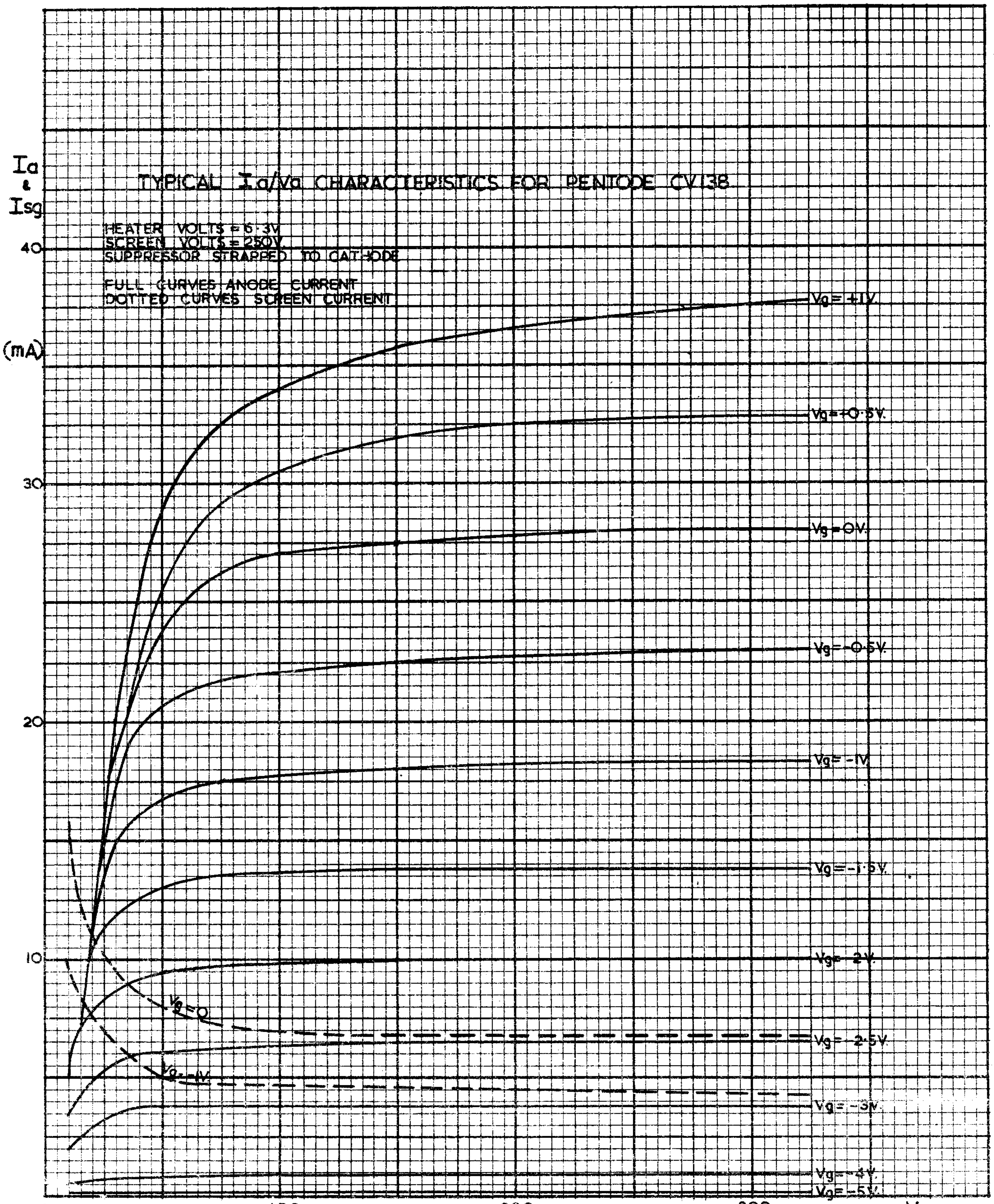

TYPICAL Ia/Vg CHARACTERISTICS FOR PENTODE CV 138
HEATER VOLTS = 6·3V
ANODE VOLTS = 250V
SUPPRESSOR STRAPPED TO CATHODE
Ia
(mA)
30
20
10
Vsg = 250V
Vsg = 200V
Vsg = 150V
Vsg = 100V
Vsg = 50V
Vsg = 25V
Vg
-6
-5
-4
-3
-2
-1
0
(VOLTS)
R34061

Fig. 6


TYPICAL Ia/Va CHARACTERISTICS FOR PENTODE CV138
HEATER VOLTS = 6·3V
SCREEN VOLTS = 250V
SUPPRESSOR STRAPPED TO CATHODE
FULL CURVES ANODE CURRENT
DOTTED CURVES SCREEN CURRENT
Ia & Isg (mA)
40
30
20
10
0
100
200
300
Va
(VOLTS)
Vg=+1V
Vg=+0·5V
Vg=0V
Vg=-0·5V
Vg=-1V
Vg=-1·5V
Vg=-2V
Vg=-2·5V
Vg=-3V
Vg=-4V
Vg=-5V
Vg=0
Vg=-1V

R34062

Fig. 7

Mutual Conductance

The mutual conductance (gm) of a pentode is substantially the same as that of a comparable triode because gm is expressed as the change in anode current for a change in grid voltage with the anode voltage constant.

Amplification Factor

The amplification factor μ is the product gm r_a. Since for a pentode r_a is large compared with the r_a of a comparable triode, μ will also be large. For the CV 138 typical figures for the three paramaters at Va = 250 volts, Vsg = 250 volts and Vg = 2 volts, are:-

Anode a.c. resistance,	r_a = 1.0 MΩ
Mutual Conductance,	g_m = 7.5 mA/V
Amplification factor	μ = 7500

VARIABLE MU VALVES

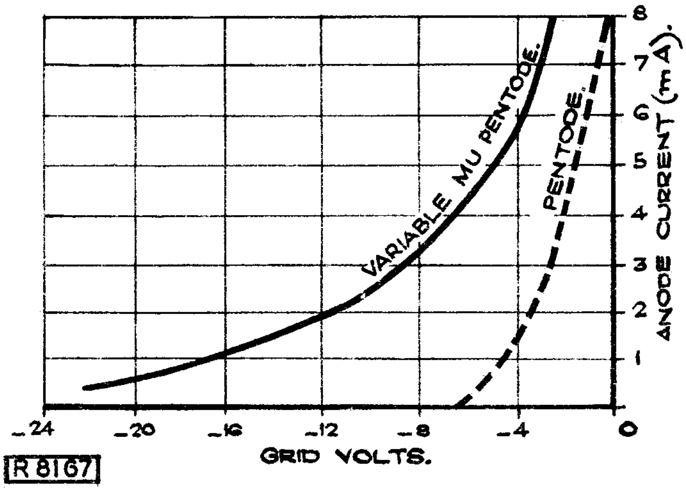


Fig. 8

It is frequently desirable to have some method of controlling the amplification of a stage either manually or by some automatic method. This may be done by using a valve which is specially constructed so that the amplification factor, μ is reduced as the control grid bias is made more negative. A variable mu characteristic is obtained by using a non-uniform control grid structure, so that the amplification factor is different for different parts of the valve. Such an arrangement makes the grid potential required for cut-off different for different parts of the valve, and those parts having the lowest value of μ will hence require an extremely negative grid potential to cut off all anode current. The usual method of obtaining the variable mu consists either in varying the pitch of the control grid in the usual way or removing one or more half turns in the centre of the grid.

The effect on the mutual characteristic is to produce a long "tail" to the curve as shown in Fig. 8. The dotted curve indicates approximately the shape of a characteristic using a constant spacing of the control grid.

Fig. 9 shows a typical family of Ia/Vg characteristic curves for a variable mu pentode CV 131.

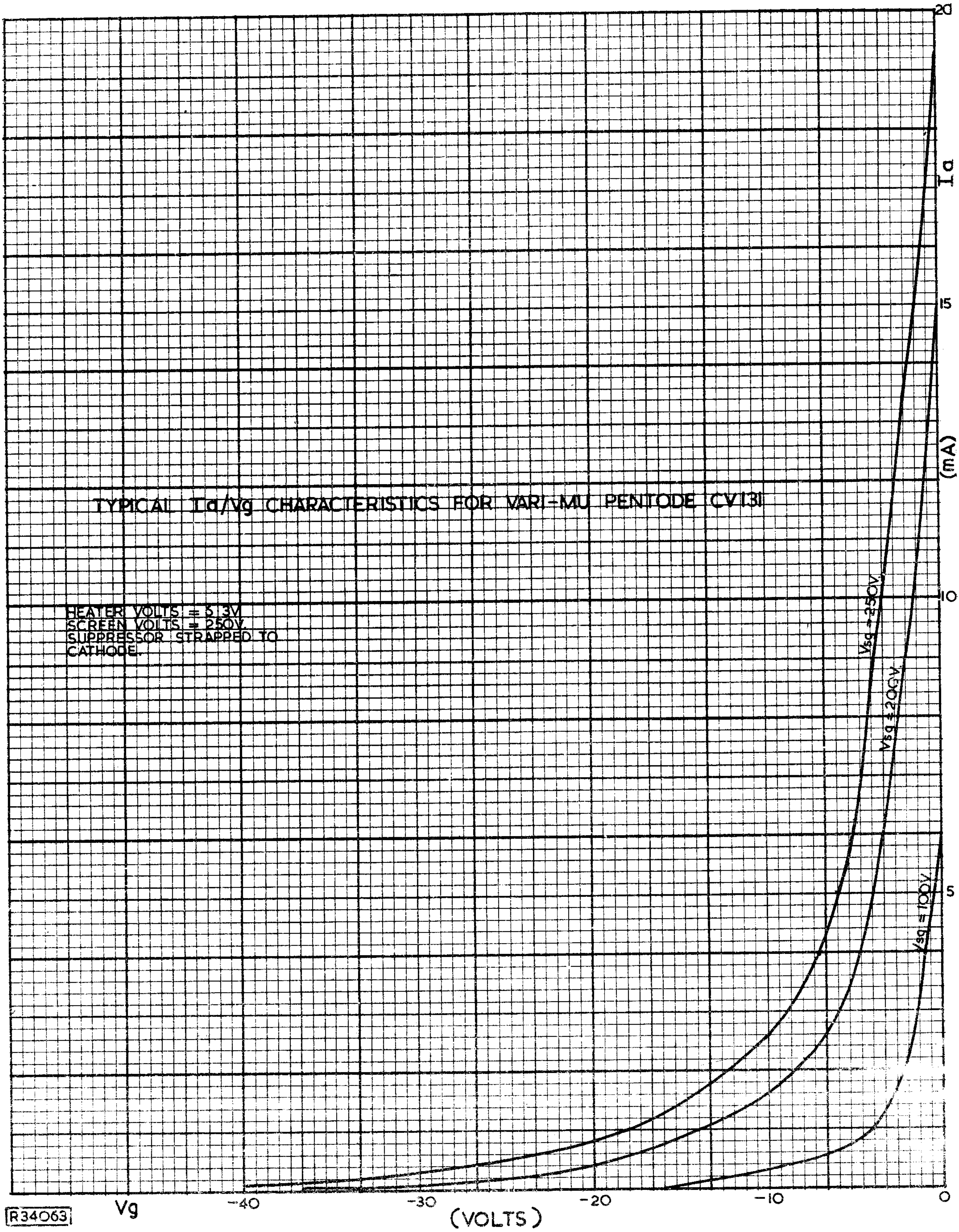

TYPICAL Ia/Vg CHARACTERISTICS FOR VARI-MU PENTODE CV131
HEATER VOLTS = 6.3V.
SCREEN VOLTS = 250V.
SUPPRESSOR STRAPPED TO CATHODE.
Vsg = 250V.
Vsg = 200V.
Vsg = 100V.
Ia
(mA)
20
15
10
5
0
Vg
-40
-30
-20
-10
(VOLTS)
R34063

Fig. 9

THE BEAM TETRODE

This valve is a special type of screen grid valve in which the effect of a suppressor grid is obtained by means of the space charge in the space between the anode and screen. This is accomplished by using a large anode-screen distance and by concentrating the electrons travelling towards the anode into a well defined beam. These modifications increase the space-charge effects existing in the anode screen. space to the point where there is a pronounced potential minimum in the inter electrode space even at low anode potentials. This potential minimum produced by the space charge performs the same function as a suppressor grid in that secondary electrons emitted from the anode encounter an opposing field which returns them to the anode. In spite of this potential minimum, the anode still collects all the electrons that pass the screen provided the minimum potential in the electrode space exceeds zero. The characteristic that results is shown in Fig. 10 and is similar to a pentode characteristic except that the transition between the region where the anode current is substantially independent of anode voltage, and where the anode current is determined primarily by the anode voltage is more abrupt and takes place at a lower anode potential. The gradual transition of the pentode is caused by the fact that the spaces between the wires of the suppressor grid tend to produce a variable mu action not present in the beam valve.

The construction of a typical beam valve is shown in Fig. 11. The beam forming plates are internally connected to the cathode and serve to concentrate the electrons in a beam as indicated. This increases the space-charge effect sufficiently so that, when coupled with the large screen-anode distance, the space charge will produce the required potential minimum. The beam forming plates also serve to keep the electrons away from the ends of the control-grid structure where pronounced dissymmetry exists. The control-grid and screen grid wires are wound to the same pitch and carefully aligned so that the screen grid wires are in the shadow cast by the control grid. This reduces to a very low value the fraction of the total space current which is intercepted by the screen.

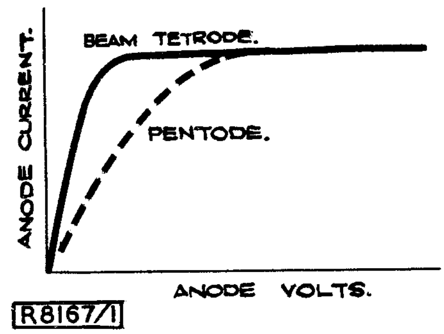


Fig. 10

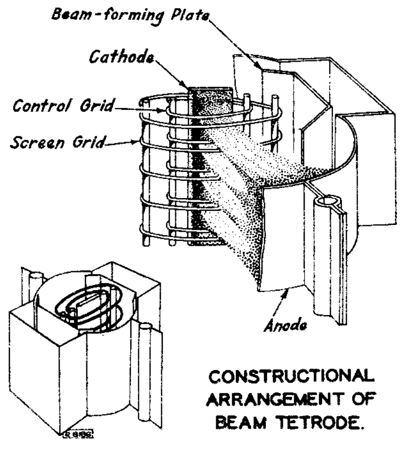


Fig. 11

The beam valve is equivalent to the pentode as far as fundamental characteristics are concerned but its abrupt transition characteristic at low anode voltage make it superior to the pentode as a power amplifier.

MORE COMPLEX MULTI-ELECTRODE VALVES

One of the first of these to be developed was the hexode which has four grids. The non-linear characteristics of this valve are used in such a manner that if a radio frequency signal is applied to one grid, and the output from a local oscillator to another, then a beat frequency component appears in the anode circuit. A later development is the triode-hexode valve which employs the triode section as a local oscillator and the hexode portion as a mixer, both electrode structures being contained in the same envelope as shown in Fig. 12.

The grid structure which surrounds the cathode acts on the left hand side as the grid of the triode section which is the local oscillator. On the right hand side it is the first grid of the mixer and modulates the electron stream in the hexode section at oscillator frequency. The third grid from the cathode is the signal grid which is completely screened by grids two and four from the oscillator section on one side and the anode on the other. The shield which is at cathode potential, prevents any stray coupling between the two sections.

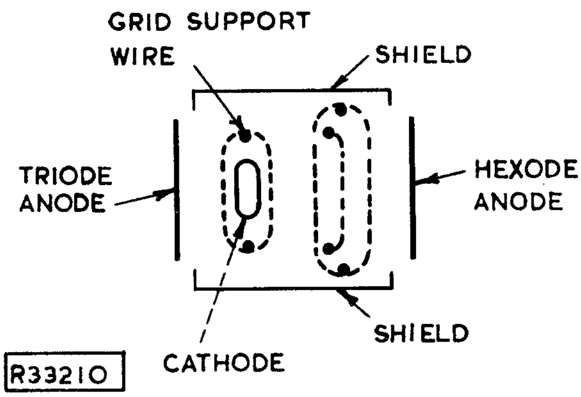
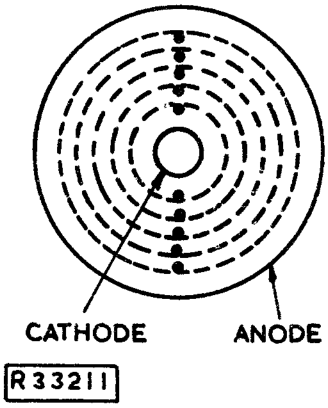


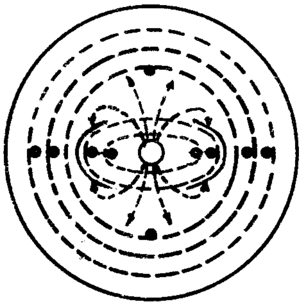
Fig. 12

The next valve to be discussed is the heptode. This valve has five grids as shown in Fig. 13(a). The first grid is used for injection of the signal voltage and the third grid for injection of the local oscillator voltage.

Grids two and four reduce the electrostatic coupling between the third grid and the input and output circuits. The fifth grid is a suppressor grid and this makes the anode current/anode voltage characteristic of the valve resemble that of a pentode. The heptode may also be used as a mixer by connecting the cathode and the first two grids as a triode oscillator in which case grid two acts as the triode anode. This arrangement has the advantage that a separate oscillator valve is not required but has the disadvantage that automatic volume control bias is more difficult to apply.



(a)



(b)

Fig. 13

Fig. 13(b) shows a heptode with a special electrode structure designed to reduce the interaction between the signal and oscillator circuits. This structure is different from the previous one in that it has curved collector plates which partly enclose the second grid and are connected to it. The third grid also has its support wires opposite the openings in the collector plates. This makes the potential opposite the openings more negative than on either side of the grid support wires and electrons are deflected sideways as shown by the arrows in Fig. 13(b). This means that electrons which are repelled by the signal grid (grid three) are unable to return to the oscillator section of the valve, but return instead to the collector plates. This considerably reduces interaction between the signal and oscillator circuits.

A valve with six grids is the octode. For normal use as a frequency changer the first two grids are connected as a triode oscillator and the signal is injected into grid four. Grids three and five are used as screen grids and the sixth grid is a suppressor. This arrangement further reduces electric coupling between signal and oscillator circuits. The valve may also be fitted with deflector plates in the same manner as the heptode with a similar effect.

<u>END</u>