Pentode and Tetrode Output Valves

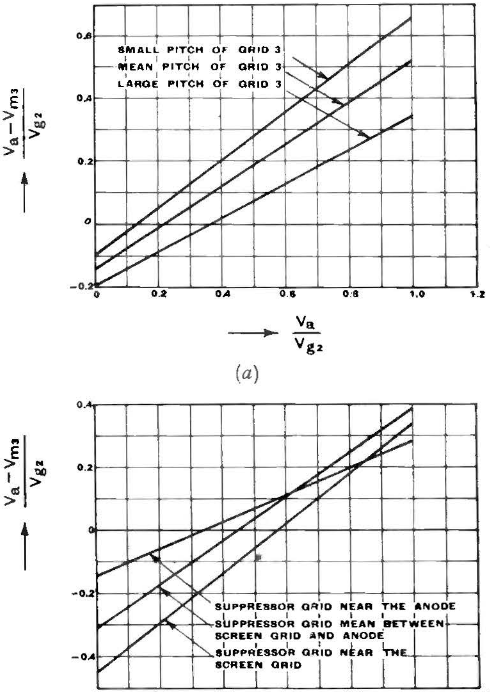
By J. L. H. Jonker

(Natuurkundig Laboratorium der N. V. Philips' Gloeilampenfabrieken, Eindhoven, Holland)

[*Concluded from page 286 of June issue.*]

§ 5. The Suppressor Grid

The use of a separate grid at cathode potential as a means of suppressing secondary emission offers the advantage that the action of the grid is entirely independent of the value of the anode current, so that the whole area of the $I_a - V_a$ characteristics may in principle be free from secondary emission. That this, however, is not sufficient for a good modern pentode, is obvious from the fact that older type pendodes with complete suppression of secondary emission are far inferior in efficiency to the more recent types. These improvements have been made possible by the increased knowledge and by the judicious application of the phenomena occurring in a pentode during operation. To illustrate this we will examine the action of a suppressor grid before making a study of the potential minimum which the suppressor grid creates between the anode and screen-grid. To facilitate comparison, a curve similar to that in Fig. 12 may be plotted for the potential minimum caused by suppressor grid. The mean potential[24] in the plane of the suppressor grid being represented by V_{m3}, we have plotted in Fig. 15 (a) the value of the counter-voltage $\frac{V_a - V_{m3}}{V_{g2}}$ for different values of $\frac{V_a}{V_{g2}}$. This has been done for different values of the pitch of the suppressor grid. Owing to the influence which the screen-grid, being at high potential, exerts upon the mean potential in the plane of the suppressor grid, it is possible that, at low values of the anode voltage, the latter may drop below the potential V_{m3}, in which case there will be no counter-voltage left. If the $I_a - V_a$ characteristic is not to show any deformation, which means that no secondary emission may be allowed to pass, the suppressor grid will need to be of so small a pitch that the potential V_{m3} up to the elbow of the $I_a - V_a$ characteristic remains sufficient to suppress secondary emission. For other reasons, however, a small pitch is undesirable, because, when primary electrons are approaching the wires of the suppressor grid, they are repelled by the negative charge on these grid wires[25] and either deflected from their path or thrown straight back. If the screen-



(*a*)

(*b*)

Fig. 15.—*Characteristic of the counter-voltage caused by a suppressor grid in a pentode, as a function of anode voltage. This counter-voltage is the difference between the anode voltage and the mean potential in the suppressor grid.* (*a*) *The pitch of the suppressor grid was taken as parameter.* (*b*) *The position of the suppressor grid between the screen-grid and anode has been taken as parameter.*

grid potential is high and the anode voltage low, a number of electrons that have been strongly deflected may return to the screen-grid. However, when the anode voltage rises, the potential V_{m3} will increase, a portion of these electrons will be deflected less and manage to reach the anode. At low anode voltages, therefore, the screen-grid current will increase at the expense of the anode current. If on this account the elbow of the $I_a - V_a$ characteristic shows too great a rounding, the valve will have too low an efficiency (§ 2).

Fig. 16 (a) gives a photograph of the course of the electrons in a grid of this type, taken from a model using small balls rolling across a sheet of rubber[26]. In order to show up the deflection, it is assumed for simplicity's sake that the electrons do not undergo tangential deflection at the other grids and therefore move straight towards the suppressor grid. V_a is assumed to be equal to $\frac{1}{8} V_{g2}$.

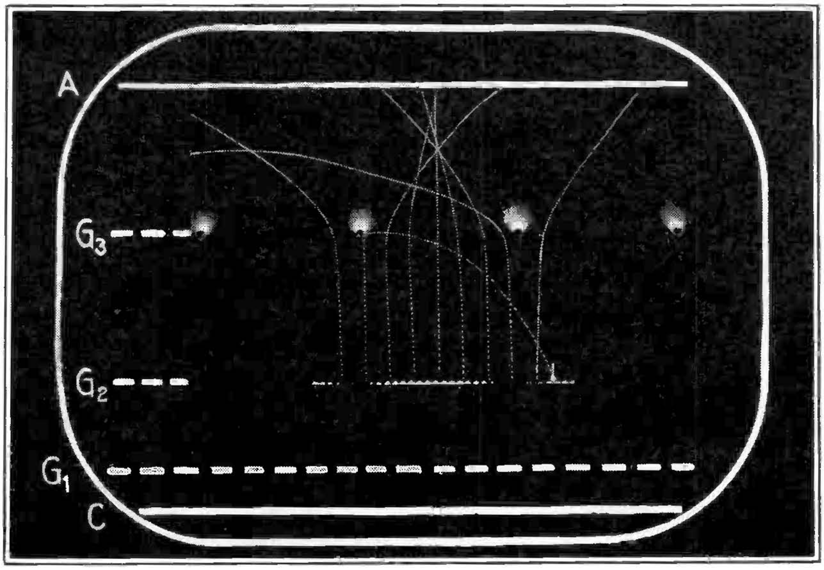


Fig. 16 (*a*).—*Photograph of the course of the electrons between the screen-grid and anode of an old type pentode output valve at low anode voltage* ($V_{g2} = 8\ V_a$). *The photograph was taken from a model using small balls rolling over a sheet of rubber. Electrons that come close to the wires of the suppressor grid are strongly deflected, so that many of them cannot reach the anode and must therefore return to the screen-grid.*

The photograph shows plainly which of the electrons are strongly deflected or thrown back ; it can be seen that these are the electrons which happen to come too close to a grid wire. In order to diminish the number of electrons returning in this way, the following expedients may be adopted :

(1) Diminish the charge of the suppressor grid wires, thus reducing the force of repulsion acting upon a passing electron and so diminishing the deflection.

(2) Give the suppressor grid a larger pitch, thus diminishing the number of points of disturbance.

(3) Direct the electron beams between the suppressor grid wires, so that no primary electrons can come within close quarters of these wires.

Points 2 and 3 have been applied in beam tetrodes. The "beam plates" are positioned as far as possible outside the electron beam and form a sort of grid with a very large pitch. In this way the rounding of the elbow is diminished, but a large part of the effect of the suppressor grid is lost. A certain counter-voltage will be possible only at high anode voltages as can easily be inferred from Fig. 15 (a). The necessary counter-voltage can, however, be obtained by the use of a space charge as we have seen in § 4. The action of the suppressor grid and space charge do not, however, completely supplement each other, as the counter-voltage produced by these two expedients decreases for lower anode voltages and is at its maximum for equal values of the anode and screen-grid voltages.

Points 1 and 2 have been applied in the modern pentodes. We will now examine, how this has been achieved while at the same time making use of space charge to supplement the action of the suppressor grid. It is found that points 1 and 2 can be complied with by placing the suppressor grid in a favourable position. In Fig. 15 (b) a graph has been plotted which shows how the trend of the counter-voltage varies with anode voltage in the case of a suppressor grid with a constant pitch, when this grid is set at different positions in the space between the anode and screen-grid. With a small distance between suppressor grid and anode, the counter-voltage at low anode potential still remains positive.

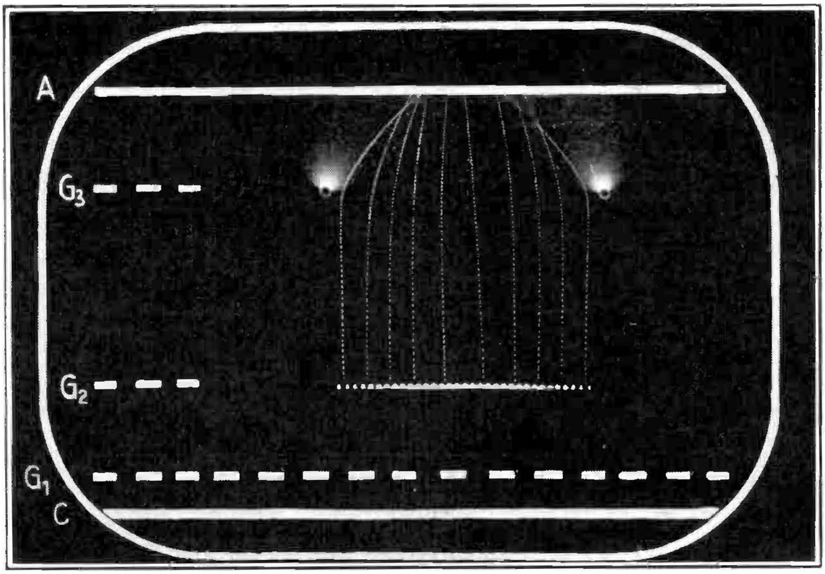


Fig. 16 (*b*).—*Photograph of the course of the electrons in the space between the screen-grid and anode of a modern pentode output valve at low anode voltage* ($V_{g2} = 8\ V_a$). *The photograph was taken from a model using small balls rolling over a sheet of rubber. In contrast to Fig.* 16 (*a*), *the deviation in this case is not so serious and the electron focus is behind the plane of the anode.*

If, therefore, the suppressor grid is positioned close to the anode and relatively far away from the screen-grid, a larger pitch may be taken. A photograph of the course of the electrons through a suppressor grid of this kind is given in Fig. 16 (b). In this example also $V_a = \frac{1}{8} V_{g2}$. A larger pitch has been selected than in Fig. 16 (a), and it can be seen that the deflections are smaller. However, the wires of the suppressor grid still tend to repel the electrons and give rise to the formation of a convergent beam whose focus is in this case behind the anode, whilst the maximum concentration of electrons on the anode is located midway between the grid wires. By means of this construction we can make the suppressor grid and the space charge co-operate in such a manner that they supplement each other. In what respect does the action of the suppressor grid need supplementing? If the pitch of the suppressor grid is made too large, the counter-voltage will prove insufficient at low anode voltages as shown by Figs. 15 (a) and 15 (b). As this action is independent of anode current, we would thus obtain—in contrast to Fig. 14—a set of curves in which all the curves show, below a certain anode voltage, a dip due to secondary electrons. The reason for this is that the anode voltage, when at low values, becomes equal to the potential at the suppressor grid and therefore the counter-voltage vanishes. This, as shown in § 2, would be no drawback for low anode currents, as the dynamic curves do not come within this region. For higher currents this would, however, cause undue distortion. We have seen in § 4 that when an electron current passes between two electrodes of equal potential, the potential characteristic soon begins to sag. A virtual cathode will, however, only be formed at very high values of the current (Fig. 12), so that an undesirable distribution of current due to returning electrons will not so readily occur. The current density in the space between the anode and the suppressor grid may be assigned such a value that a sufficient potential minimum is formed at high current values. The beam formation caused by the convergent lens effect of the suppressor grid wires helps to bring about this result. In old pentodes, on the contrary, the current density in the electron focus occurring between anode and suppressor grid (Fig. 16a) may cause the appearance of a virtual cathode at a relatively high anode voltage. Up to now we have, for simplicity's sake, only taken into account the mean potential in the plane of the suppressor grid. If the grid has a large pitch, the potential characteristic will show a pronounced sag in the plane between two wires of the suppressor grid[25]. The potential is most positive midway between these wires, so that this is the first place at which secondary electrons can pass to the screen-grid. It is at this spot, therefore, that the supplementary effect of space charge should first be exercised, and we achieve this by forming the primary electrons into a beam at the middle position as mentioned above.

It thus appears that, by selecting a suitable value for the current density and a suitable geometrical form for the suppressor grid, a space charge can be made to act as a very good supplement to the action of an open meshed suppressor grid.

An open meshed suppressor grid does not cause the detrimental rounding at the elbow of the anode current/anode voltage characteristic, common to the older grid constructions, and at the same time secondary emission can be suppressed over the entire region of operation.

§ 6. Deflection of the Electron Paths in Grids

As we have already seen, a sharp bend in the $I_a - V_a$ characteristic is not of itself sufficient to ensure good efficiency in a power valve. To enable the valve to be " swung out " to the fullest extent, the envelope formed by the elbows of the various anode current characteristics should be positioned as close as possible to the vertical axis. Hence, with increase of anode voltage, from zero onwards, the anode current should show as steep a rise as possible.

There are, however, two important factors, indicated by Below[14] and other writers, which tend to diminish the steepness of this rise. These are: the formation of a virtual cathode between the anode and screen-grid, and the deflection of the electron paths in the grids. The electrons which are most strongly deflected have a lower velocity in the anode direction and hence do not reach the anode until higher anode voltages are applied, and this causes the elbow of the $I_a - V_a$ characteristic to be shifted over a certain voltage $V_{\max}$ to higher potentials. As we have seen above, a virtual cathode is only formed in tetrode output valves, so that these valves are at a disadvantage as compared with pentodes. In both cases, however, the deflections in the grids should be reduced to a minimum. Deflection in the suppressor grid has already been dealt with.

As the screen-grid voltage V_{g2} is the highest potential, the absolute value of the sideways velocity component due to deflection will be greatest in this grid, so we must investigate this deflection. Assuming for simplicity's sake that the mean potential in the 1st and 3rd grid is nil, we can deduce from Below's calculations for concentric cylindrical electrodes that the maximum voltage (velocity) which electrons can lose for a plane parallel electrode arrangement in the anode direction will be

$$V_{\max} = \frac{V_{g2} S^2}{16}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)^2,$$

where S is the pitch of the screen-grid and d_1 and d_2 are the distances to the adjacent electrodes.

It is thus essential to make this deflection as small as possible. This means that the screen-grid should have a small pitch and that its distance to the adjacent electrodes should be large. If the screen-grid had a small pitch the screen-grid current would show too great an increase unless the wires of the 1st and 2nd grid were placed one behind the other. By doing this it is possible to direct the concentration of electrons in the screen-grid in such a manner that the bulk of the electrons do not come near the screen-grid wires and hence are less liable to be picked up and diverted from their path (Fig. 17).

This state of affairs has been realised, for instance, in certain tetrode output valves. However, it also has its disadvantages. For instance, the screen-grid current differs considerably in different specimens of the same valve type, because a very slight displacement of the grids with respect to each other gives rise to large differences. This will be no drawback if the screen-grid current is not supplied via a series resistance. A drawback does, however, lie in the fact that the size of pitch is subject to practical limits. If the screening of the screen-grid wires by the wires of the control grid is to be effective, the electron lens formed by these grids should have its focus as close to the screen-grid as possible. It is obvious, however, that for certain grid voltages, we are bound down to certain geometrical relationships. The minimum distance between the two grids, itself limited for constructional reasons, determines the pitch of the two grids and hence the distance between the control grid and the cathode, which is an undesirable restriction.

For valves with a high slope it is, however, particularly desirable to have a small distance between the control grid and the cathode. Modern valve technique is perfectly able to achieve distances of from one to three tenths of a millimetre between an incandescent cathode and a grid of very fine wire (30 — 80μ). But in that case it is also necessary to give the control grid a small pitch, otherwise the slope, especially for small currents, will be diminished by the formation of a tail (diode effect). This would cause undue distortion at high signal amplitudes. Hence, even with a system of grids placed one behind the other, we must accept a compromise between distortion, slope and screen-grid current.

It is also possible in this way to obtain a more uniform distribution of electrons in the space between the anode and screen-grid, which in tetrodes is of special interest for the formation of space charge. A possible advantage would thus seem to be afforded for tetrodes, whereas in modern pentodes no improvement is to be gained. Deflection at the control grid is usually of less consequence than in the screen-grid, though under certain conditions it may tend to increase the anode voltage at which the elbow in the $I_a - V_a$ characteristic occurs.

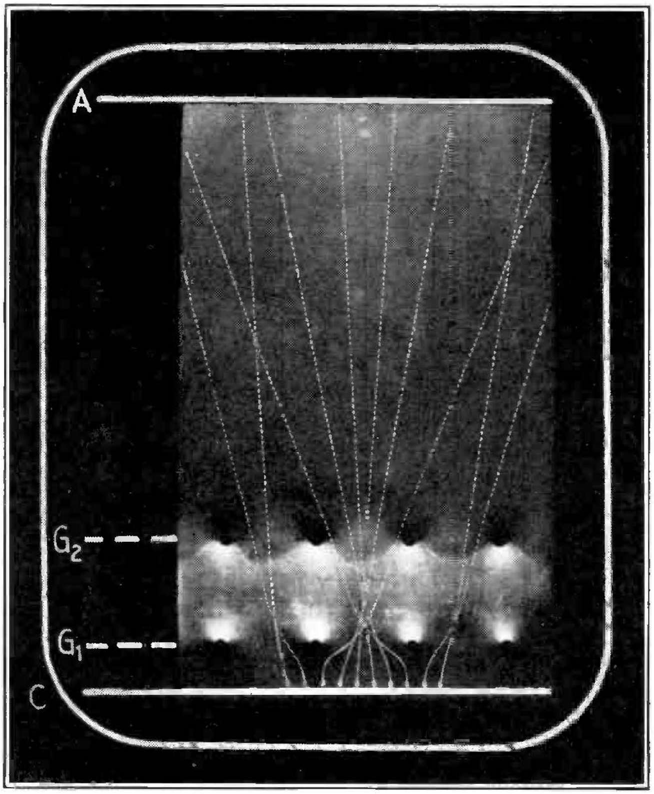


Fig. 17.—*Photograph of the course of the electrons in the space between cathode and anode when the wires of the control grid and screen grid are positioned one behind the other. The photograph was taken from a model using small balls rolling over a sheet of rubber. By placing the grid wires one behind the other a decrease of the screen-grid current has been achieved. A considerable deflection still occurs, however, in the screen-grid. The anode voltage was low* ($V_{g2} = 8\ V_a$), *and the control grid was at zero potential.*

§ 7. Conclusion

Both the tetrode and pentode output valves, when used singly, are able at low potentials to yield a good efficiency with low distortion. This can be achieved by employing a simple construction and by suppressing secondary emission by means of a minimum potential which is formed by the mixed effect of a suppressor grid and a space charge. In the tetrode, the effect of space charge is predominant and the suppressor grid is reduced to a pair of plates. This involves the disadvantage that for *low currents* the detrimental influence of secondary emission cannot be entirely avoided The maximum output that can be delivered is then limited by the fact that the formation of a virtual cathode reduces the swing of the anode voltage.

In the pentode, secondary emission is suppressed mainly by the action of the suppressor grid, and this action can be supplemented at low anode voltages by the use of space charge. Distortion may be less than in tetrodes, as the entire serviceable region of the $I_a - V_a$ characteristics can be kept free from secondary emission and as a result the characteristics show less deformation.

As the formation of a virtual cathode can be avoided, the " elbow voltage " will be determined only by deflections in the grids. By the employment of good geometrical proportions these deflections can be reduced to a very low value.

Finally, I should like to tender my hearty thanks to Messrs. Gall and Heins van der Ven for the kind assistance they have rendered in enabling me to obtain some of the data used in this paper.

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Correspondence

Ground and Ionospheric Rays

To the Editor, The Wireless Engineer.

SIR,—In the course of some recent work I have discovered an error in some of the curves given in my paper " Ground and Ionospheric Rays—A Computation of the Relative Intensities on Various Wavelengths from Existing Data " which was published in *The Wireless Engineer*, June, 1937, Vol. XIV., pp. 306–314. I wish to draw your attention to this error and to correct it as far as possible. The error was due to a slip in the computation of the attenuation of the direct ray over sea and was of such a nature as to have a negligible effect on wavelengths of 300 metres and above.

The curves which are in error are those giving the intensity of the " ground " ray for earth conductivity $\sigma = 10^{10}$ e.s.u. (i.e. over sea) in Figs. 1–5 inclusive and 10 and 11. All the other curves in the paper are unaffected, in particular all the curves for the ground ray over soil having specific conductivity $\sigma = .9 \times 10^8$ e.s.u. and the curves for the intensity of the ionospheric ray are correct as published.

I should be indebted to you if you would publish the two diagrams given herewith. The curves

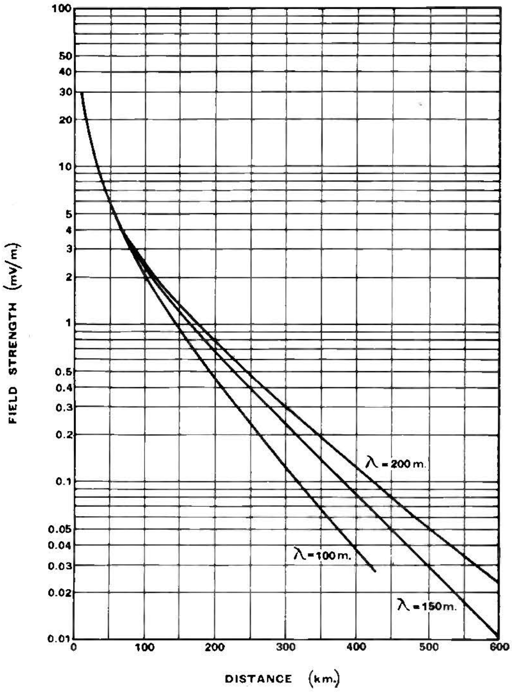

Fig. 1.—*Field strength over sea ($\sigma = 10^{10}$ e.s.u.). Transmitter — ground level. Radiation — 1.5 kW. Energy uniformly distributed in all directions.*