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THERMIONIC VALVE AMPLIFIER

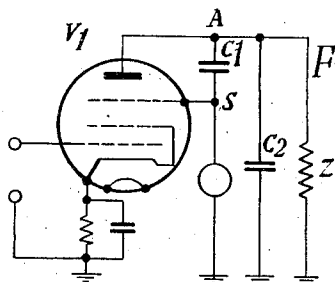Filed March 24, 1942
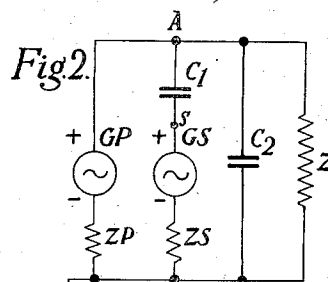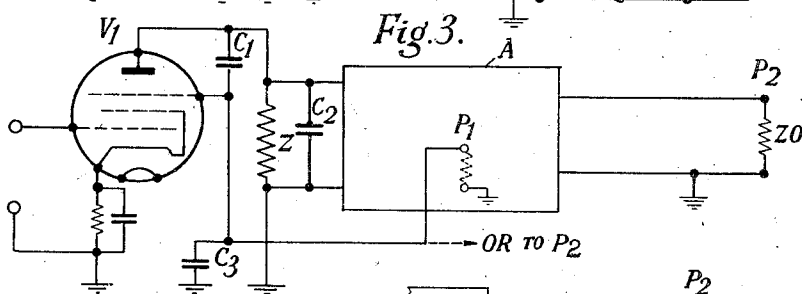
Fig.1.

Fig.2.
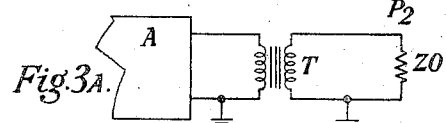
Fig.3.

Fig.3A.

Fig.4.
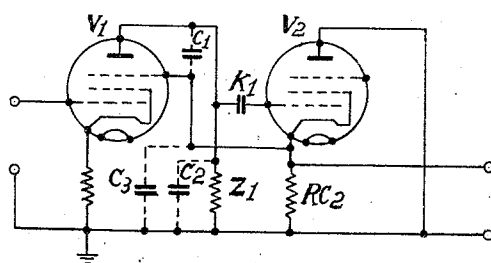
Fig.4A.
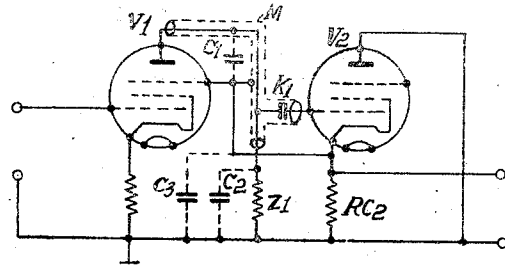
Fig.5.
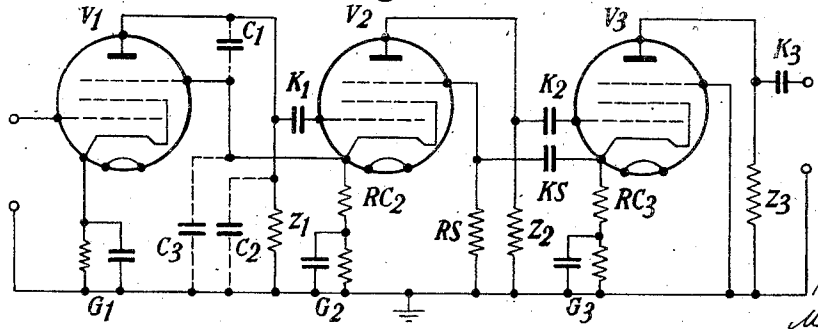
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This invention relates to improvements in amplifier circuits using pentode valves. It concerns the reduction of the effect of certain stray capacities associated with such valves.

One of the causes which limits the efficiency of an amplifying valve at high frequencies is the capacity associated with the plate and its connections, which shunts the load connected in the plate circuit. In pentodes a large proportion of this undesirable capacity is represented by the capacity between the plate and the suppressor grid. By eliminating or reducing the effect of this capacity in the manner to be explained, the amplification obtainable from the pentode stage may be increased by 10 decibels, for example.

The invention is particularly easy to apply to circuits including pentode valves followed by impedance reducing stages, such as valves connected as cathode followers. It is also applicable to circuits in which the valves operate on the nonlinear parts of the characteristics, for example, to circuits for amplifying impulses.

The principal object of the invention therefore is to improve the operation of pentode amplifiers at high frequencies by the elimination, partly or wholly, of the effect of the stray capacities associated with the plate circuit of the pentode valves. This object is accomplished by connecting the suppressor grid of any such pentode to some point in the amplifier, the alternating potential of which is equal to or nearly equal to the alternating potential of the plate of the pentode. In this way the terminals of the capacity between the plate and the suppressor grid (which frequently is a large fraction of the total plate capacity) are maintained at nearly the same potential. Thus the current which would flow through this condenser is reduced to a very small value.

According to another aspect, the suppressor grid is made to screen the plate from earth, and the principle may be extended by supplying the external connections to the plate of the pentode with a screen which is connected to the suppressor grid, and in this way the capacities associated with the external circuit are also eliminated or reduced. The effect of this process may be regarded as equivalent to connecting across the unwanted capacity a negative capacity by which it is neutralised.

According to certain special features of the invention, the point in the amplifier to which the suppressor grid should be connected should preferably be such that the impedance measured between the point and earth is relatively low in

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order that the capacity which will be introduced by the connection of the suppressor grid and the external screen, if any, may have an inappreciable effect.

The phase of the alternating potential of the point to which the suppressor grid is connected should preferably be the same as the phase of the alternating potential which appears on the plate of the pentode in order that the corresponding difference of potential shall at all times be small. It may happen that the point to which it is desired to connect the suppressor grid has the opposite phase in which case connection is made through a transformer, the windings of which are connected in such a direction that the desired phase is produced on the suppressor grid.

According to another feature, the alternating potential of the suppressor grid may also be chosen to be higher than that of the plate of the pentode in which case additional current is fed through the stray capacity concerned. This enables other stray capacities associated with the plate impedance to be neutralised. By another variation, the phase of the alternating potential applied to the suppressor grid may be chosen to have any relation with respect to the phase of the plate and by this the effect of shunting the capacity between the plate and suppressor grid by any impedance, positive or negative, can be produced.

According to an embodiment of the invention, an amplifier consists of a first pentode stage followed by other stages comprising valves connected as cathode followers. The suppressor grid of the pentode is connected to the cathode of the following valve, the AC potential of which will generally be very nearly the same as the potential of the plate of the pentode. Furthermore, the impedance to ground of this cathode is usually small compared with the impedance to ground of the plate of the pentode. In this way the principles of the invention which have just been explained are carried out. The same arrangement may be adopted for any pentode in any of the subsequent stages of the amplifier.

In another embodiment, the amplifier comprises some stages with negative cathode feedback. The cathode of any valve is then connected to the suppressor grid of the preceding valve. In this way, the capacity between the plate and suppressor grid of certain of the valves may be reduced by an amount depending upon the value of the negative feedback of the corresponding following valve.

These features of the invention will be more

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clearly understood from the following detailed description and by consideration of the attached sketches in which:

Fig. 1 shows schematically a pentode valve arranged as an amplifier;

Fig. 2 shows the schematic of the equivalent electrical circuit;

Figs. 3 and 3a show the method of connecting the suppressor grid of a pentode valve in accordance with the invention;

Fig. 4 shows an embodiment in which a pentode valve is followed by a valve connected as a cathode follower;

Fig. 4A shows a modification of the embodiment shown in Fig. 4.

Fig. 5 shows the circuit of an amplifier having stages with negative reaction.

In Fig. 1 is shown a pentode valve V1 which may form part of an amplifying circuit. The load impedance Z of the plate circuit is shunted by a series of stray capacities which limit the amplification of the circuit at high frequencies. These capacities can be conveniently divided into two portions; C1 which represents the capacity between the plate and the suppressor grid, and C2 which represents the capacity to ground of the plate (exclusive of C1) and of the connecting leads. Fig. 1 is intended to show the circuit effective as regards the amplification of high frequency voltages, which may be assumed to be applied to the control grid. The arrangements for polarising the plate and grids and other details are accordingly omitted.

The effect of the capacity C1 can be reduced if a varying potential, in phase with the plate potential produced by the signal applied to the grid, be connected to the suppressor grid. If this varying potential be nearly equal to the plate potential, then the voltage across the condenser C1 will always be small and its effect will thus be greatly reduced.

This will be made clearer by reference to Fig. 2 which shows the essential circuit characteristics of Fig. 1. The points A and S correspond in the two circuits. The plate circuit is represented by a generator GP in series with an impedance ZP corresponding to the internal output impedance of the valve. The generator GS in series with ZS represents the effect of connecting the varying potential to the suppressor grid. The generator GS as already explained is in phase with GP, as indicated by the plus and minus signs in Fig. 2. If GS is adjusted to bring the points A and S to the same or nearly the same A. C. potential, then the current which flows through C1 will be small or zero. The corresponding voltage drop produced in ZP by the current in C1 will thus be practically eliminated. Further, if the point S can be brought to a potential higher than that of A, current will flow in the reverse direction in C1 from GS. This means that extra current will be supplied to Z by which the effect of C2 (and perhaps also of other similar stray capacities introduced in Z) will be neutralised.

The effect of the generator can be regarded as equivalent to connecting a negative capacity in parallel with C1, whose value depends upon the voltage of the generator. It is also possible to produce the effect of connecting various kinds of negative or positive impedances in parallel with C1 by suitably choosing the amplitude and phase of the output of the generator GS with respect to GP.

According to the usual method of operating pentodes, the suppressor grid will be connected to

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a point of constant potential (normally equal to or near that of the cathode) in order to maintain it at a potential sufficiently low with respect to the plate to suppress the secondary electrons produced thereat. The potential difference between the plate and the suppressor grid will thus usually be equal to or a little less than the applied plate voltage. The alternating plate potential in an amplifying valve due to the signal is however generally small compared with the applied plate voltage, and accordingly the suppressor grid can be connected to a point of alternating potential without substantially affecting its function in suppressing the secondary electrons, so long as this alternating potential is of the same order as the alternating plate potential. In general this will be the case and in the most interesting case when the potentials of the plate and suppressor grid vary in phase for eliminating the effect of C1, the difference of potential between the plate and the suppressor grid will be maintained approximately constant.

Fig. 3 shows schematically one way in which the desired varying potential may be obtained. The block A represents the remainder of the amplifier of which the valve V1 is supposed to form a part. The effective ground capacity of the suppressor grid is represented by C3.

The required variable potential for the suppressor grid is preferably taken from some point P1 in the amplifying circuit as shown where the impedance to ground is sufficiently small for the effect of the capacity C3 added in parallel to be unimportant. A particularly interesting case is that in which the amplifier works into a low output impedance ZO. If the output potential is in phase with the plate voltage of the valve V1 the suppressor grid may be connected to the output at P2, for example. If there is phase opposition, a transformer T may be connected in front of ZO as indicated in Fig. 3A, and the suppressor grid can be connected to the output side of the transformer at P2. The capacity C3 which now comes in parallel with ZO will have a negligible effect because ZO is small.

If it should be desired to connect the suppressor grid to an internal point such as P1 (Fig. 3), where the phase is opposite to that necessary to eliminate the effect of C1, a transformer may also be used in a manner similar to that just described.

Fig. 4 shows the circuit of a two-stage amplifier which exhibits certain other aspects of the invention. The stray capacities C1, C2 and C3 are shown in dotted lines associated with the first valve V1. The second valve V2 is shown connected as a cathode follower.

The suppressor grid of the valve V1 is connected to the cathode of V2, and on account of the fact that V2 is arranged as a cathode follower, the potential of the suppressor grid of V1 will be generally nearly the same as the potential of the grid of V2. As this grid is coupled to the plate of V1 through the condenser K1 it follows that the potential of the suppressor grid of V1 will always be very nearly the same as the potential of the plate. Thus the effect of the capacity C1 will be practically eliminated.

Since V2 is connected as a cathode follower, the cathode resistance RC2 can be very small compared with the plate resistance Z1 of the valve V1. It can, for instance, be 1/10 or even 1/20 of Z1. It will be seen from Fig. 4 that the capacity C3 is connected across RC2, and its effect

will accordingly be negligible because RC2 is small.

Some idea of the advantage gained by this arrangement will be obtained from the following numerical example. If the valve V1 is a high slope pentode, the capacity between the plate and earth will be about 9 $\mu\mu f$. The capacity to earth of the grid of valve V2 might be about 12 $\mu\mu f$., but since this valve is connected as a cathode follower the effect of this capacity could be reduced to $\frac{1}{10}$, for instance, because the grid and the cathode will be nearly at the same potential. Accordingly the grid earth capacity of V2 can be taken as effectively equal to about 1.2 $\mu\mu f$. The capacity to earth of the external connections to the plate of V1 can generally be arranged to be not more than about 2 $\mu\mu f$. Thus the total effective capacity to earth of the plate of V1 would be

$$9+1.2+2=12.2 \ \mu\mu f.$$

that is, if the suppressor grid of V1 is not connected to the grid of V2. When, however, this connection is made, the effect of the capacity C1 may be reduced to $\frac{1}{10}$. In many valves, C1 will be 80% of the total plate-earth capacity that is, about 7 $\mu\mu f$. say. Accordingly the capacity C1 is effectively reduced to about 0.7 $\mu\mu f$. The total capacity of the plate of V1 now becomes

$$2+0.7+1.2+2=5.9 \ \mu\mu f.$$

that is, a little less than $\frac{1}{2}$ of the preceding value. With a given value, and with the same circuit configuration, therefore, it would now be possible to increase the plate resistance Z1 twice, thereby increasing the gain by 6 decibels.

It will be noted that the suppressor grid forms a partial screen between the plate and earth. This screen may be extended as shown in Fig. 4A to include the external connections to the plate by surrounding them by a conducting metal screen M which is connected to the suppressor grid. This screen could with advantage include also the condenser K1 which couples the plate of V1 to the grid of V2 in Fig. 4. This will have the effect of suppressing part of the capacity C2 because most of it now comes in parallel with C1. The capacity of the screen which has been added will, of course, increase the capacity C3, but so long as this increase of capacity is not too great, or so long as the resistance RC2 is sufficiently small, this will not introduce any objection.

In Fig. 5 is shown a three-stage amplifier containing valves connected with negative reaction and in which the capacity of C1 is effectively suppressed in a manner very similar to that of Fig. 4. The first valve V1 is connected as an ordinary amplifier without reaction and has a shunted biassing resistance G1 connected in series with the cathode. It is coupled to the next valve V2 by means of the plate resistance Z1 and the coupling condenser K1. Valve V2 is provided with a shunted biassing resistance G2 and also with a resistance RC2 in series to provide the negative reaction. This valve is in turn coupled to the valve V3 by means of plate resistance Z2 and coupling condenser K2. The valve V3 is similarly provided with a shunted biassing resistance G3 and resistance RC3 to provide the negative reaction. The output is taken from valve V3 across the plate resistance Z3 through coupling condenser K3. The stray capacities C1, C2 and C3 are shown connected to the valve V1, as before, by dotted lines. The suppressor grid of V1 is connected to the cathode of V2 as in Fig. 4 and

the suppressor grid of V2 is coupled to the cathode of V3 by an alternative arrangement involving a shunt resistance RS and a coupling condenser KS, which has been shown by way of example. The suppression of the effect of capacity C1 in the circuit of Fig. 5 occurs in a manner similar to that in Fig. 4 and the degree of suppression will depend upon the amount of negative reaction in the valve V2. For example, if the negative reaction produced by RC2 is 12 decibels, the potential of the cathode of V2 will be about $\frac{3}{4}$ of the potential of the grid, and accordingly the effect of the capacity C1 will be reduced to about $\frac{1}{4}$. The effect of the capacity in valve V2 corresponding to C1 will be reduced by valve V3 in exactly the same way, because as before the resistance RC3 will be much smaller than the plate resistance Z2, and will not be affected by the alternative method of coupling the suppressor grid which has been shown. The suppressor grid could also have been coupled to the cathode by other means such as, for example, by the use of a transformer.

It will be seen that as regards the function of suppressing the effect of the capacity C1, the circuits of Figs. 4 and 5 are equivalent, but the suppression in the case of Fig. 4 is likely to be more complete because the grid potential is generally nearly the same as the cathode potential while in Fig. 5 the grid potential will usually be somewhat higher than the cathode potential, depending upon the amount of reaction.

The arrangements which have been described are also applicable to amplifiers in which the valves operate on the non-linear portions of the characteristics, such as are used for amplifying impulses. The potential of the cathode of any of the valves follows substantially the corresponding grid potential and so also the preceding plate potential as soon as the impulse reaches a certain voltage; the circuit then operates as described.

The preceding circuits have been given only as examples, and various other means for connecting the suppressor grid in accordance with the invention can be imagined; for example, in an amplifier with feed-back, the feed-back circuit can be used for transmitting the desired potential to the suppressor grid.

What is claimed is:

1. A thermionic amplifier system comprising amplification means including a series of coupled amplifying stages having a tube in each stage, the first stage tube being a pentode, and means for at least partially neutralizing capacity between the pentode anode and ground, comprising potential-transmitting coupling between the pentode suppressor grid and a point in the amplifier system having an alternating potential of the same frequency and phase as the alternating potential of said anode and a maximum value at least equal to the maximum value of said anode potential.

2. A thermionic amplifier system comprising amplification means including a series of coupled amplifying stages having a tube in each stage, the first stage tube being a pentode, and means for at least partially neutralizing capacity between the pentode anode and ground comprising a potential-transmitting coupling between the pentode suppressor grid and a point in a subsequent stage having an alternating potential of the same frequency as the alternating potential on said anode, and of no lower peak value.

3. A thermionic amplifier system as set forth in claim 2, in which said suppressor grid is con-

nected to the cathode of a tube in a subsequent stage, said cathode being at a potential different from ground potential.

4. A thermionic amplifier system as set forth in claim 2, in which said suppressor grid is connected to the cathode of the tube in the succeeding stage, and said succeeding stage has a negative reaction coupling with the first stage.

5. A thermionic amplifier system as set forth in claim 2, in which said suppressor grid is connected to the output of a subsequent stage.

6. A thermionic amplifier system as set forth in claim 2, including means for shifting the phase of the alternating potential applied to said suppressor grid.

7. A thermionic amplifier system as set forth in claim 2, including means for reversing the phase of the alternating potential applied to said suppressor grid.

8. A thermionic amplifier system as set forth in claim 2, in which said point in the amplifier system has a low impedance to earth, the arrangement being such that the capacity intro-

duced by said coupling between said point and said suppressor grid is substantially without effect on the operation of said subsequent stage.

9. A thermionic amplifier system as set forth in claim 2, in which said coupling comprises a shield connected to said suppressor grid, said shield being in shielding relation to and capacitatively coupled with the connection between the control grid of the subsequent stage and the anode of said pentode.

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