Sept. 1, 1942. B. M. HADFIELD 2,294,862

THERMIONIC VALVE CIRCUITS

Filed July 10, 1940

Fig. 1.

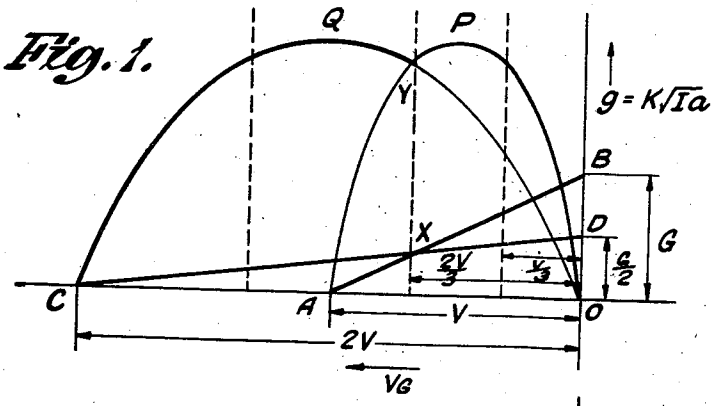
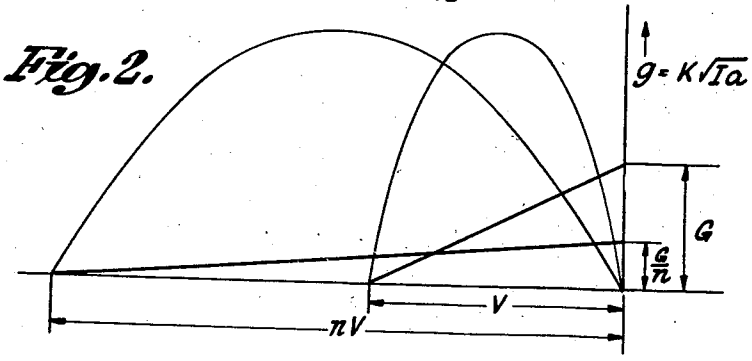


Fig. 2.



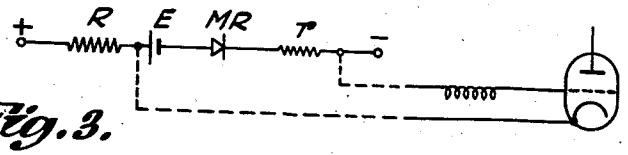
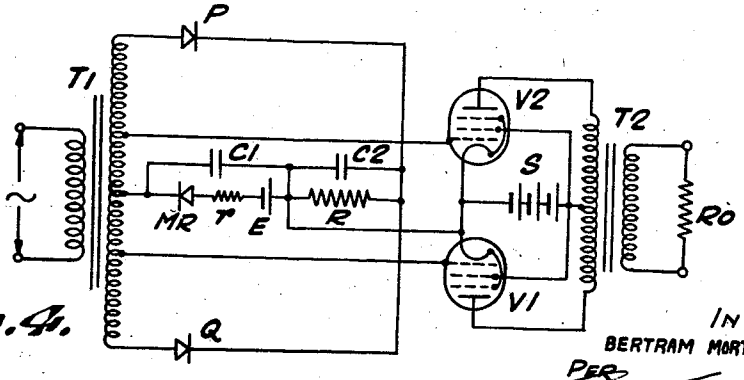


Fig. 3.

Fig. 4.



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THERMIONIC VALVE CIRCUITS

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5 Claims. (Cl. 179—171)

The present invention relates to thermionic valve circuits and is more particularly concerned with thermionic valve circuits in which a substantially constant alternating output may be obtained over any given range of input levels.

The object of the invention is to provide a circuit of this type in which the output has substantially the same waveform as the input.

It is well known that the thermionic valve characteristic connecting the anode current and the potential on a control grid is closely parabolic over a wide range, so that the anode current is proportional to the square of the control grid potential, reckoning the latter from the value which produces substantially zero anode current. At any given value of control grid potential, the slope of the tangent to the characteristic will represent the mean change of anode current per unit change of control grid potential, so that if an additional alternating input be applied to the control grid, the output of alternating anode current will be proportional to the product of the input alternating control grid voltage and the slope of the tangent, the latter being expressed as a ratio of the change in anode current per unit change in control grid potential.

It can be shown that the slope of the tangent, as defined above is proportional to the control grid potential (reckoned from the zero anode current potential) and as the latter is proportional to the square root of the anode current, it follows that if the square roots of the anode currents at various control grid potentials are plotted, a straight line will be obtained which represents the variation of the slope of the tangent at these control grid potentials.

According to one feature of the invention a direct current bias, whose value is proportional to the alternating input, is applied to a control grid of a thermionic valve in series with the alternating input, the initial bias on the control grid being very small so that a large anode current flows in the absence of an alternating input. As described above, the output of alternating anode current will be proportional to the product of the slope of the control grid/anode current characteristic and the alternating input. As the latter is proportional to the control grid potential, the variation of alternating output with input can be determined by taking the product of the control grid direct current potential (due to the alternating input) and the slope of the control grid/anode current characteristic at each potential. Since the relation between these two variables is linear, the relation between the alternating input and the output will be a parabola, whose maximum value occurs at a control grid potential of one half the difference between the initial bias (with no input) and the bias necessary to produce zero anode current. The output will be zero when the alternating input is zero and also when the bias due to the alternating input is such as to produce zero slope (i. e. zero anode current).

Figures 1 and 2 show characteristics explaining the operation of the invention.

Figure 3 and 4 show specific embodiments of the invention.

Thus referring to Fig. 1 of the accompanying drawing, the mutual conductance or slope of the grid volts/anode current characteristic has been plotted on a vertical axis as g, whilst the corresponding grid voltage Vg is plotted on a horizontal axis. As pointed out above the relation between g and Vg is a straight line such as AB, if the grid volts/anode current characteristic is a parabola. The parabola APO represents the relation between the output and input voltages.

Let the difference in biasses on the control grid between the initial value (with not input) and the value producing no anode current be V, and the value of the initial slope be G (i. e. at V=0). Then the output is proportional to the product V. G., and since the relation between them is linear the maximum output is

$$\frac{V.\ G.}{4}$$

occurring at an input bias of $V/2$. The change of output above this value is small depending on the working limits assigned to V. For instance, assuming that V varies from $V/3$ to $2V/3$, then G will vary from $2G/3$ to $G/3$ respectively, and therefore the output at these values is $2VG/9$. The change in output therefore, over this range of input levels (6 db. on voltage ratio basis) is from $VG/4$ to $2VG/9$, or a change of 11.2%.

As a further feature of the invention it is proposed to reduce the rate of change of direct current bias on the control grid due to the alternating input, at a predetermined value of the bias, leaving the alternating input to the grid unaltered. For the purpose of illustrating the effect of this alteration, the initial working range taken above will be considered, i. e. a working range of 6 db. over a change of V from $V/3$ to $2V/3$. At a bias of $2V/3$ on the control grid due to the alternating input i. e. at the point X, let the rate of change of such bias with increasing

input be reduced to one quarter. It can be shown that this amounts to altering the slope of the linear relationshp between V and g at this point to one quarter of that formerly obtaining i. e. changing AB to CD. The intercepts of this new linear relationship on the V and G axes can be shown to be 2V and G/2 respectively. Hence with increasing input the output will describe a fresh parabola CQO whose maximum will occur at an input corresponding to V and at an anode current/control grid slope of $G/4$; the value of the maximum being therefore $VG/4$. This is the same maximum value as was attained previous to the reduction of the rate of increase of bias, whilst at an input corresponding to $4V/3$ the output will against $2VG/9$. Hence the resultant output curve will be CQPO and the working range has been extended by a further 6 db. with the same change in output of 11.2% as was formerly obtained.

In order to estimate the change of output voltage for a given range of input levels, with one change of bias ratio, the general case will now be taken.

In Fig. 2 the same basic characteristic is shown, but the rate of change of grid bias is altered, at a given input, by $1/n^2$ so that the intercepts of the new slope/grid bias line are G/n and nV respectively. Let the form of the equation for the slope/grid bias line be $g=A+CVg$, then for the original line,

$$g=G+\frac{G}{V}\cdot Vg \quad \text{----------(1)}$$

and for the expanded line,

$$g=\frac{G}{n}+\frac{G}{n_2}\frac{Vg}{V} \quad \text{----------(2)}$$

Equating these will give the point of intersection.

$$G+\frac{G}{V}\cdot Vg=\frac{G}{n}+\frac{G}{n^2V}Vg$$

$$\therefore Vg=\frac{V(n-1)n^2}{n(1-n^2)}$$

$$\therefore Vg=-V\cdot\frac{n}{1+n} \quad \text{----------(3)}$$

The value of g at the point of intersection,

$$g_1=G+\frac{G}{V}\left(-V\cdot\frac{n}{1+n}\right)$$

$$\therefore g_1=\frac{G}{1+n} \quad \text{----------(4)}$$

Also the minimum output at the point of intersection, is

$$\frac{G}{(1+n)}\cdot\frac{Vn}{(1+n)}=GV\frac{n}{(1+n)^2} \quad \text{---------(5)}$$

But the maximum output is $GV/4$.
Therefore the ratio of minimum to maximum output is

$$\frac{4n}{(1+n)^2} \quad \text{----------(6)}$$

If the working range is expressed as the ratio of the grid bias at the point of intersection to that which initially produces the same output, then from inspection it is plain that if the former by V1 then the latter will be $V-V1$. Also the total range will be the "initial" range (from V1 to $V-V1$) multiplied by the number of times the rate of change of grid bias is altered, plus one. Therefore the working range is

$$\frac{(V1)}{(V-V1)}(1+p),$$

where p is the number of times the rate of change of grid bias is altered.

$$\therefore \text{working range}=\frac{\frac{(Vn)}{(1+n)}}{\left(V-\frac{Vn}{1+n}\right)}\cdot(1+p), \text{ from (3)}$$

$$=n(1+p) \quad \text{--(7)}$$

It can be shown that values of p greater than 1 are not profitable, besides adding to the complexity of the grid bias circuit. Likewise values of n greater than 3 do not add materially to the range and affect the change of output to a greater degree. If n is taken at 3 the calculated range is 16 db.

The process of reduction of rate of change of bias with increasing input at such predetermined points can, of course, be extended almost indefinitely, each reduction giving an extension of working range of amount equal to the initial range (the range being expressed in terms of ratio i. e. deci-bels for instance). The determination of the points at which reduction of rate of change is desired depends on the amount of change tolerable in the output, over the working range.

Furthermore, by using two valves in push-pull and applying the direct current bias derived from the input to the control grids in parallel, the changes in the direct current component of the anode currents are prevented from affecting the waveform of the alternating output. In addition, as is well known, the output impedance, such as a transformer, need not be designed with a view to carrying large direct currents.

In order that the application of the invention may be more easily understood, reference should be made to Figs. 3 and 4 of which Fig. 3 shows a specific method for obtaining the desired reduction in rate of change of control grid bias at a specific bias while Fig. 4 shows a complete circuit. The input transformer, which may also supply the alternating input to the control grid or grids, is arranged with a winding, which by means of any well known rectifying system supplies a direct current bias between the cathode and control grids. For a reduction in rate of change of say, one quarter, the bias is developed across the following network shown in Fig. 3. Between the positive and negative output terminals of the rectifier system is connected in series a resistance R, a battery E (or other source of direct current potential) in such a manner as to tend to oppose currents from the rectifier system, a rectifier MR in such a manner as to tend to allow currents to pass from the rectifier system, and a resistance r. The cathodes of the valves are connected to the junction of R and E, whilst the grids are connected (via the push-pull alternating input voltage) to the negative terminal.

If the backward resistance of the rectifier be very large compared with R, then substantially no potential exists between the cathodes and grids in the absence of an alternating input. When an alternating input is applied, until the voltage delivered by the rectifier system exceeds E, no current will pass through the rectifier MR and the whole of the bias is applied to the control grid of the valve. When the rectifier voltage exceeds E a current passes through the rectifier MR in its forward direction, so that it becomes of small resistance compared to r. Therefore for increased input the rate of change of bias voltage is reduced to $r/R+r$, after a voltage E is attained, and if a reduction ratio of one quarter

is desired r will be made equal to one quarter of the sum of R and r.

For a range of levels of some 20 db. it is generally not necessary to apply more than one reduction in ratio as most valve characteristics tend to deviate from the true parabola at low anode currents, the effect being to prolong the characteristic over a further small range of control grid potential. This factor gives an extra working range over and above that formerly calculated. Likewise the points of minimum output indicated by the calculations (i. e. where the rate of change of bias is altered) are not so pronounced in practice, because of the gradual change of the resistance of the rectifier MR from a high backward value to a low forward value. This factor may be made use of with advantage to produce a more nearly constant output over the desired range.

Referring now to Fig. 4, in which an input transformer T1 supplies both the grid bias and the alternating voltages to push-pull pentode valves V1 and V2 from its secondary winding. A push-pull rectifier system P and Q is shown supplying unidirectional voltage to the grid bias circuit. The output impedance Ro may be made much larger than usual when the valves V1 and V2 are pentodes and the grid swing is small. It is not essential that the valve be critically balanced, although a small cathode potentiometer is useful for initially balancing the anode currents, so that no direct current change is transmitted through T2.

Owing to the balanced nature of the output circuit, it is apparent that the device is immune from surges on the supply.

As the portion of the bias network applied between the cathodes and grids is of relatively high impedance in the absence of an alternating input, it is found in practice that voltages may be picked up on this impedance from surrounding sources, such as the 50 cycle mains supply. This results in a corresponding modulation of the output and can be eliminated by placing a suitable condenser C1 across the impedance. Such a device however, introduces a relatively long charging time constant for input voltages producing a bias which is sufficient to cause the network to assume its reduced ratio condition (since the condenser C1 is now effectively charged via R and discharges via r). In order to obviate this effect it is proposed to connect a further condenser C2 across R such that the time constants $C2.R$ and $C1.r$ are equal. The condensers may then form the normal storage condenser for the rectifier system which produces the bias.

In order that full advantage may be taken of the parabolic nature of the anode current/grid voltage characteristic of a thermionic valve (since a more rapid attainment of constancy of output with low levels is thereby achieved) it is desirable that the static characteristic normally obtained by neglecting the effects of an anode load impedance, shall be used. For this reason it is preferred to use pentode valves, in which the anode load has relatively little effect on the static characteristic.

It will be realised that if the output is to be kept reasonably undistorted at input levels exceeding the upper limit of the working range, so as to obtain the full benefit of the reduction in output at this point, the alternating input to the grids must be kept low enough to avoid anode bend rectification. It has been found that if the ratio of the bias voltage produced by the rectifier system to the alternating peak input per grid is some ten to one the output remains substantially pure.

Despite the reduction in output which this entails as compared with the output of the valve as a linear amplifier for the same anode impedance, it is possible to attain a substantial percentage of the maximum output by the use of pentode valves in conjunction with high anode load impedances. As the effective alternating output current over the working range will be constant and smaller than that giving the maximum output from the valve, it is possible to increase the working anode impedance (over and above that normally used), to a value approximating to the dynamic impedance of the pentode valve, without introducing distortion due to curvature of the anode or grid characteristics, and more especially when a push-pull system is used.

In the foregoing description of the principles and embodiments of the invention, where reference is made to the control grid, this electrode need not necessarily be that nearest the cathode or filament, although this is generally advantageous since the maximum sensitivity is here obtained. The invention can be applied to control on the suppressor grid of a pentode valve or valves in push-pull, whose anode current/suppressor grid characteristic is closely parabolic. In using the suppressor grid, advantage can be taken of the fact that the gain of the valve as a whole tends to remain constant with variations in suppressor potential (since the screen current and conductance are increased as those of the anode are diminished), by deriving the bias proportional to the alternating input from the common electron path (for instance from a cathode impedance). Likewise other types of valves having one or more control grids with a suitable parabolic characteristic can be used, such as the heptode and octode.

The bias proportional to the input need not be derived directly therefrom and more especially when the resulting load on the input is not permissible; it can be derived from a thermionic amplifier or from a self rectifying valve of the cathode follower type.

One of the applications of the invention occurs in the reception of signals of alternating current over telephonic lines, where the invention forms the first stage of a receiver connected to the line. Such signals may be received at widely differing levels and may be of definite frequency or frequencies, whilst it is desired to prevent the response of the receiver to currents which may include components at the signal frequencies. The invention enables subsequent frequency selective devices to function constantly despite changes in received level within the working range, and without detrimental effects normally due to modulation or harmonic production. Furthermore as the output diminishes rapidly to zero at received levels greater than the working range, the output of the components of signal frequency in non-signal currents will be greatly reduced so as to be innocuous, such effect being greater as the received level of non-signal currents becomes higher.

I claim:

1. An amplifier having a space discharge device and an input transformer, a rectifier circuit including a portion of the secondary of said transformer for initially applying a grid potential to

the device when alternating current is supplied to the primary of said transformer, said potential varying in proportion to the input volume, a network connected across said rectifier circuit effective when the direct current bias reaches a predetermined value to vary the rate of change of the grid potential with respect to the input volume.

2. An amplifier as claimed in claim 1 in which said network is nonconductive until the grid potential reaches a certain point and then becomes conductive to act as a shunt for a part of said rectifier circuit.

3. In a thermionic amplifier, an input transformer, a space discharge device, a connection from said transformer to the grid of said device for supplying alternating current thereto for amplification, a rectifier circuit also connected to said transformer and to said grid to supply biasing potential thereto derived from the input, a second rectifier circuit connected to said first rectifier circuit, a source of potential and a rectifier in said second circuit normally effective to prevent any flow of current therein, said second circuit effective when the current in said first circuit reaches a certain value to cause a current to flow therein from the first circuit to thereby effect a change in the ratio of the biasing potential to the input volume.

4. In a thermionic amplifier, a pair of space discharge devices connected in push pull relation, an input transformer therefor, the outer ends of the secondary of said transformer connected through a pair of rectifiers to the filaments of said devices, a connection from each control grid of said devices to a point on said secondary, a second connection from the filaments of said devices through a source of current and a rectifier to the center point of said secondary, said pair of rectifiers supplying a grid potential to said control grids whenever alternating current is supplied to the primary of said transformer, said last connection being effective, after the input volume reaches a certain point, to vary the rate of change in the grid potential with respect to the input volume.

5. An amplifier such as claimed in claim 4 in which the potential of said source in said last connection opposes the potential in the circuit including said pair of rectifiers and prevents a flow of current in said last connection until the volume of the input has reached said certain point.

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