Nov. 2, 1954 B. M. HADFIELD 2,693,536

THERMIONIC VALVE OSCILLATOR

Original Filed Sept. 24, 1945 2 Sheets-Sheet 1

FIG. 1

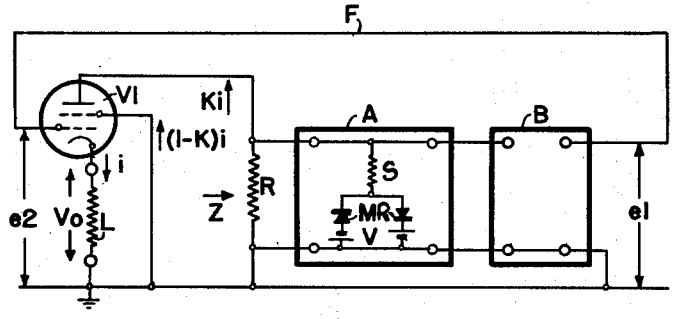


FIG. 2

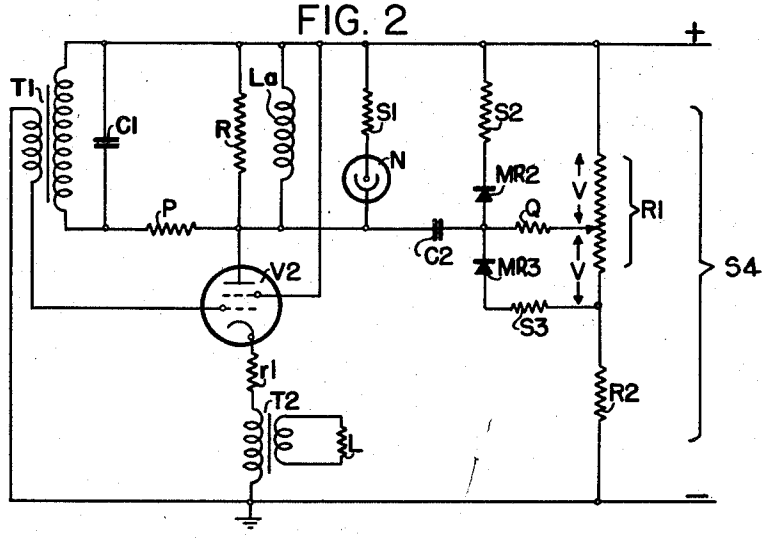
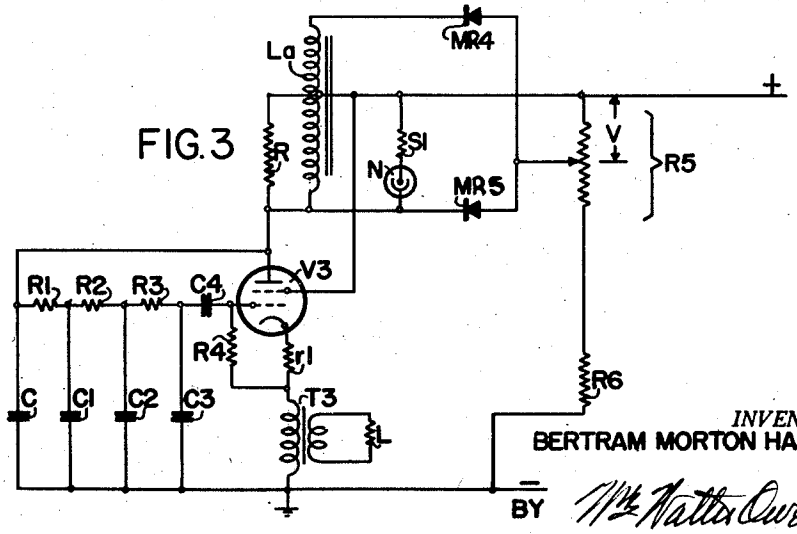


FIG. 3



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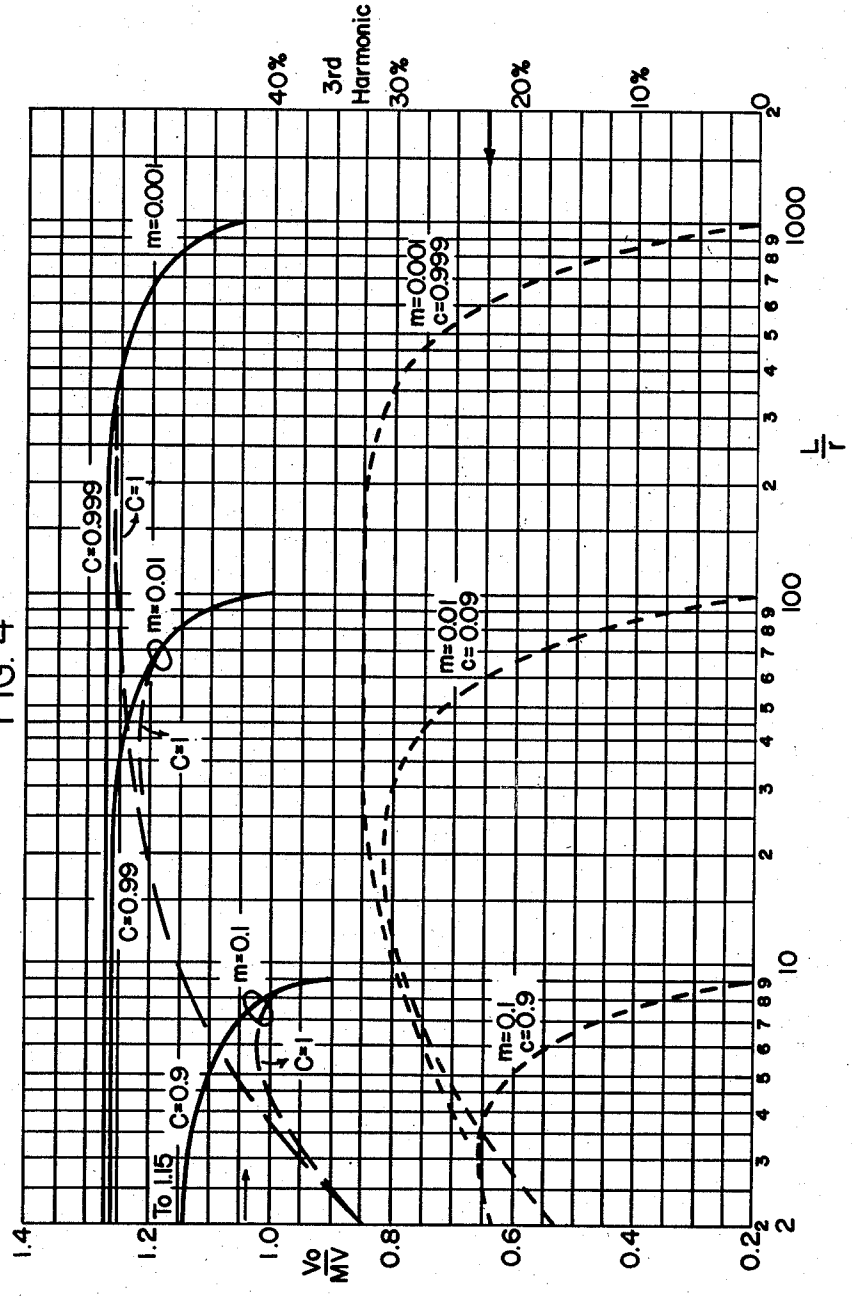
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FIG. 4



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THERMIONIC VALVE OSCILLATOR

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Original application September 24, 1945, Serial No. 618,348, now Patent No. 2,583,837, dated January 29, 1952. Divided and this application September 16, 1950, Serial No. 185,249

4 Claims. (Cl. 250—36)

The present invention relates to thermionic valve oscillation generators and is more particularly concerned with generators capable of delivering power to an output impedance.

This application is a division of application No. 618,348, filed September 24, 1945, and now Patent No. 2,583,837.

One of the objects of the present invention is the provision of an oscillation generator employing a single thermionic valve both for the generation of oscillations and as a source of power of the oscillating frequency. A further object of the invention is the provision of an oscillation generator which will deliver a substantially constant output voltage of sinusoidal form over a wide range of values of the output load impedance.

According to one feature of the invention, a frequency selective transfer device is connected between the anode circuit and the grid-cathode circuit of a thermionic valve and the power output is taken from an impedance included in the cathode lead.

According to a further feature of the invention, a frequency selective transfer device is connected between the anode circuit and the grid/cathode circuit of a thermionic valve and means are provided for introducing a non-linear voltage regulating action in the anode circuit of the valve.

The valve employed may be a triode but it is preferred to use a valve of the tetrode or pentode type, the non-linear characteristic of which may provide at least part of the non-linear voltage-regulating action.

Alternatively or in addition the voltage-regulating action is provided by a non-linear network connected in the anode circuit and acting as an amplitude compressor or amplitude limiter. In such a case it is advantageous that the valve employed should be a pentode or a tetrode, since any change in anode circuit impedance due to the voltage regulating action will be substantially without effect on the relationship between the input voltage to the grid/cathode circuit and the current flowing in the cathode lead.

The invention will be better understood from the following description taken in conjunction with the accompanying drawings.

Fig. 1 illustrates the invention diagrammatically,

Figs. 2 and 3 show by way of example two alternative embodiments of the invention, and

Fig. 4 shows certain curves illustrating the results obtained with different values of the circuit parameters.

Referring first to Fig. 1, the valve VI combines the functions of an oscillator and output valve. The preferred type of valve shown is a pentode or tetrode and the normal direct current supplies are not shown; the currents i in the cathode, $k.i$ in the anode, and $(1-k)i$ in the screen electrode being the alternating component magnitudes, where k is the anode current-cathode current ratio the value of which is substantially constant when the valve is operated over its substantially linear ranges of voltage and current. The valve may be of the triode type, when there is no screen electrode and k becomes unity, but is not preferred since as mentioned above, it is desired that the relationship between the cathode current and the grid input voltage $e2$ shall be substantially unaffected by any changes in the anode impedance, for instance those due to the amplitude regulating action.

The output energy is taken from the cathode circuit and is dissipated in the load resistance L. The alternating anode voltage is developed by the passage of $k.i$ through the net anode circuit impedance Z, which is constituted by the shunt circuit comprising resistance R, amplitude regulating device A, and transfer device B. One form for A is shown within the block and comprises a resistance S in series with back-to-back rectifiers MR individually biased by voltage V. The transfer device B has a voltage transfer ratio M at the desired frequency of oscillation determined primarily by the production of the necessary phase angle so that the output voltage $e1$ is in phase with the grid output voltage $e2$.

Assuming for the moment that the dotted connection F is cut and that a sinusoidal input voltage of magnitude $e2$ produces an in-phase sinusoidal output voltage $e1$ at the desired frequency, the necessary condition for self-oscillation when F is completed is that $e1$ shall be equal or greater than $e2$. Now $e1=k.i.Z.M.$, and $e2=i(L+r)$, where r is the working grid voltage/cathode current mutual resistance of the valve. More accurately, where μ is the amplification factor and V_0 the output

$$\frac{\mu e2}{\mu+1}=V_0=i(L+r)$$

but for the purpose of the present invention the cathode follower factor

$$\frac{\mu}{\mu+1}$$

will be neglected.

Hence for self oscillation:

$$L+r\leqslant M.k.Z \qquad (1)$$

There is an upper limit to the value of load resistance L, but, provided any lower value continues to satisfy (1), there is no lower limit other than that set by the incidence of the overload voltages and currents of the valve. The practicable lower limit to L may therefore be assumed to be that which will give the maximum output energy for a given set of operating conditions for the valve, as in normal output stage design. In the case where VI consists of a pentode or tetrode, then, provided the anode circuit is suitably designed so that the anode voltage excursions are within the normal limits, the design for power output in the cathode circuit can proceed on the assumption that the valve is a triode acting as a cathode follower. In these circumstances a minimum value for L in terms of r for maximum power output may be obtained, which will form a useful reference point in subsequent design; for it will be noted from (1) that the upper limit to L can be made higher at will merely by increasing the value of the voltage gain M.

As regards such a minimum value for L, it is unlikely that the load resistance will be permitted to fall below the known practical value of $2.Ra$, where Ra is the assumed linear anode impedance of the valve regarded as a triode; lower values will give a poorer conversion efficiency from the direct current supply without any corresponding advantage in other respects. Since r may be defined as Ra/μ, where μ is the amplification factor of the valve regarded as a triode, then the likely minimum value for L/r is $2.Ra, \mu/Ra$, i. e. $2.\mu$. A more strict analysis taking the power law characteristic of the valve into account can be shown to give a value of

$$\frac{4}{3}\cdot\mu$$

The lowest value of μ likely to be used is that of the power output type of valve, and is approximately 6. Hence, on these grounds the likely minimum usable value for L/r will be, say, 10.

It will be understood that changes in the load impedance L will cause changes in the cathode current i and hence in the anode current $k.i$. This will result in variations in the output voltage and the purpose of the amplitude regulating device A is to reduce these variations. Further by employing a non-linear network smaller variations of output voltage occur than if a linear network is used. To this extent the non-linear network may be termed an amplitude compressor if it does not produce waveform distortion or an ampli-

tude limiter if it does. The voltage *e*1 is fed into the input circuit of the oscillation generator to maintain the valve in a state of oscillation, the voltage limiting device A being adapted to limit equally both half-waves of the alternating voltage applied thereto. The limiting device will pass little or no current until the voltage applied exceeds the value of the bias voltage V at which time the impedance falls to a low value to allow the flow of a large amount of current. The maximum generated voltage, if the device is to operate perfectly, is dependent upon the polarizing voltage V of the rectifiers or in the event that a gaseous discharge device is employed, upon the flashing voltage of the tube. The polarizing voltage for the rectifiers in Figure 1 is provided by a set of batteries and in Figures 2 and 3 by a tap on potentiometers R1 and R5 respectively which is adjusted so that the potentiometer will produce the same internal resistance regardless of which rectifier is conducting. If the device A operated perfectly, then above a certain value of *k.i* the output *e*1 would be constant and, provided Equation 1 were also always satisfied it is clear that the load voltage regulation would be due solely to the mutual grid resistance of V1; that is, $V_0/e2=L/(L+r)$, and the output voltage V_0 would fall as L is decreased. It is therefore possible to ameliorate this state of affairs by arranging that A is not perfect, but has a rising output *e*1 with rising input *k.i*, by causing it to have a regulation, or internal resistance effect, of equal and opposite sign to that produced by *r*. The internal resistance effect is produced by means of resistance S in Figure 1, S1 or the combination S2, S3 and R1 and R2 in Figure 2. In this manner, whenever the oscillator output is such that A is regulating to maintain the voltage at the desired value the feedback voltage to the valve V1 will vary with increased load to thereby maintain a constant output even while device A is operating and will eliminate to some extent the heretofore described difficulties encountered wherever A is a perfect operating device.

Referring now to the specific embodiments shown, by way of example, in Figs. 2 and 3, Fig. 2 shows a form of the invention incorporating a shunt connected tuned circuit as the transfer device. The anode resistance R of the tetrode valve V2 corresponds to R in Fig. 1, but is shunted by a choke L*a* in order to utilize fully the available direct current supply between the positive and negative supply leads. The transfer device is comprised by series resistance P and shunt transformer T1 whose primary is tuned to the desired frequency by condenser C1, the phase of the voltage applied to the grid of V2 being determined by the poling of the connections of the secondary winding, while the overall M value can be adjusted by the transformer ratio. The load resistance L is coupled to the cathode connection via transformer T2 while series resistance *r*1 (which may be comprised in part by the resistance of the cathode winding of T2) gives the normal grid bias voltage. The amplitude regulating device may be either the neon tube N and series resistance S1 shown connected by dotted lines, or rectifiers MR2, MR3 polarized by voltages V derived from a supply potentiometer R1 and R2. In the former case the series resistance S1 plus the differential resistance of N form the controllable regulation of the device adjusted to give a substantially constant output voltage for loads less than about one-third the maximum resistance sustaining oscillation, the striking voltage of the tube corresponding to the bias voltages V. In the second case series resistances S2, S3, are arranged in conjunction with the resistance S4 which comprises the bias voltage potentiometer R1 and R2 to give the same internal resistance whether MR2 or MR3 be conducting, and of value to give the above-mentioned constant output. Condenser C2 serves to couple the circuit to the anode of V2 while resistance Q enables the bias voltages to appear individually on the respective rectifiers, and to be adjusted by the tapping so that the regulating effect takes place over equal portions of the positive and negative anode alternating waveforms.

In the alternative arrangement shown in Fig. 3, the main connections are essentially the same as for Fig. 2, the differences being in the forms of the devices A and B. The transfer device B now consists of three or more resistance/capacity networks which produce a phase angle of 180° at the desired oscillation frequency; four such networks are shown, RC, R1C1, R2C2, R3C3, utilizing the anode resistance R as part of the first network. Condenser C4 couples the transfer device to the grid of the pentode or tetrode valve V3, the necessary grid bias being obtained by cathode resistance *r*1 and passed to the grid via resistance R4. The load L is coupled to the cathode via transformer T3. The amplitude regulating device A may again consist of a neon tube N and regulation resistances S1 as for Fig. 2, or of an alternative form of the rectifier circuit by connecting the center tap of the choke L*a* to the positive supply lead, whereby rectifiers MR4, MR5 can be operated in a full wave circuit and biased by a common potential V derived from the supply potentiometer R5, R6, the resistive impedance looking into the tapping point constituting the regulation resistance.

The factors governing the design of circuits according to the invention will now be discussed with reference to Fig. 1 taking the typical waveform-distorting amplitude regulating device shown within the rectangle A.

Assuming the linear resistance R includes any other linear resistance in the anode circuit (e. g. the input impedance of B at the oscillation frequency), then, when currents pass through S, the voltage waveform across R for a sinusoidal current *k.i* will have a discontinuity at an angular displacement of *a*, and at $\pi-a$, $\pi+a$, $2\pi-a$, and so on. Between the first two and last two angles, the waveform will consist of part of a sinusoid of reduced amplitude (due to the reduction of anode circuit impedance by the switching-in of the resistance S). The magnitude of the reduction of the maximum amplitude of the waveform from the previous sinusoidal value may therefore be denoted by the fraction *c*, where

$$c=\frac{R}{R+S}$$

Fourier analysis of the resulting anode voltage waveform gives the following maximum amplitudes for the various harmonic components:

$$\text{Fundamental}=R.k.i.\left\{1-c\left[1-\frac{2}{\pi}\left(\frac{\sin 2a}{2}+a\right)\right]\right\} \quad (2)$$

$$\text{Third harmonic}=R.k.i.\left[\frac{2c}{3\pi}\left(\frac{\sin 4a}{4}+\frac{\sin 2a}{2}\right)\right] \quad (3)$$

$$\text{Fifth harmonic}=R.i.i.\left[\frac{2c}{5\pi}\left(\frac{\sin 6a}{6}+\frac{\sin 4a}{4}\right)\right] \quad (4)$$

and so on. If the transfer device B reduces the harmonic components to negligible proportions and imparts a voltage gain M at the oscillation frequency, then, when the circuit is oscillating

$$e2=e1$$

i. e.

$$i(L+r)=MRKi\left\{1-c\left[1-\frac{2}{\pi}\left(\frac{\sin 2a}{2}+a\right)\right]\right\}$$

or

$$\frac{L}{r}+1=\frac{MRK}{r}(x) \quad (5)$$

where *x* represents the expression within the brackets. Also when the anode current attains the value *ki* sin *a*, the voltage on R is just equal to the rectifier bias voltage V i. e. $kiR \sin a=V$. Hence

$$kiR=\frac{V}{\sin a}$$

Further

$$i=\frac{V_0}{L}$$

and hence substituting these values in (5) gives:

$$\frac{V_0}{L}(L+r)=\frac{MV}{\sin a}\cdot(x)$$

$$\frac{V_0}{MV}=\frac{L/r}{L+1}\cdot\frac{(x)}{\sin a} \quad (6)$$

$$=\frac{L/r}{\sin a}\cdot\frac{r}{MRK}$$

$$=\frac{L/r}{\sin a}\cdot m \text{ where } m=\frac{r}{MRK} \qquad (7)$$

Since a must clearly lie between 0 and 90°, inclusive, over the working range, then by assuming such values for a, and taking specific values for c and m in turn, the corresponding values of L/r may be obtained from (5). Using these in (7) gives the output voltage regulation curves in terms of L/r. The maximum L/r value will be obtained when the amplitude regulating device is just not functioning, i. e. when a is 90°, which makes the bracketed terms in (5) unity independent of the value of c. Since it has been shown that the minimum usable value L/r is likely to be 10, then values of $M.k.R/r$ less than 11 need not be considered; that is, m should be taken less than 0.091. As regards c, its value must lie between 1 and 0, inclusive; a value of 1 inferring that resistance S is zero and that the amplitude regulation is as drastic as possible, while a value of C infers that S is infinite and that there is no amplitude regulation. Since the object is to use a value of S which will give a constant output voltage with changes in L/r, consideration of the equations shows that this is only possible when sin $2a$ tends towards $2a$ radians. Under these conditions

$$\frac{L}{r}+1=\frac{1-c(1-4\cdot a)}{} \qquad (8)$$

and

$$\frac{V_0}{MV}=\frac{L/r\cdot m}{a} \qquad (9)$$

From these it follows that

$$\frac{V_0}{MV}=\frac{L/r\cdot 4\cdot c}{L/r+1-\frac{(1-c)}{m}}$$

so that if c is made equal to $1-m$, then V_0 will be independent of L/r and will be given by

$$\frac{V_0}{MV}=1.272c \qquad (10)$$

If this value of c be taken, then the output voltage curves against L/r will rapidly tend to a constant value. Some typical curves are shown in Fig. 4 for L/r values between 1000 and 2 and for three values of m at 0.1, 0.01 and 0.001; the full line curves being for the correct value of c (equal to $1-m$), and the dashed curves being for the c value of 1. It is of course possible by taking arbitrary value of c less than $1-m$ to obtain a rising output voltage with changes in L, and vice-versa, but generally speaking the equality will be used.

It will be observed from Fig. 4 that the full line curves show substantially constant output for values of L/r less than about one-third of the maximum value permissible for oscillation, even over the wide range of m values taken, so that provided the m value is fixed at a sufficiently low value the actual range over which constancy is obtainable (assuming that $L/r=10$ is the usable minimum) can be increased at will. For instance, when m is 0.001, there is a constant output range for L/r of from 300 to 10, or 30:1. With a given setup the value of m will of course vary with changes in r, i. e. with life changes in the mutual resistance of the valve, but c may be restored by having the resistance S variable and testing for an output voltage change with load variations. The actual output voltage will then be different but may be independently restored to normal by adjusting the value of V. The net result of these adjustments will be that the maximum permissible L/r value for just sustaining oscillation will be different, but this is of little importance if the maximum value used lies at or below about one-third this value, i. e. on the constant output range. An alternative method for taking up changes in r which does not affect any other feature, is to make r artificially larger by means of a series cathode resistance in the initial design and to vary this resistance according to the changes in r. The cathode bias resistance $r1$ in Figs. 2 and 3 can be used for this purpose, since, except at the value of L giving maximum watts output, the grid bias for a cathode follower is not a critical matter.

With the type of amplitude regulating device described above, the harmonic output of the oscillator depends

largely on the efficacy with which the frequency selective circuit disposes of such harmonics as are generated. In the present oscillator the harmonic percentage will vary with the load L, and by taking the ratio of Equations 3 or 4 with 2 an estimate of the generated harmonic with changes in a may be obtained. Taking the third harmonic as a typical example:

$$\text{Third harmonic ratio}=\frac{\frac{2c}{3\pi}\left(\frac{\sin 4a}{4}+\frac{\sin 2a}{2}\right)}{1-c\left[1-\frac{2}{\pi}\left(\frac{\sin 2a}{2}+a\right)\right]} \qquad (11)$$

For the case when sin $4a$ tends to $4a$ radians, i. e., over the constant output range before-mentioned, this expression becomes

$$\text{Third harmonic ratio } (4a \text{ small})=\frac{1}{3}\left(\frac{1}{1+\frac{(1-c)\pi}{4c\cdot a}}\right) \qquad (12)$$

This agrees with the well-known fraction of 0.333 when the waveform becomes rectilinear, i. e., for $c=1$, but it is of interest to note that when c is not 1 as in the present case, then the ultimate harmonic ratio is not 0.333 but zero. Hence over the desired range of L/r values the harmonic ratio will have a maximum value and will tend to zero as L/r tends either to the maximum sustaining oscillation or to zero. Furthermore this will be the case for any order of harmonic, so that the harmonic curves shown dotted in Fig. 4 for the third may be taken as representative of the tendency, although the higher orders will, of course, have lower maxima.

While these generated harmonic ratios may appear large it should be noted that the derivation is quite general and applies equally well to all oscillators using the above form of amplitude regulating device, whether intentional or otherwise. For instance, if the oscillator circuit has fixed parameters (i. e. L fixed) the design must be based on a margin of say 6 db if oscillation is to be consistently ensured. This means for instance that the design figure for L as a fixed value must be one-half that which will just sustain oscillation, i. e. L/r is one-half its maximum value. Reference to Fig. 4 will show that the third harmonic then generated is about 27% which is not significantly different from the maximum of the circuit according to the invention 33% from the point of view of designing the frequency selective circuit for adequate suppression in the output. A resonant circuit of Q value equal to 50 (Fig. 2) will give at least 40 db suppression of the third harmonic, so that the maximum output third harmonic of the circuit according to the invention may attain a value of 0.33% as compared to 0.27% for a conventional fixed parameter circuit. Harmonic generation in the remaining portions of the circuit is reduced to a minimum with the present invention, even when the minimum load ratio $L/r=$ is used and the watts output is the maximum possible for the valve working as a triode. For with this ratio the distortion due to the non-linear valve characteristics is reduced by the cathode follower action to the degree of 21 db feedback.

The oscillator may be used as a source of alternating energy of constant or variable frequency, and has particular application to the provision of signal tones for transmission over communication circuits to effect the operation of selective receiving devices, since it may be made to feed many such circuits at a time without significant change in transmitted signal level, and is of compact and economic form for mounting as common equipment in telephone exchanges and the like.

What is claimed is:

1. In an oscillation generator, one thermionic tube having an anode circuit, a grid circuit and a cathode circuit including power leads connected to said anode and cathode circuits for energizing said tube, a non-linear voltage regulating network, a transformer, the primary of said transformer connected in said cathode circuit, a load impedance connected across the secondary of said transformer, a transfer device comprising a plurality of resistance-capacitance networks, said last networks connected between said grid and said cathode circuits, one of said networks also connected to said anode circuit, said transfer device thereby causing said

tube to provide oscillating voltages, said voltage regulating network comprising a full wave rectifier arrangement and a potentiometer connected across said power leads to said anode and cathode circuits, said rectifier arrangement connected at a point on said potentiometer between said power leads to said anode and cathode circuits whereby a contant voltage is supplied to said load impedance over wide values of said load impedance.

2. In an oscillation generator, one thermionic tube having an anode circuit, grid circuit and a cathode circuit, means for energizing said tube, a transformer, the primary of said transformer connected in said cathode circuit, a load impedance connected across the secondary of said transformer, a transfer device comprising a plurality of resistance-capacitance networks, said networks connected between said cathode and said grid, one of said networks also connected between said grid and said anode circuit for causing the production of oscillating voltages by said tube, a series resistance in said anode circuit, and an amplitude regulating device comprising a resistance and a neon tube connected in series with said last resistance and both connected in shunt with said series resistance whereby a constant voltage is supplied to said load impedance over a wide range of values of said load impedance.

3. An oscillation generator comprising one thermionic tube having anode, grid and cathode circuits, a transformer having the primary thereof connected in said cathode circuit, a load impedance connected across the secondary of said transformer, a transfer device comprising a plurality of resistance-capacity networks connected between said anode circuit and said grid circuit for transferring a portion of the output voltage of said tube to said grid circuit for causing said tube to provide oscillating voltages, a source of potential, means for connecting said source of potential to said anode and cathode circuits for energizing said tube, a non-linear voltage regulating device connected between said anode circuit and said cathode circuit, means for applying a bias potential to said non-linear voltage regulating device to thereby prevent the passage of current through said regulating device unless the voltage in said anode circuit attain a predetermined value, said non-linear voltage regulating device thereby serving to maintain the output

of said generator at a constant output voltage between the limits where the maximum value of said impedance is that which will just sustain oscillation and the minimum value of said impedance is that which occurs when the grid-cathode circuit is overloaded.

4. In an oscillation generator, one thermionic tube having anode, cathode and grid circuits, a source of potential, means for connecting said source of potential to said anode and cathode circuits for energizing said tube, a transformer having a primary connected in said cathode circuit, a load impedance connected across the secondary of said transformer, a potentiometer connected between said anode and cathode circuits, an impedance in said anode circuit, a coil of which only part is connected in shunt with said anode impedance, a plurality of rectifiers, one of which rectifiers is commonly joined on one side to said anode impedance and said coil and on the other side to said potentiometer to thereby prevent current flow through said rectifier unless the output voltage of said oscillator be of a predetermined value and polarity, another of said rectifiers joined on one side to the part of said coil not in shunt with said anode impedance and on the other side to said potentiometer for preventing current flow through said other rectifier unless the output voltage of said oscillation generator be of a predetermined value and of opposite polarity to the current that may pass through said first rectifier, said arrangement thereby providing a constant voltage to said load impedance over a large range of values of said load impedance.

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