April 16, 1935. J. O. McNALLY 1,998,091

ELECTRON DISCHARGE DEVICE

Filed March 1, 1933

FIG. 1

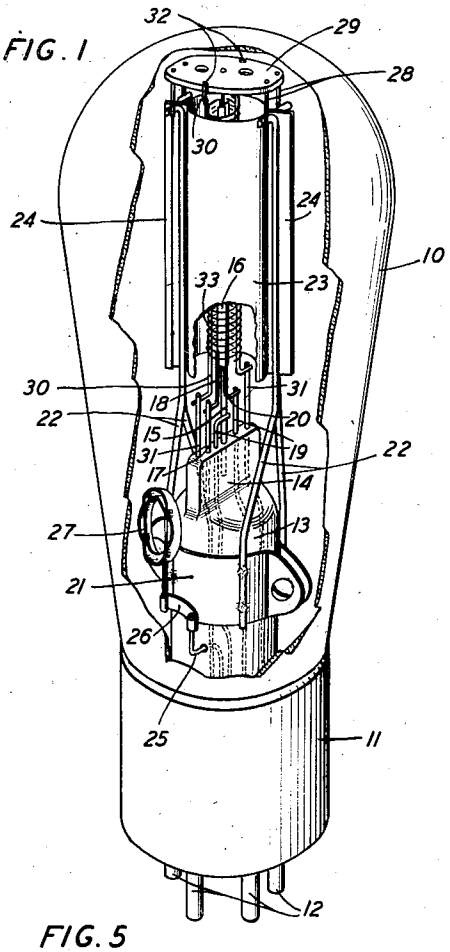


FIG. 2

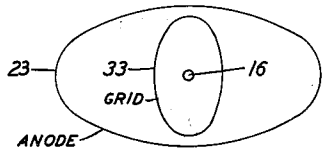


FIG. 3

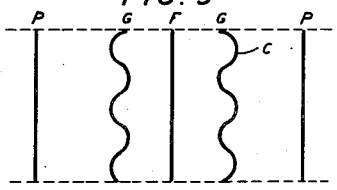


FIG. 4

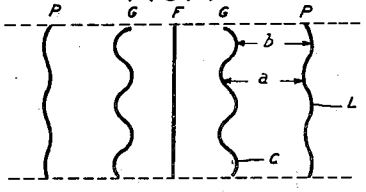


FIG. 5

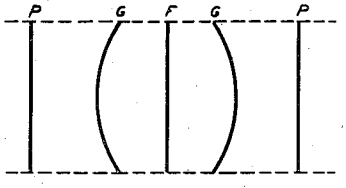


FIG. 7

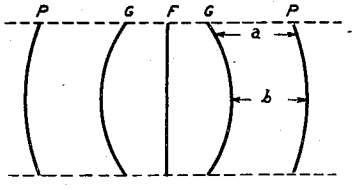


FIG. 6

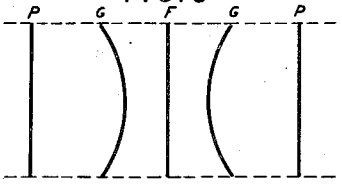
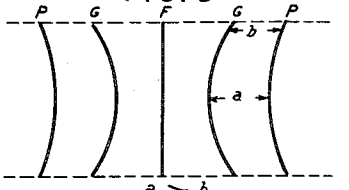


FIG. 8



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ELECTRON DISCHARGE DEVICE

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Application March 1, 1933, Serial No. 659,029

2 Claims. (Cl. 250—27.5)

This invention relates to electron discharge devices, and more particularly to such devices adapted primarily for use as amplifiers.

It is known that when a signal voltage of a single frequency is applied to the control electrode or grid of an electron discharge device of the amplifier type, the output of the device contains various harmonics of this single frequency as well as the amplified fundamental frequency. If a complex signal voltage covering a wide frequency band, such as is involved in the translation of speech and music, is applied to the control electrode or grid, it follows that because of the higher order modulation, particularly the second order, the output of the device will contain harmonics of the various fundamental frequencies in the complex signal so that the signal is not reproduced with fidelity and exactness.

An object of this invention is to reduce higher order modulation in electron discharge devices and to thereby amplify signal voltages, such as those utilized in the transmission of speech and music, accurately and efficiently.

In accordance with a feature of this invention, the parameters involved in the structure of an electron discharge device are so correlated that the magnitude of the harmonics, particularly the second harmonic, in the output of the device is small in comparison with the magnitude of the translated fundamental frequency.

More specifically, in accordance with this invention, a grid, such as the control electrode, and an anode in an electron discharge device are so shaped and spaced relative to each other that a plurality of electron paths of different impedances are provided between the cathode and the anode, each path with respect to the other paths having an amplification factor that is lower than that of another path of lower impedance, and a higher amplification factor than a path of higher impedance.

The invention and the features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which

Fig. 1 is a perspective view of an electron discharge device illustrative of one embodiment of this invention, with portions of the enclosing vessel and the anode broken away to show the inner electrodes more clearly;

Fig. 2 is a diagrammatic end view showing the configuration of the opposed surfaces of the electrodes in the device shown in Fig. 1;

Fig 3 is a sectional view in outline of the electrode surfaces illustrative of another embodiment of this invention;

Fig. 4 illustrates a modification of the electrodes represented in Fig. 3.

Fig. 5 shows a sectional view in outline of the electrode surfaces in another embodiment of this invention in which the control electrode or grid is concave with respect to the cathode.

Fig. 6 shows a sectional view in outline of the electrode surfaces in another embodiment in which the control electrode or grid is convex with respect to the cathode;

Fig. 7 illustrates a modification of the arrangement shown in Fig. 5, in which the anode surface is curved in the same direction as the control electrode or grid but to a lesser degree; and

Fig. 8 illustrates a modification of the arrangement shown in Fig. 6, in which the opposed surfaces of both the anode and the control electrode or grid are convex with respect to the cathode.

It is known that the current in a plate circuit of an electron discharge device may be expressed as a power series in the input voltage on a grid, for example on the control electrode.

Thus

$$i_p = a_1 e + a_2 e^2 + a_3 e^3 + \ldots a_n e^n \qquad (1)$$

where

i_p=plate current.

e=input voltage on a grid or on the control electrode.

a_1, a_2, a_3, etc. are coefficients depending upon the parameters of the tube and the circuit conditions.

For

$$e = A \sin \omega t$$

$$i_p = a_1 A \sin \omega t + \frac{a_2 A^2}{2} - \frac{a_2 A^2}{2} \cos 2\omega t + \ldots \qquad (2)$$

By assuming that the contributions to the double frequency term,

$$\frac{a_2 A^2}{2} \cos 2\omega t,$$

from the higher even order powers are sufficiently small to be neglected, it will be seen that the magnitude of the double frequency component in the plate current will be proportional to a_2. It has been ascertained (see "Operation of thermionic vacuum tube circuits", F. B. Llewellyn, Bell System Technical Journal, vol. 5, 1926, pp. 433–462) that the coefficient a_2 may be expressed as

$$a_2 = \tfrac{1}{2}\left[\frac{-\mu^2 R_0 \frac{\delta R_0}{\delta E_B} + \mu \frac{\delta \mu}{\delta E_B}(R_0^2 - Z^2) + \frac{\delta \mu}{\delta E_C}(R_0 + Z)^2}{(R_0 + Z)^3}\right] \qquad (3)$$

where:

R_0 is the plate resistance of the electron discharge device,

Z is the load impedance,

E_B is the plate voltage,

E_C is the grid voltage, and

μ is the amplification factor of the device.

For practical purposes

$$\mu \frac{\delta \mu}{\delta E_B} = \frac{\delta \mu}{\delta E_C}$$

so that Equation (3) may be rewritten as

$$a_2=\tfrac{1}{2}\left[\frac{-\mu^2 R_0\frac{\delta R_0}{\delta E_B}+2R_0(R_0+Z)\frac{\delta\mu}{\delta E_C}}{(R_0+Z)^3}\right]= \tfrac{1}{2}\frac{R_0}{(R_0+Z)^2}\left[-\frac{\mu^2}{R_0+Z}\frac{\delta R_0}{\delta E_B}+2\frac{\delta\mu}{\delta E_C}\right] \quad (4)$$

In a three electrode electron discharge device operating at temperature saturation the plate resistance, R_0, increases as the plate voltage E_B increases. It follows, therefore, that in Equation (4)

$$\frac{\delta R_0}{\delta E_B}$$

is always negative so that the term

$$-\frac{\mu^2}{R_0+Z}\frac{\delta R_0}{\delta E_B}$$

is positive. It has been found by extensive tests on various types of triodes that the term

$$\frac{\delta\mu}{\delta E_C}$$

is also positive so that the two terms within the brackets in Equation (4) are cumulative to give a large value of a_2. To decrease a_2, therefore, requires decreasing either

$$\frac{\delta R_0}{\delta E_B} \text{ or } \frac{\delta\mu}{\delta E_C}.$$

The former term is dependent upon the 3/2 power law and, as is known, cannot be decreased appreciably without sacrificing power output. It remains, therefore, in order to decrease a_2 and to thereby reduce second order modulation, to decrease the term

$$\frac{\delta\mu}{\delta E_C}.$$

It would be most desirable, of course, to change the sign of this term and in the limit to equate it to the first term within the brackets in Equation (4), that is to

$$\frac{\mu^2}{2(R_0+Z)}\frac{\delta R_0}{\delta E_B}.$$

In accordance with the commonly accepted theory, in three electrode discharge devices, for large negative grid biases, and hence for small plate currents, the electrons constituting the plate current pass through the grid in relatively small streams, the streams passing midway between adjacent grid wires being of the greatest densities. The effect of the charge on the grid upon these streams of greatest densities is relatively small and as a consequence the amplification factor, μ, is correspondingly small. As the grid voltage is made less negative, the plate current increases and the increased space charge of the electron streams forces more electrons to pass in the vicinity of the grid wires. The effect of the charge on the grid upon the electrons in the vicinity of the grid wires is relatively great so that for the conditions described the amplification factor is increased. The effect, therefore, is an increase in the amplification factor with an increase in the plate current, or a decrease in the grid voltage, and may be considered in a sense as one caused by electrons being forced to use the higher impedance, higher μ portions of the device as the plate current increases.

In order to obtain an appreciable reduction in the increase of μ with decreasing negative grid voltage, it is necessary to design the device so that the electrons constituting the plate current will pass through a path having a low μ at the higher plate currents. In other words the grid should have what may be termed a low μ portion through which relatively few electrons will flow at the lower plate currents and the effect of this low μ portion should become prominent as the plate current increases. It follows, therefore, from the foregoing that if the grid or control electrode of an electron discharge device has a plurality of sections one in a path having a low μ and a high impedance and another in a path having a high μ and a low impedance, the increasing space charge with increased plate current through the high μ section will force a correspondingly larger number of electrons to pass through the low μ path so that the effect sought, namely a decrease in the term

$$\frac{\delta\mu}{\delta E_C}$$

in Equation (4), will be obtained.

Considering first a three electrode electron discharge device having effectively plane parallel electrode surfaces, if a portion of the control electrode or grid is displaced outwardly toward the anode, the amplification factor μ for this portion is decreased and the plate current for the section may or may not increase, depending upon the sign of the rate of change of plate current with respect to the grid-cathode spacing. For the desired condition this rate of change, which may be expressed as

$$\frac{\delta I_B}{\delta\beta}$$

should be negative.

For an electron discharge device having effectively plane parallel electrode surfaces, the plate current I_B, may be expressed as

$$I_B=K\frac{(E_B+\mu E_C)^{3/2}}{(\nu+\mu\beta)^2} \quad (5)$$

where K is a numeric constant and ν is the anode-cathode spacing, β is the grid-cathode spacing and the remaining characters have the same significance as in Equation (3).

If μ is considered as proportional to $\nu-\beta$, then

$$\frac{\delta I_B}{\delta\beta}=\frac{-I_B}{\nu-\beta}\left[\frac{3/2\mu E_C}{E_B+\mu E_C}+\frac{2\mu(\nu-2\beta)}{\nu+\mu\beta}\right] \quad (6)$$

In order that

$$\frac{\delta I_B}{\delta\beta}$$

be negative to satisfy the desired conditions, as pointed out hereinbefore, the term

$$\frac{3/2\mu E_C}{E_B+\mu E_C}$$

which is always negative, must be less than the term

$$\frac{2\mu(\nu-2\beta)}{\nu+\mu\beta}$$

which is practically always positive.

It will be noted from Equation (6) that if ν is made some factor greater than unity times β, that is $\nu=C\beta$,

$$\frac{2\mu(\nu-2\beta)}{\nu+\mu\beta}=2\frac{\mu}{\mu+C}(C-2) \quad (7)$$

so that the second term in Equation (6) is less than 2 $(C-2)$ and approaches this value in the limit as μ is increased.

At the preferable operating point of an electron

discharge device the first term within the brackets in Equation (6)

$$\frac{3/2\mu E_C}{E_B+\mu E_C}=\frac{-3/2f}{1-f} \quad (8)$$

where

$$f=\frac{-\mu E_C}{E_B}.$$

In order to obtain the desired conditions, therefore, it is necessary that f should be small and the ratio of anode-cathode and grid-cathode spacing should be large. The value of f is effective in defining the power output for a given percentage of second harmonic output, assuming no μ modulation is present. For small values of f the power output is small and the magnitude of the second harmonic is relatively low.

The factors involved in the proper correlation of the grid and anode in electron discharge devices to obtain the desired conditions noted hereinbefore will be understood from the following:

The plate current in a three electrode discharge device may be considered as a function of the grid-anode spacing, α, and the grid-cathode spacing, β.

Thus

$$I_B=K\frac{(E_B+\mu E_C)^{3/2}}{(\alpha+\beta+\mu\beta)^2}. \quad (9)$$

Assuming μ to be proportional to α, and differentiating Equation (9) with respect to β

$$\frac{\delta I_B}{\delta\beta}=\frac{-I_B}{\alpha}\left[\frac{2\alpha(\mu+1)}{\alpha+\beta+\mu\beta}-\frac{\delta\alpha}{\delta\beta}\left(\frac{3/2\mu E_C}{E_B+\mu E_C}-\frac{2(\alpha+\mu\beta)}{\alpha+\beta+\mu\beta}\right)\right] \quad (10)$$

For a fixed value of α independent of changes in β,

$$\frac{\delta\alpha}{\delta\beta}=0,$$

and μ is constant, so that Equation (10) becomes

$$\frac{\delta I_B}{\delta\beta}=\frac{-I_B}{\alpha}\left[\frac{2\alpha(\mu+1)}{\alpha+\beta+\mu\beta}\right] \quad (11)$$

From Equation (11) it will be apparent that for the conditions specified

$$\frac{\delta I_B}{\delta\beta}$$

is always negative. If

$$\frac{\delta\alpha}{\delta\beta}$$

is taken as -1, $\alpha+\beta$ is constant; that is, the anode-cathode spacing is fixed and the expression

$$\frac{\delta I_B}{\delta\beta}$$

must agree with that for

$$\frac{\delta I_B}{\delta\beta}$$

where β was considered the only variable. For the latter condition as pointed out under the discussion of Equation (6)

$$\frac{\delta I_B}{\delta\beta}$$

may be either positive or negative. Since

$$\frac{\delta\alpha}{\delta\beta}=\frac{\alpha}{\mu}\frac{\delta\mu}{\delta\beta},$$

it follows that for some values of

$$\frac{\delta\alpha}{\delta\beta}$$

between 0 and -1, both μ and I_B will be decreasing with increasing β and a grid section in a path of low μ and high impedance is obtained as desired. Thus, it is possible by the proper design of the anode and grid to maintain

$$\frac{\delta I_B}{\delta\beta}$$

negative even for those conditions, e. g. a large negative grid swing, when the term

$$\frac{3/2\mu E_C}{E_B+\mu E_C}$$

in Equation (6) becomes relatively large.

Considering now an electron discharge device having concentric cylindrical electrodes, the anode current for such devices may be expressed as

$$I_B=KR_p\frac{(E_B+\mu E_C)^{3/2}}{[R_p-\mu(R_g-R_c)-R_c]^2} \quad (12)$$

where R_p, R_g, and R_c are respectively the radii of the anode, grid and cathode.

On differentiating Equation (12)

$$\frac{\delta I_B}{\delta R_g}=I_B\left[\frac{3/2\mu E_C}{E_B+\mu E_C}-\frac{2(R_g-R_c)}{R_p+\mu(R_g-R_c)-R_c}\right]\frac{\delta\mu}{\delta R_g}-\frac{2I_B\mu}{R_p+\mu(R_g-R_c)-R_c} \quad (13)$$

For devices of the type under consideration,

$$\mu=\frac{2\pi nR_g\log_e\frac{R_p}{R_g}}{\log_e\coth 2\pi n\gamma} \quad (14)$$

where n is the number of convolutions per inch in the grid and γ is the radius of the grid wire.

Differentiating

$$\frac{\delta\mu}{\delta R_g}=\frac{\mu}{R_g}\left[1-\frac{1}{\log_e\frac{R_p}{R_g}}\right]. \quad (15)$$

It will be seen from Equation (15) that if

$$\frac{R_p}{R_g}$$

is made equal to e, or approximately 2.72,

$$\frac{\delta\mu}{\delta R_g}$$

will be zero and that for values of

$$\frac{R_p}{R_g}$$

less than 2.72,

$$\frac{\delta\mu}{\delta R_g}$$

will be negative. If

$$\frac{\delta\mu}{\delta R_g}$$

in Equation (13) is zero, it will be noted that

$$\frac{\delta I_B}{\delta R_g}$$

will be negative and for relatively small negative values of

$$\frac{\delta\mu}{\delta R_g},$$

the negative coefficient of

$$\frac{\delta\mu}{\delta R_g}$$

will not be sufficiently large to make

$$\frac{\delta I_B}{\delta R_g}$$

change sign. It follows, therefore, that an in-

crease in the radii of sections of a control electrode or grid in an electron discharge device having cylindrical electrodes will provide the desired low μ, low plate current sections.

Various forms of grids to provide the desired low μ high impedance sections may be employed. For example, as shown in Fig. 3, the grid G may be provided with a plurality of corrugations C, and the cathode or filament F and the anode P may have effectively plane parallel surfaces or concentric cylindrical surfaces. This construction provides a plurality of alternately arranged high and low μ grid sections, the high μ sections having a low impedance and the low μ sections having a relatively high impedance.

In other embodiments illustrated diagrammatically in Figs. 5 and 6 the grids or control electrodes G may be concave or convex respectively with respect to the cathode or filament F.

A further reduction in second order modulation may be obtained by suitably varying the spacing between portions of the anode and the cathode. Thus, as indicated in Fig. 4 the surface of the anode may be provided with undulations or corrugations L in alignment with the corrugations in the grid surface, the depth of the corrugations L being less than that of the corrugations C and the corrugations being so formed that, as indicated in Fig. 4, the distance a between juxtaposed portions of the anode and the grid is greater than the distance b between other juxtaposed portions.

In other embodiments illustrated diagrammatically in Figs. 7 and 8 the anodes P are curved in the same direction as the corresponding grids G but to a lesser degree so that, as indicated in these figures, the distance a is greater than the distance b.

The electron discharge device shown in Fig. 1 is contained in an enclosing vessel **10** suitably secured to a base **11** carrying a plurality of terminal prongs **12**. The vessel **10** is provided with a reentrant stem portion **13** which terminates in a substantially rectangular press **14**. A rigid metallic rod **15** is embedded in the press **14** and supports a heater type cathode having a cylindrical metallic sleeve **16** coated with an electron emitting material, such as barium and strontium oxides. The metallic sleeve **16** is electrically connected to one of the terminals **12** through a leading-in conductor **17** embedded in the press **14**, and a wire strip **18** connected to the sleeve **16** and to the conductor **17**. The heater current for the cathode may be supplied through leading-in conductors **19**, one of which is connected to the rod **15** and the other of which is connected to one end of the heater unit, not shown, by a wire **20**.

A two piece flanged metallic collar **21** is clamped about the stem **13** and has secured thereto a plurality of bent metallic supports **22** which extend lengthwise of the vessel **10**. A hollow anode **23** is provided with outwardly extending flanges **24** which are secured, as by welding, to the supports **22**. Electrical connection is established between the anode **23** and one of the terminal prongs **12** through the intermediary of a conductor **25** sealed in a wall of the stem **13** and connected to a metallic strip **26** which is secured, as by welding to the collar **21**. An annular support **27** is mounted on the strip **26** and carries a getter material, such as magnesium, for fixing residual gases within the enclosing vessel **10**.

A plurality of metallic stubs **28** is secured to the supports **22** at the end thereof remote from the stem **13** and carries an insulating disc **29**. A plurality of upright wires **30** is supported at one end by rigid short wires **31** embedded in the press **14** and the wires **30** are seated at the other end in slots **32** in the insulating disc **29**. A helical wire control electrode or grid **33** is supported on the wires **30** and is symmetrically positioned with respect to the cathode **16** and coaxial therewith, electrical connection between the grid **33** and one of the terminals prongs **12** being established through the intermediary of one of the rigid wires **31**.

As shown more clearly in Fig. 2, the control electrode or grid **33** and the anode **23** are both oval or elliptical in lateral cross-section and are coaxially arranged with respect to the cathode **16**. The major axis of the oval defined by the grid wires is at an angle, preferably a right angle, to the major axis of the anode oval. This arrangement, it will be apparent, provides a plurality of electron paths of different μ and different impedance between the cathode and the anode, the paths of high impedance having a low μ and the paths of low impedance having a high μ.

Although various forms for the control electrode or grid and for the anode have been shown and described, it will be understood, of course, that these forms are merely illustrative of the invention and that modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims. It will be realized also, of course, that the invention is not limited to three electrode electron discharge devices but may be embodied in such devices having more than one grid, for example screen grid discharge devices. In devices of the latter type either or both the control electrode and the screen grid might be of any of the forms shown for the control electrode in the drawing.

What is claimed is:

1. An electron discharge device comprising a cathode, an oval shaped anode encompassing said cathode, and an oval shaped control electrode intermediate said cathode and said anode, said anode and control electrode having their similar lateral axes intersecting.

2. An electron discharge device comprising a rectilinear cathode, an elliptical shaped anode symmetrically disposed about said cathode, and an elliptical shaped grid intermediate said cathode and said anode and symmetrically disposed about said cathode, said anode and grid having their similar lateral axes intersecting at substantially right angles.

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