

July 21, 1936.

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2,048,232

VACUUM TUBE

Original Filed Dec. 13, 1930. 2 Sheets-Sheet 1

Fig. 1

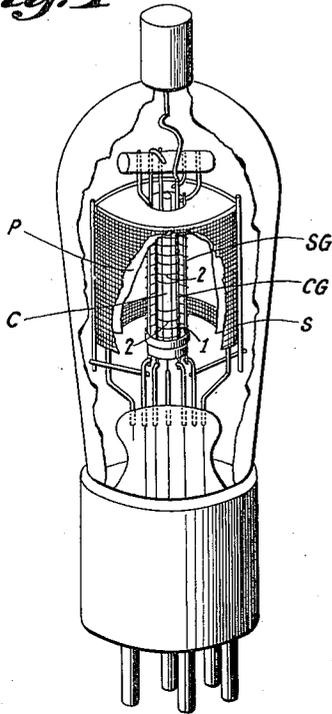


Fig. 2a

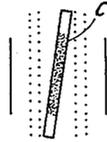


Fig. 2b

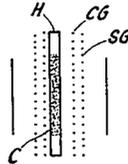


Fig. 3

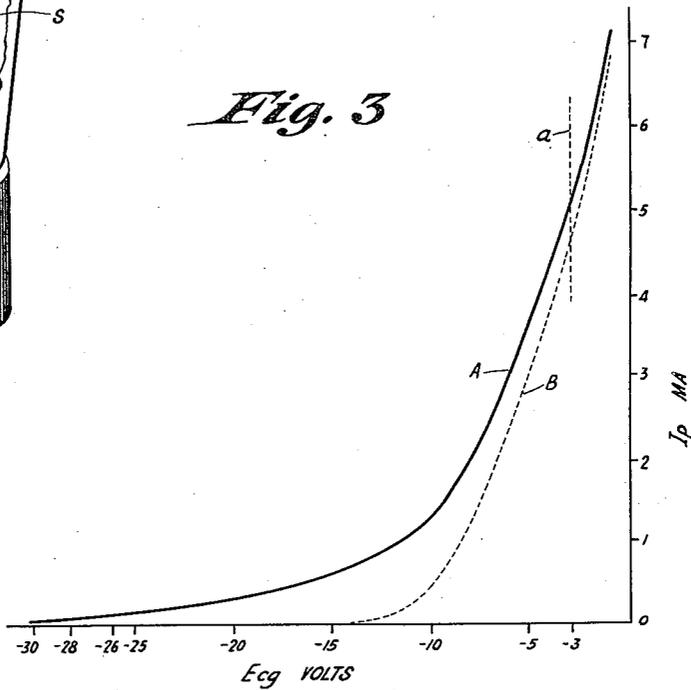
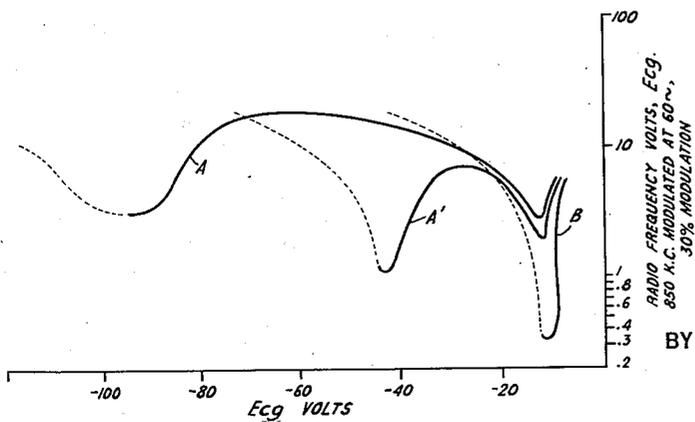


Fig. 5



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2 Sheets-Sheet 2

Fig. 4

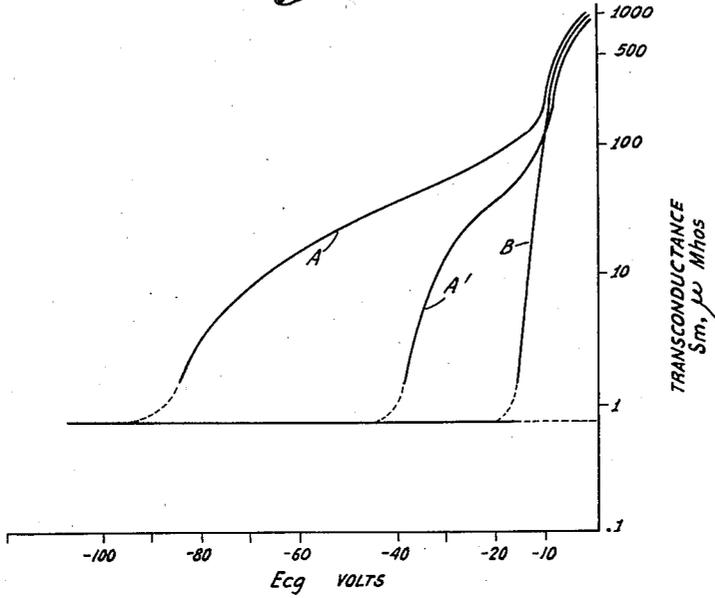
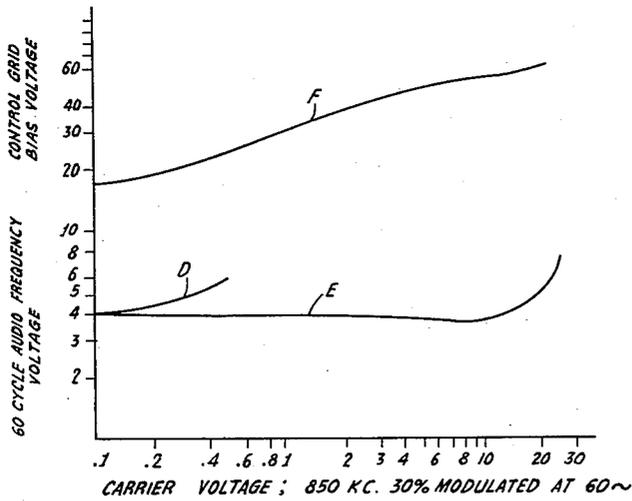


Fig. 6



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VACUUM TUBE

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Original application December 13, 1930, Serial
No. 437,225. Divided and this application July
2, 1931, Serial No. 548,298. Renewed June 12,
1936

8 Claims. (Cl. 250—27.5)

The present application relates to space discharge tubes of the type including a cathode, a control grid and an anode, and is a division of my application, Serial No. 437,225, filed December 13, 1930.

The problem of preventing modulation distortion in an amplifier stage, or in cascaded stages, has imposed severe limitations upon the range of signal voltages which may be applied to the amplifier. In radio receivers, for example, high sensitivity is desirable for the reception of weak signals, and some form of manual, or automatic, control must be provided to reduce the amplifier transmission, or gain, when stronger signals are received. When a receiver of high sensitivity is operated in the vicinity of a broadcasting station, it is not unusual to find that the signal voltage applied to the first carrier wave amplifier is greater than the voltage required on the detector for normal output at the loud speaker. With the present types of electron discharge tubes, it is usual to adjust one of the operating potentials applied to the tube electrodes to decrease the amplification as the received signal strength increases.

Within the range of relatively low signal strengths, this reduction of amplification is not accompanied by modulation distortion, but with increasing signal strengths distortion is introduced when the amplification rate is adjusted to maintain an approximately constant output. Furthermore, within the range of higher signal strengths, it is frequently difficult to adjust the amplification to maintain constant output since the transconductance of the tube changes very rapidly for small changes in the transmission control voltage. This restricts the amplification control to a small range of applied control voltages, and unfortunately, the rate of change of amplification is more gradual in the range of high amplification where a rapid change of amplification for small changes in control voltage would be permissible.

Cross-talk effects in radio frequency amplifiers depend upon the high-order curvature parameters of the tube, and are to that extent related to the problem of distortion discussed heretofore. It can be pointed out that the term "cross-talk" is employed to designate that species of interference which originates in the radio frequency amplifier tubes by modulation between two, or more, signals. The improvements discussed herein in connection with an electron discharge tube amplifier to reduce distortion will also reduce a large

part of the cross-talk. Reference is made to the Proceedings of the Institute of Radio Engineers for December, 1930, wherein in an article entitled "Reduction of Distortion and Cross-talk in Radio Receivers by Means of Variable-Mu Tetrodes" there is demonstrated the intimate relationship between the problems of distortion and cross-talk in radio frequency amplifiers, and their elimination by means of variable mu tubes.

It is, therefore, one of the main objects of the present invention to provide a space discharge tube having such operating characteristics that no distortion is introduced when, for increasing signal strengths, the operating potentials are so adjusted that the amplification rate is reduced to a small fraction of the maximum amplification.

A further object of the invention is to provide an electron discharge tube having such characteristics that, when the potentials are adjusted to give a relatively low amplification of strong signals, the change in transconductance for a given change in the gain control voltage is much lower than is the case with the known types of tubes.

Another, and important object of the invention is to provide a high frequency amplifier tube capable of adjustment to give an undistorted output of approximately constant magnitude over a wide range of applied carrier voltages.

A more specific object of the invention is to provide an electronic amplifier in which different portions of the electron stream are influenced at different rates by the voltages applied to the control grid.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims, the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawings in which I have indicated diagrammatically several arrangements whereby my invention may be carried into effect.

In the drawings,

Fig. 1 is a perspective view, partly in section, of a screen grid tube embodying the invention,

Figs. 2a and 2b are diagrammatic views illustrating two embodiments of the invention,

Fig. 3 is a curve sheet showing the variations of plate current with grid bias for a tube such as shown in Fig. 1,

Fig. 4 is a curve sheet showing the relation between control grid voltage and transconductance for tubes embodying the invention,

Fig. 5 is a curve sheet showing the relation be-

tween permissible maximum input voltages and control grid bias voltages, and

Fig. 6 is a curve sheet showing the performance of a three stage amplifier employing the novel form of tube.

Referring to the accompanying drawings wherein like reference characters in the different figures designate the same elements, the invention is shown in Fig. 1 as embodied in a form of tube known commercially as a screen grid tube, the latter having a separate heater for the cathode. As is well known, this particular type of tube comprises an evacuated envelope enclosing a cathode C, heated by a resistance (not shown) within the cathode, an inner grid CG, an outer grid SG, a plate, or anode P, and an outer screen S which is electrically connected to the outer grid. Except for the novel construction of the control grid CG and its novel functional relationships to the remaining elements of the tube, the several elements of the tube, and their relative physical arrangement, may be substantially the same as that employed in the present commercial tubes.

In tubes of this general type, the control grid comprises a helical winding supported by one or more wires 1. In this particular embodiment of the present invention, the helical winding is not continuous, as in the known constructions, but comprises two sections 2, 2 that are separated by a distance of the order of twice the pitch of the winding. The windings of each section are of the same pitch, which may be the same as that now employed in tubes of this type. This particular physical embodiment of the invention therefore physically differs from the known construction, of the same general physical design, by the absence of two complete circumferential turns of the control grid winding.

This particular construction results in a tube in which the control exercised upon the electron stream is not uniform over the entire extent thereof.

The operation of the tube shown in Fig. 1 may be explained as follows:

The control grid has been shown to be divided into two sections which are mounted with a gap between them. At low negative biases the entire cathode is operative, and the tube has about the same characteristics it would have if the gap were in place. As the grid bias increases negatively the electron current through the upper and lower parts of the control grid are cut off leaving a low mu control through the gap. At these bias voltages the tube acts as if the upper and lower sections of the control grid were formed of solid metal, and controlled the current through the gap in the ordinary manner.

An eccentric arrangement of one, or more, elements may be employed, Fig. 2a showing the axis of the cathode C inclined to the axes of the other elements, and Fig. 2b showing the cathode C parallel to but co-axial with, the other elements.

The mode of operation of the modifications disclosed in Figs. 2a and 2b can be explained in the same manner as has been explained in connection with the embodiment shown in Fig. 1. Essentially, and basically considered, all of the tube structures disclosed herein provide a radio frequency amplifier tube having a mu-factor which decreases continuously with increasing negative grid bias.

It is well known that the amplification of a

vacuum tube may be regulated by adjusting the bias voltage upon the control grid, the amplification decreasing as the bias voltage becomes more negative. Curves showing the relation between plate current and grid bias, i. e., transfer characteristics, afford an indication of the amplification at different bias voltages, since the slope of the curve at any point is a measure of the amplification when the tube is biased for operation at that point.

In Fig. 3, the solid line curve A is the transfer characteristic for a tube such as shown in Fig. 1, and the dotted line curve B is a similar curve for a commercial screen grid tube of the same general type but having a continuous control grid winding of uniform pitch. An examination of curve A shows that, with tubes embodying the invention, a control of amplification extends over a range of control grid bias of from zero to more than -30 volts. With the known tubes, the curvature of the transfer characteristic approaches zero at a control grid bias of about -15 volts.

In other words, an increase of the grid bias above approximately 15 volts negative will not be accompanied by a decrease in amplification when the known type of tube construction is employed, but with tubes embodying the invention, the amplification may be varied with changes of control grid bias throughout a range of from zero to upwardly of -30 volts. The tubes will still pass signals, by leakage transmission when the control grid biases exceed these respective values, but control of amplification is no longer possible in regions where the transconductance curves become substantially horizontal.

The curves of Fig. 4 show the relation between control grid bias and transconductance for two tubes embodying the invention, and for a similar tube which has the usual grid construction. Curve A is the transconductance-control grid bias curve for a screen grid tube of the type shown in Fig. 1, having two turns omitted from the center of the control grid. The data for this curve and for curve A' of Fig. 3 relates to the same tube. Curve A' is a similar curve for a screen grid tube in which only one turn was removed from the center of the control grid, and curve B shows the characteristic properties of the conventional type of tube having a continuous control grid winding.

An examination of these curves shows that the useful range of transmission control is considerably extended by the present invention. With the known constructions, a decrease of the transconductance from about 500 micromhos to the value, about 0.8 micromho, at which leakage transmission prevents further amplification control, corresponds to a change in control grid bias of about ten volts. The corresponding ranges of control grid bias for the tubes of curves A' and A are, respectively, about 30 and 60 volts.

As stated above, modulation distortion may occur when, for a given signal strength, the amplification is so adjusted as to bring the output down to a desired, or standard, level. Since such distortion is due to the curvature of the transfer characteristic it will be apparent that a tube having a curve of lower curvature can transmit, without distortion, higher voltage signals than a tube having a characteristic which exhibits a region of higher curvature. An examination of the curves of Fig. 3 will show that the

maximum curvature of curve A' is substantially lower than that of curve B.

Modulation distortion introduced by a tube may be determined by applying a signal having a definite and constant modulation to the input of the tube and measuring the modulation of the output signal. For small input signals the tube introduces practically no change in modulation. When the input signal increases beyond a certain value the modulation of the output signal increases rapidly due to the curvature in the tube transfer characteristic. This increase in modulation (modulation distortion) limits the maximum input signal that may be transmitted by the tube without distortion.

The curves of Fig. 5 show the relation between control grid bias voltages and the maximum input signal voltages which produce a twenty per cent rise in modulation. The 20% rise in modulation was chosen as a standard as a matter of convenience since distortion of this magnitude may be observed by ear when the modulation is within the range of audible frequencies as is the case with speech or music. The data for curves A, A' and B was obtained for the same tubes as those whose characteristic curves are identified by corresponding characters in Fig. 4; the signal in each instance being an 850 kilocycle carrier, modulated 30% at 60 cycles.

In the case of the commercial tube, curves B of Figs. 4 and 5 show that over the range of bias voltages which control the amplification, i. e., from zero to about twelve volts negative, the maximum input signal voltage which can be transmitted with not more than 20% distortion is about five volts.

When the bias is adjusted to maintain a constant output signal, the maximum input signal voltage that can be applied to the tube with less than 20% distortion is about 0.3 volt, corresponding to a control grid bias of approximately 12 volts negative. For greater signal strengths, the increases of control grid bias do not alter the amplification, but do affect the maximum signal strength which may be transmitted with less than 20% distortion. For a single tube, signal strengths falling outside the range of volume control cannot be handled by the amplifier if a constant output is essential, but in cascaded amplifiers having two or more controlled stages, the maximum voltages, as shown by the dotted line portion of curve B, may be transmitted by the first stage when amplification control without additional distortion is provided in a subsequent stage.

A similar analysis of curve A' will show that the maximum signal strength which may, without undue distortion, be transmitted to give the desired constant output voltage is about 1.1 volts, corresponding to a control grid bias of about -38 volts. For the tube with two turns removed from the control grid, curve A shows a permissible input voltage of 3 volts, with a bias of -95 volts. Furthermore, by so restricting the control grid bias voltages that the maximum can never exceed about 28 volts negative in the case of the tube of curve A', and about 65 volts in the case of the tube of curve A, the maximum carrier voltages which may be transmitted in approximately 7 and 22 volts, respectively.

The observations have been verified by tests made with a commercial radio receiver having three radio frequency amplifier stages employing commercial screen grid vacuum tubes of the "224" type. Measured carrier wave voltages, 850 kilo-

cycle modulated thirty per cent at 60 cycles, were impressed upon the first amplifier and the amplification was adjusted to maintain a constant carrier voltage on the detector which, for undistorted carrier amplification, corresponded to a 60 cycle audio frequency output of 4 volts across the speaker terminals.

Modulation distortion in the amplifier is evidenced by an increase in audio frequency output voltage when the carrier component of the detector input remains constant. By maintaining a constant carrier voltage at the detector the demodulated audio frequency output will remain constant up to the point at which modulation distortion begins. Beyond that point, the audio frequency output will rise even though the carrier voltage across the demodulator is maintained constant as the signal strength increases.

In Fig. 6, curve D shows the relationship between audio output and carrier wave input when 20 commercial 224 tubes were used in the amplifier. To eliminate distortion in the third radio frequency stage, only the first two stages were adjusted to control the amplification. The distortion was of the same values whether the bias on the control grid of the first tube was varied, or the bias control was extended to include both the first and second tubes. From curve D it will be noted that the modulation rise begins at a carrier input of about 0.15 volt, and reaches 20% at 0.3 volt signal voltage on the first tube.

Curve E was plotted from data obtained with the same radio receiver when tubes embodying the invention were substituted in the radio frequency stages. The tubes were of the type shown in Fig. 1, i. e., of standard "224" type construction except that two turns were omitted from the center of the control grid. With increasing signal strength, the detector input was maintained constant by adjusting the control grid bias simultaneously on the three amplifier stages. It is to be noted that the carrier input across the first tube increased to 10 volts before a modulation rise was apparent, and that it reached 17 volts before the modulation rise reached 20%. The variation of control grid bias with input signal strength is shown by curve F.

These results were checked qualitatively by a listening test with ordinary broadcast (music) modulation. It was found that the distortion on high modulation peaks became apparent when the input on the first amplifier was from 15 to 20 volts, becoming worse as the input was increased beyond 20 volts.

These observations of actual performance in a receiver check closely with the results plotted in Figs. 4 and 5 for single stages. By employing tubes constructed in accordance with the invention, the permissible input voltage was raised from 0.3 volt to 17 volts, i. e. volume control with good quality reproduction can be had with input voltages about 57 times as great as those which may be applied when the known commercial form of tube is employed.

It is to be understood that the invention is not limited to any particular type of tube, but is, in general, applicable to all tubes employed for amplification control. The physical construction of the control grid, or the geometric and structural relationships of the tube elements are subject to wide variation so long as the control grid exercises different rates of control at different portions of the electron stream. Considered broadly, the invention provides in a single tube, the electrical equivalent of two, or more, amplifier tubes oper-

ating in parallel, one tube having a relatively high ratio of plate voltage to control grid voltage (high μ), and one, or more, of the remaining tubes having lower ratios of plate voltage to control grid voltage (low μ). In fact, the same distortionless amplification control and substantial reduction of cross-talk over a wide range of input voltages may be secured when two or more tubes of the described different characteristics are operated in parallel. A single tube exhibiting these characteristics will usually be more economical and convenient than the parallel tube arrangement.

Although the above discussion has been limited to a consideration of modulation distortion in radio receivers, it will be apparent that the curvature of the transfer characteristic gives rise to other forms of distortion which limit the range of continuous wave and audio frequency voltages within which a tube acts as a substantially linear amplifier. The invention provides a means for extending the range of signal voltages which may be transmitted without distortion, the signals being either of audio or radio frequency, and if of radio frequency, either continuous wave or modulated. By transconductance is meant the ratio of the change in the current in the circuit of an electrode to the change in the voltage on another electrode, under the condition that all other voltages remain unchanged. By μ -factor is meant the ratio of the change in one electrode voltage to a change in the other electrode voltage, under the condition that a specified current remains unchanged.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim is:

1. An electron discharge tube comprising an emission electrode, a positive cold electrode surrounding said emission electrode, and an auxiliary cold electrode disposed between said emission electrode and said positive electrode, the axis of one of said electrodes being inclined with respect to the axes of the remaining electrodes.

2. An electron discharge tube comprising an equipotential cathode, a cylindrical anode surrounding said cathode, a cylindrical screen grid electrode surrounding said cathode and disposed between said anode and cathode, and a cylindrical control grid electrode surrounding said cathode and disposed between said screen grid and said cathode, said anode, screen grid and control electrode having a common axis, and said cathode being disposed with its axis out of alignment with said common axis.

3. An electron discharge tube comprising a straight unipotential electron emitting electrode, a tubular control electrode surrounding said emitting electrode, and a tubular cold electrode surrounding said control electrode, the longitudinal axis of one of said electrodes diverging from the longitudinal axis of another of said electrodes.

4. An electron discharge tube comprising a tubular plate and a tubular control grid coaxially mounted along common longitudinal axis, an elongated, thermionic cathode mounted inside said control grid with its longitudinal axis parallel to and non-coincident with said common axis of said control grid and said plate.

5. An electron discharge device comprising an elongated thermionic cathode, a cylindrical main cold electrode, and a cylindrical auxiliary cold electrode concentric with said main electrode and disposed between said cathode and said main electrode, the longitudinal axis of said cathode being eccentric to said cold electrodes.

6. An electron discharge tube comprising a cylindrical equipotential cathode electrode and tubular grid and plate electrodes surrounding said cathode, the longitudinal axis of one of said electrodes being inclined to the longitudinal axis of another of said electrodes.

7. An electron discharge tube comprising cylindrical cathode, grid, and plate elements, two of said elements being coaxial, and the third element having its longitudinal axis inclined to the common axis of said other two elements.

8. An electron discharge tube comprising a cylindrical equipotential cathode and coaxial tubular grid and plate elements surrounding said cathode, the longitudinal axis of said cathode being inclined to the axis of said elements at an angle.

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