

Sept. 14, 1937.

H. A. SNOW

2,092,893

HIGH FREQUENCY AMPLIFIER

Original Filed March 19, 1930. 4 Sheets-Sheet 1

Fig. 1

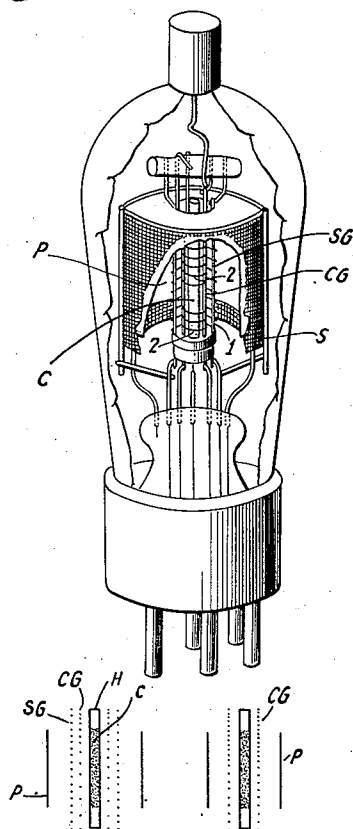


Fig. 2

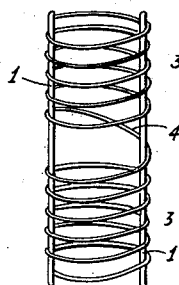


Fig. 3

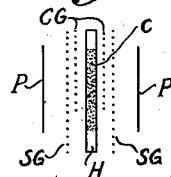


Fig. 4a Fig. 4b Fig. 4c Fig. 4d Fig. 4e

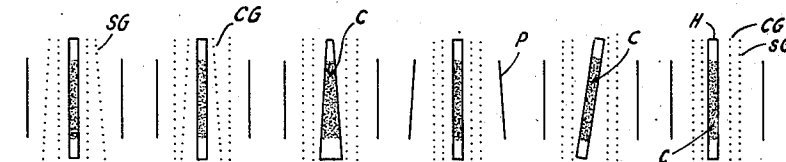


Fig. 5a Fig. 5b Fig. 5c Fig. 5d Fig. 6a Fig. 6b

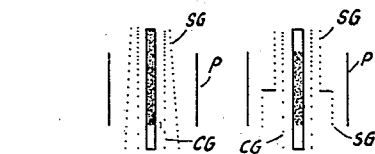
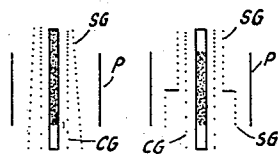


Fig. 7a Fig. 7b



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Fig. 8

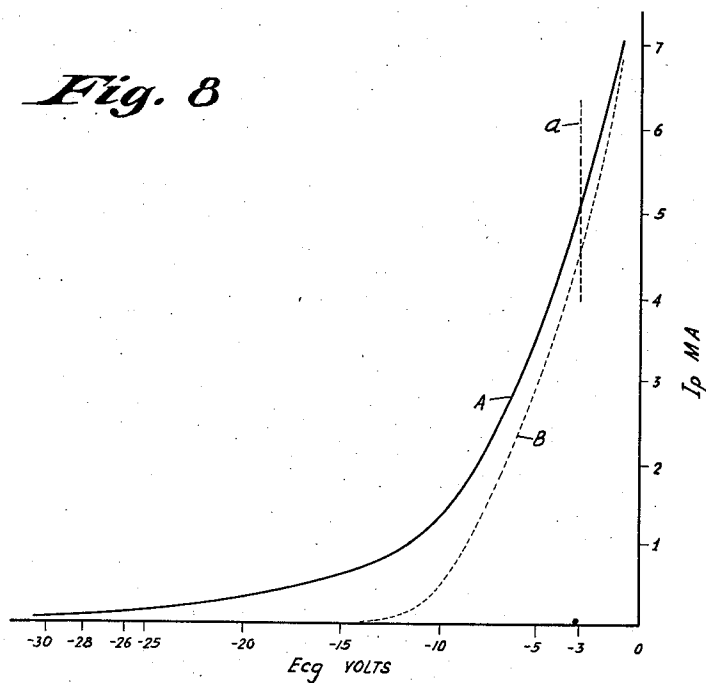
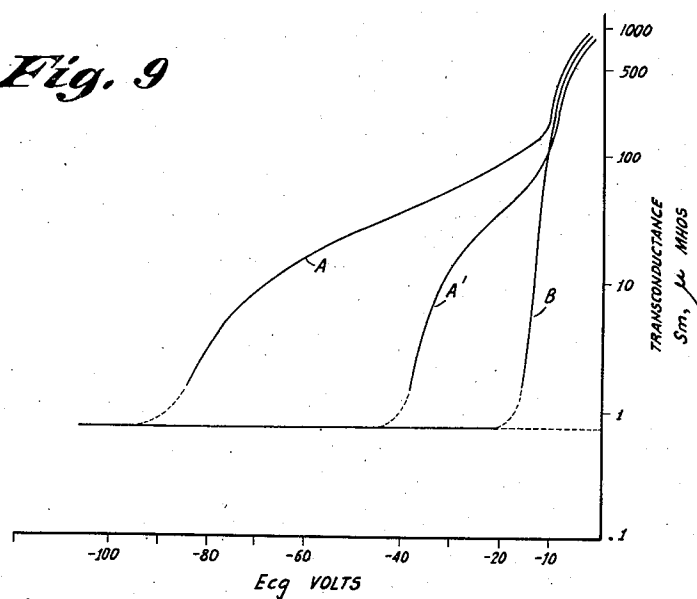


Fig. 9



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Fig. 10

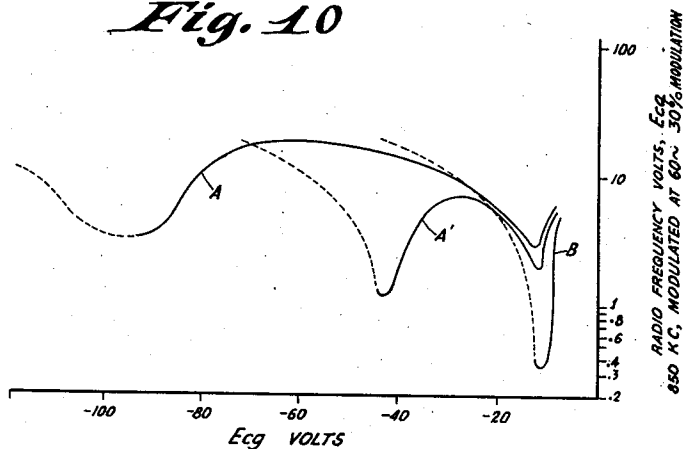


Fig. 11

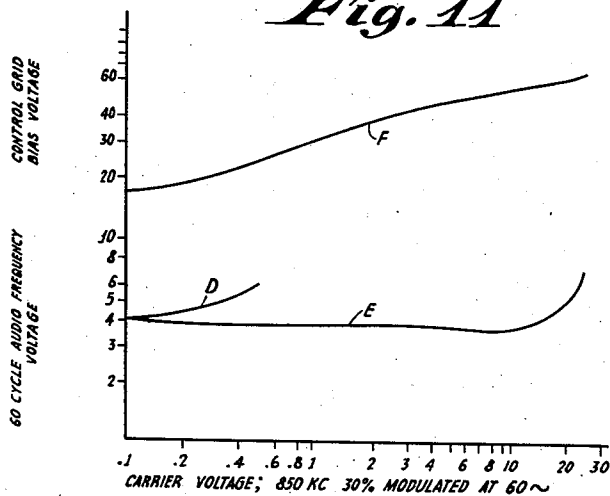
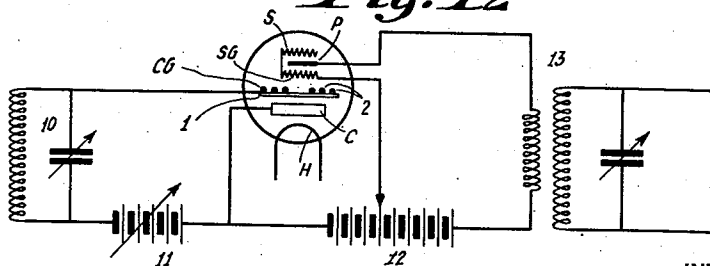


Fig. 12



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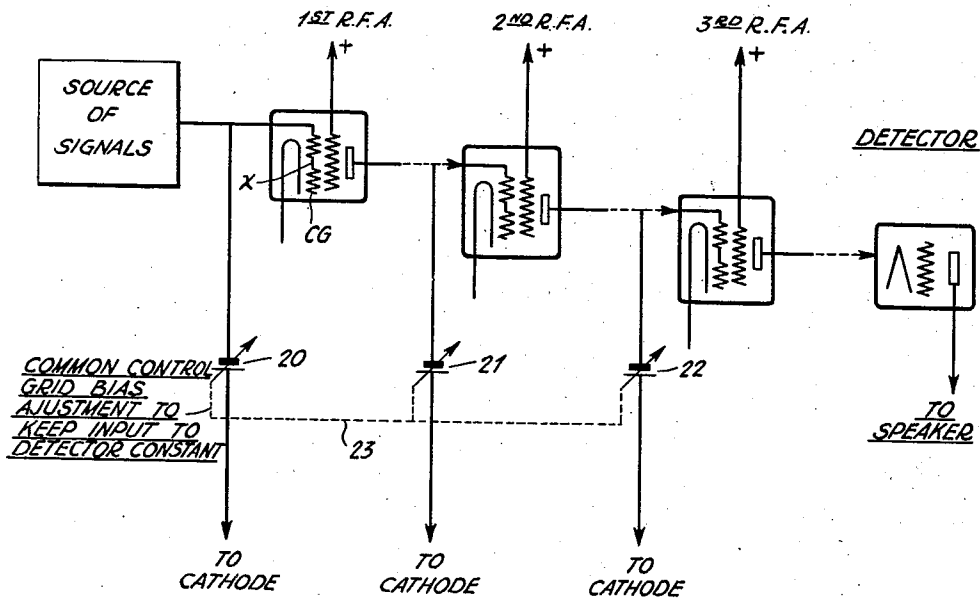
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HIGH FREQUENCY AMPLIFIER

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Fig. 13



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UNITED STATES PATENT OFFICE

2,092,893

HIGH FREQUENCY AMPLIFIER

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Original application March 19, 1930, Serial No.
437,225. Divided and this application July 2,
1931, Serial No. 548,300. Renewed May 13,
1936

24 Claims. (Cl. 179—171)

The present invention relates to high frequency amplifier circuits, and more particularly to such circuits utilizing electron discharge tubes of the type shown in my copending application Serial No. 437,225, filed March 19, 1930, now United States Patent No. 2,048,224, the present application being a division of said application.

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 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.

There has been disclosed by Stuart Ballantine in application, Serial No. 551,625, filed July 18, 1931, now United States Patent No. 2,066,284, the basic method of, and apparatus for, substantially diminishing distortion and cross-talk in a radio frequency amplifier utilized in a radio receiver. This general method is accomplished by providing an arrangement wherein the mu-factor of the amplifier decreases continuously as the amplifier gain control bias increases negatively to keep step with the increasing carrier input volt-

age. Additionally, as pointed out by Ballantine, 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 in virtue of 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.

An object of the present invention is to provide an amplifier circuit including an electron 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 is to provide an amplifier including 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.

A further object is to provide a radio frequency amplifier provided with an electron discharge tube capable of adjustment to give an undistorted output of approximately constant magnitude over a wide range of applied carrier voltages.

And more specifically, an object of this invention is to provide an amplifier of high frequencies using an electronic discharge tube in which different portions of the electron stream are influenced at different rates by the voltages applied to the control grid.

Still other objects of the present invention are to improve generally the efficiency of high frequency amplifiers provided with one, or more, stages, and to particularly provide in at least one of the stages a tube of a characteristic to be

adapted to render the amplifier highly economical and reliable in operation.

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 circuit organizations 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. 2 to 7b inclusive are diagrammatic views illustrating various embodiments of the invention,

Fig. 8 is a curve sheet showing the variations of plate current with grid bias for a tube such as shown in Fig. 1,

Fig. 9 is a curve sheet showing the relation between control grid voltage and transconductance for a tube embodying the invention,

Fig. 10 is a curve sheet showing the relation between permissible maximum input voltages and control grid bias voltages,

Fig. 11 is a curve sheet showing the performance of a three stage amplifier employing the novel form of tube, and

Fig. 12 is a diagram of an amplifier stage including a tube such as shown in Fig. 1,

Fig. 13 is a diagram of a conventional radio receiver embodying three radio frequency amplifier stages employing the present invention.

Referring to the accompanying drawings wherein like reference characters in the different figures represent the same structural elements, the invention is shown in Fig. 1 as embodied in a form of tube known commercially as a screen grid tube 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 P and an outer screen S which is electrically connected to the outer grid. Except for the novel construction of the control grid CG, 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 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 as 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.

This variation in control at different parts of the tube may be effected by other control grid constructions or by other physical arrangements of the tube elements. Instead of removing turns from a grid winding of uniform pitch, the construction shown in Fig. 2 may be employed. In this form, the control grid is a continuous winding carried by the supports 1, the end portions 3 of the winding being of the same pitch and joined by an intermediate section 4 of much longer pitch.

In Fig. 3 the cathode C takes the form of a coating, represented by the stippled section on the heater element H. The plate P and screen grid SG are of the usual construction and arrangement but one end of the control grid CG stops short of the end of the cathode.

The diagrammatic views 4a to 4e inclusive show control grids in which the winding pitch is not uniform throughout the entire length of the grid. In Fig. 4a, the winding is of progressively varying pitch from one end to the other. The grid of Fig. 4b has one section of one pitch and a second section of a different pitch. Fig. 4c is a diagrammatic view showing the omitted turns arrangement which is illustrated in Fig. 1, and Fig. 4d shows one turn omitted at each side of the central turn of the grid winding. Fig. 4e shows an arrangement similar to that of Fig. 4b, but having three sections of different pitch.

Another general method for securing an equivalent operation is shown in the diagrammatic views, Figs. 5a to 5d.

As shown in Fig. 5a, the screen grid SG may take the form of a conical or tapered winding of uniform pitch, the remaining tube elements being of the usual cylindrical form. Any one or more of the tube elements may be tapered, and Figs. 5b to 5d show, respectively, a tapered control grid, a tapered cathode, and a tapered plate.

An eccentric arrangement of one or more elements may be employed, Fig. 6a showing the axis of the cathode C inclined to the axes of the other elements and Fig. 6b showing the cathode C parallel to, but not coaxial with, the other elements.

It will be apparent that various combinations of the several described constructions may be included in a single tube. As shown in Fig. 7a, a tapered screen grid SG may be used with a control grid having windings of two different pitches, or as shown in Fig. 7b the screen grid SG may comprise two cylindrical sections of different diameters. To prevent the flow of an excessive plate current the larger diameter section of the screen grid is located opposite the portion of the control grid from which the windings are removed or are of the greater pitch.

The mode of operation of the modifications disclosed in Figs. 2 to 7b inclusive 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. The term "control grid" is used herein with the meaning given in definition 7023 found on page 65 of the "Year Book of the Institute of Radio Engineers" (1931), wherein there is stated the following: "A control electrode is an electrode upon which a voltage is impressed to vary the current to one or more other electrodes". 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. 8, 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 slope 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. 9 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 having two turns omitted from the center of the control grid. The data for this curve and for curve A of Fig. 8 relate 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. 8, 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. 10 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 were 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. 9 and 10 show that over the range of bias voltage 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 5 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 -48 volts, and 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, if the control of amplification is restricted to values of control grid bias not in excess of about 38 volts negative in the case of the tube of curve A and about 65 volts negative for the tube of curve B, the maximum carrier voltages which may be transmitted are approximately 19 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 kilocycles modulated 30% 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. 11, curve D shows the relationship between audio output and carrier wave input when 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 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.

Fig. 13 shows in purely conventional manner a receiver of the type referred to for securing curve E. The three radio frequency amplifier stages are designated "1st R. F. A."; "2nd R. F. A."; "3rd R. F. A.", and the final tube is designated "Detector". A speaker reproduces the detector output. The control grid CG of each radio frequency tube is schematically shown as having two turns omitted at the center thereof, as at x. A purely conventional representation has been utilized to illustrate the means for maintaining the detector input constant with increasing signal strength, this representation including the control grid bias sources 20, 21, 22 and a common adjustment 23 shown in dotted lines. It will be readily understood by those skilled in the radio receiver art that the elements 20, 21, 22, 23 represent any well known device for adjusting the control grid bias simultaneously on the three amplifier stages. The specific circuit connections between the source of signals and the first tube, between the various tubes, and between the detector and speaker, have all been omitted since they are well understood by those skilled in the art, and espe-

cially in view of the fact that Fig. 13 is purely schematic in nature.

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. 9 and 10 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.

A typical arrangement of the novel type of tube in a conventional amplifier circuit is illustrated in Fig. 12. As shown diagrammatically, the tube elements are constructed as illustrated in Fig. 1, and the tuned input circuit 10 is connected in the customary manner between the control grid CG and cathode C through the battery 11 which provides an adjustable source of direct current potential for determining in the well known manner the amplifier gain control bias applied to the control grid. Appropriate direct current potentials are applied to the screen grid SG and plate P by a suitable current source, such as battery 12, and any suitable impedance, such as the primary winding of an output transformer 13 is included in the plate circuit.

The bias battery 11 should, of course, provide for a wider variation of grid bias potential than has been customary with the known constructions since, as shown by the curves of Fig. 9, negative bias potentials as high as about 40 and 80 volts may be required to cover the full range of amplification control with tubes embodying the invention while the known valves of the same general type require but 15 volts. Except for the fact that the source of control grid bias must be capable of adjustment to deliver higher voltages than have been previously required, the circuit illustrated in Fig. 5 will be recognized as one of the conventional circuit arrangements for screen grid amplifiers.

Similarly, tubes embodying the invention may be used in other screen grid amplifier circuits by increasing, if any increase is necessary, the range of adjustment of the control grid bias potential to provide for amplification control over the entire range which is made possible by the novel tube construction. 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 physical arrangements 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 operating in parallel, one tube having relatively high ratio of plate voltage to control grid voltage (high μ) and other tubes having lower ratios of plate voltage to control grid voltage (low μ). In fact, the same distortionless amplification control over a wide range of input voltages may be secured when two or more tubes of the described different characteristics are operated in parallel, as disclosed

specifically in the said Ballantine application, but 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 change in the voltage of another electrode, under the condition that all other voltages remain unchanged. By mu-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 organization 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. In an amplifier circuit including a multi-electrode screen grid tube wherein alternating current energy of magnitudes ranging up to a value of the order of 17 volts is relayed through the control action of a grid electrode upon an electron stream in a vacuous space, the method of adjusting the transmission through said amplifier circuit throughout said energy range without distortion which comprises the steps of controlling by different amounts the portions of said electron stream flowing through different regions of said vacuous space, impressing upon said grid electrode a steady polarizing voltage, and adjusting said polarizing voltage through a range extending from zero to a value to the order of 80 volts without cutting off the flow of said stream.

2. The combination with a signal input circuit of an electron discharge device of the type having as elements, an equi-potential cathode, a cylindrical anode surrounding and coaxial with said cathode and a cylindrical control grid interposed between and coaxial with said cathode and said anode and comprising a variably spaced helically wound wire whereby the control grid is adapted to exercise different rates of control over different portions of the electron stream, a source of direct current potential of a magnitude effective if applied to the control grid to suppress the flow of current in all of said portions of the electron stream and means for adjusting the polarizing potential applied by said source to said control grid through a range extending to a value of the order of -30 volts without suppression of said stream flow.

3. In an electric wave amplifier circuit, a screen grid tube including in parallel two substantially independent space charge paths, control electrode means positioned in said space charge paths, an input circuit connected to said control

electrode means and upon which the electrical waves to be repeated are impressed, a direct current source for impressing a bias potential upon said control electrode means, and means for adjusting the impressed bias potential over a range of values extending from zero up to at least -30 volts such that current flow, under the influence of electrical waves applied to said input circuit, may take place in one, or in both, of said space current paths.

4. The method of increasing the distortionless operating range of an alternating current wave amplifier of the type in which a space current flows between cathode and plate elements in an electron discharge tube and the wave to be repeated is impressed upon a control electrode positioned between said elements, which comprises establishing in parallel within the tube two space current paths over which polarizing potentials applied to said control electrode exercise substantially different rates of control, and controlling the amplification by adjusting the polarizing potential between a limit corresponding to current flow in but one of said paths and a limit corresponding to current flow in both of said paths.

5. In an alternating current repeater circuit including a space discharge tube provided with a control grid, the method of reducing distortion resulting from the higher order curvature of the plate current-grid bias characteristic, which comprises reducing the curvature of the characteristic of a high mu space current path by arranging in parallel therewith within said tube a low mu space-current path, and controlling the gain of the repeater by adjustment of the control grid bias through a range of values extending to at least -30 volts.

6. In an alternating current repeater circuit including a space discharge tube, means establishing a space current path within the tube having in parallel a high mu section and a low mu section, control electrode means in both portions of said path, means for impressing an alternating wave upon said control electrode means, and means for adjusting the bias potential upon said control electrode means between a value effective to establish space current flow in both of said sections of the space current path and a value effective to establish a current flow in only one section of said space current path.

7. An alternating current repeater circuit including a tube of the space current flow type, comprising cathode and plate means between which a space current flow may be established, control means between said cathode and plate electrodes for exercising different rates of control over the space current from different parts of said cathode means, said control means comprising a grid provided with perforations through which electrons can pass between the cathode and plate means, said perforations being larger along one portion of the grid structure than along another portion thereof, and means for controlling the gain of said repeater, said means comprising a source of bias potential adjustable between limits of zero and at least -30 volts effective to establish a flow of space current from a part only or from all parts of said cathode means.

8. In an alternating current wave repeater circuit including a space discharge tube, cathode and anode means between which a flow of space current may be established, control means extending transversely of the path of space current flow and comprising a grid structure pro-

vided with perforations of unequal size along different portions of the structure, an input circuit connected between said cathode means and said control means, an output circuit for said space current path, said control means exercising substantially different rates of control over current flow in different portions of said path as the bias potential on said control means is varied, a source of direct current for impressing upon said control means a negative bias potential of such magnitude as to substantially suppress the flow of current in all portions of said path, and adjustable means for progressively increasing the negative bias potential applied to said control means to a value of at least the order of -30 volts, thereby to bring successively into operation and to control the current flow in the said different portions of said path.

9. A radio frequency amplifier circuit comprising an electron discharge tube having cathode and anode elements and an equi-potential perforated control element interposed between the cathode and anode elements the spacial relation of the parts of said elements which are in the paths of electron flow from adjoining areas of said cathode differing successively with corresponding differences which cause the potential gradients along said paths to differ substantially exponentially and thereby cause the trans-conductance of said tube to vary substantially as an exponential function of the voltage applied to said control element, a signal input circuit connected between the control element and cathode of the tube and adapted to have radio frequency signal potentials impressed thereon, said signal potentials ranging between limits of the order of 0.3 volt and 17 volts, an output circuit connected between the cathode and anode of the tube, a source of negative biasing potential connected to said control element, said source being adjustable to vary the potential of said control element between limits of the order of zero and at least -30 volts, and said tube having a control element voltage-anode current characteristic such that the flow of the electron stream within the tube is not cut off when the said biasing source is adjusted to said negative limit.

10. An amplifier circuit including an electron discharge device, an input circuit and an output circuit for said device, said discharge device including an anode, a cathode and a grid structure, the grid structure being interposed between the anode and cathode and having perforations throughout its length through which electrons can pass from the cathode to the anode, the perforations along one part of the grid structure being larger than those along another part thereof whereby the discharge device is provided with a characteristic such that the anode current varies substantially exponentially with the voltage applied to the grid structure, the grid structure being normally biased with respect to the cathode and means for varying the biasing potential applied to the grid structure.

11. An amplifier circuit including an electron discharge device, input and output circuits connected to said device, said electron discharge device comprising a cathode, a plate, a signal grid and an auxiliary grid, one of said grids being provided throughout its length with perforations through which electrons can pass between the cathode and plate elements, said perforations being larger along one portion of the grid structure than along another portion thereof whereby said tube is provided with a characteristic such

that the anode current varies substantially in spacial relation with the voltage applied to one of said grids, means for varying the difference in potential between the control grid and cathode and means for adjusting the potential applied to the auxiliary grid.

12. An amplifier circuit including an electron discharge tube, input and output circuits connected to said tube, means in said input circuit for tuning it through a desired signal frequency range, said tube including at least cathode, control grid, and anode elements, said control grid being provided with perforations of different sizes along different portions thereof to thereby provide said electron discharge tube with a characteristic such that the anode current varies substantially in exponential relation with the voltage applied to said control grid, said control grid being normally maintained negative with respect to said cathode, and means for varying the difference in potential between the control grid and cathode.

13. In combination with a plurality of cascaded radio frequency amplifiers each of said amplifiers including an electron discharge tube having cathode and anode elements and an equi-potential perforated control element interposed between said cathode and anode elements the spacial relation of the parts of said elements which are in the paths of electron flow from adjoining areas of said cathode differing successively with corresponding differences which cause the potential gradients along said paths to differ substantially exponentially and thereby cause the trans-conductance of the tube to vary substantially as an exponential function of the voltage applied to said control element, means for simultaneously adjusting the control grid bias on said amplifiers to maintain the output of the last amplifier substantially constant despite variations in the intensity of the radio frequency energy input to the first amplifier.

14. In a radio frequency amplifier, a source of oscillations to be amplified and a utilizing circuit for the amplified oscillations, a coupling between the source and the utilizing circuit comprising an electronic relay device having a cathode and an anode and means for energizing said cathode and anode for establishing a flow of space current between the cathode and anode, control means in the path of the space current flow comprising a grid structure, a source of biasing potential for the grid structure for impressing upon the grid structure a negative potential with respect to the cathode, said grid structure being constructed with relation to the cathode and anode so as to affect the flow of space current between the cathode and anode differently along different portions of the electronic stream and adjustable means for varying the bias potential applied to the control means to thereby vary the flow of space current between the cathode and anode, said grid structure causing different degrees of variations along different portions of the electronic stream for like increment changes in the bias potential, there being at least one portion of the electronic stream that is substantially unaffected for normal values of the biasing potential whereby the amplification characteristics of the amplifier may be varied without modulation distortion of the desired signals or production of cross-talk effects between the oscillations to be amplified and undesired oscillations.

15. In an alternating current repeater circuit including a space discharge tube provided with an

anode, a cathode and at least one control grid, the method of reducing distortion resulting from the rapid increase in the higher order curvature parameters of the tube characteristic which occurs as the amplification factor of the tube is decreased by varying the potential on a control grid of the tube which comprises reducing the curvature of the characteristic of a high mu space current path by arranging in parallel therewith within said tube a low mu space current path, and controlling the gain of the repeater by adjustment of the potential on the control grid to impart a controlling action simultaneously upon both the high and low mu paths of the tube.

16. In an alternating current repeater circuit including a space discharge tube provided with an anode, a cathode, a signal grid and an auxiliary grid, the method of reducing distortion resulting from rapid increase in the higher order curvature parameters of the tube characteristic which occurs as the amplification factor of the tube is decreased below a predetermined value by varying the potential applied to one of the grids thereof, which comprises reducing the curvature of the characteristic of a high mu space current path in the vicinity of the lower knee of the characteristic curve to such an extent that the cut off point of the curve is considerably extended toward the negative grid potential region, whereby the gain of the repeater may be controlled by adjustment of the grid potential through a range of values extending to at least -30 volts without reaching the point of cut-off.

17. The combination with a signal input circuit of a screen grid tube provided with an equi-potential cathode, a cylindrical plate coaxial with and surrounding said cathode and a cylindrical grid of uniform diameter throughout its length mounted coaxial with said cathode and said plate and having throughout its length perforations through which electrons can pass radially of said grid and which are wider near the middle of said grid than near the ends thereof, means for applying a potential to said grid, said grid potential exercising different rates of control over different portions of the electron stream, a source of direct current potential of a magnitude effective if applied to the grid to suppress the flow of current in all of said portions of the electron stream and means for adjusting the polarizing potential applied by said source to said control grid through a range extending to a value of the order of -30 volts without completely suppressing the flow of said electron stream.

18. In an amplifier circuit, a source of signal voltage and a utilizing circuit, means for transferring energy from the source to the utilizing circuit comprising anode and cathode means between which a flow of space current may be established, control means interposed between the anode and cathode means, said control means comprising a grid structure having throughout its length perforations through which electrons can pass, said perforations being larger near the middle of the grid structure than near the ends thereof, an input circuit connected between the cathode and control means including means for impressing bias voltage upon the control means and means for connecting the input circuit to the source whereby signal voltage is impressed upon the control means, an output circuit connected between the anode and cathode means including a source of space current and means for connecting the output circuit to the utilizing circuit,

said control means exercising substantially different rates of control over space current flow between different portions of the anode and cathode means for the same changes in voltage impressed upon the control means, said space current path having a space current grid-voltage characteristic which is, in effect, similar to the characteristic of a high mu electronic tube the curvature of which is reduced in the vicinity of the lower knee thereof to such an extent that the cut off point of the curve is considerably extended toward the negative grid potential region.

19. An electrical relay circuit including a tube provided with a cathode, a control grid, an auxiliary grid and an anode, one of the grids of said tube being sufficiently structurally irregular with respect to the other elements of the tube to thereby give the tube substantially an exponential trans-conductance characteristic, power supply means connected to the elements of said tube to energize the cathode, establish a flow of space current between the anode and the cathode and potentialize the grids and means for varying the potential applied to one of said grids to thereby vary the trans-conductance of the tube.

20. A multi-stage amplifier, each stage including an electronic tube provided with a cathode, a control grid, an anode and an auxiliary grid, each electronic tube having at least one of its elements sufficiently structurally irregular with respect to the other elements of the tube to thereby give the tube a trans-conductance characteristic which is substantially exponential in nature, a power supply means connected to the elements of the tubes to energize the cathodes thereof, establish a flow of space current between the respective anodes and cathodes of the tubes and to potentialize the various grids and means for simultaneously varying the potential applied to at least one of the grids of each of the tubes to thereby vary the trans-conductance of each of said tubes simultaneously and thereby maintain the output of the amplifier substantially constant with varying input to the first stage of the amplifier.

21. An amplifier including an electronic tube provided with a cathode, a control grid, an anode and a screen shielding said grid from said anode, said control grid being in the form of a cylindrical grid of uniform diameter throughout its length and having perforations through which electrons can pass, said perforations being larger along one portion of said grid than along another portion thereof whereby the trans-conductance of said tube varies in exponential relation to the voltage applied to said grid, power supply means connected to the elements of said tube and means for varying the voltage applied to said grid to thereby vary the trans-conductance of said tube.

22. In an electrical circuit, an electronic tube comprising an equi-potential cathode, a coaxial plate and a helical equi-potential grid coaxial with said cathode and having between all of its turns openings to permit an electron stream to flow radially of said grid between said turns, the spacial relation of adjoining parts of said grid to corresponding parts of said cathode differing successively by uniform increments whereby as the potential of said grid becomes increasingly negative the flow of electrons is stopped from different parts of said cathode in succession whereby the trans-conductance of said tube varies in exponential relation to the voltage applied to said grid, power supply means connected to the elements of said tube and means for varying the

voltage applied to one of said elements to thereby vary the trans-conductance of the tube.

23. In an electrical circuit, an electron discharge device provided with an equi-potential cathode, a cylindrical plate coaxial with and surrounding said cathode, and a cylindrical grid of uniform diameter throughout its length mounted coaxial with said cathode and said plate and having throughout its length perforations through which electrons can pass radially of said grid and which are wider near the middle of the grid than near the ends thereof whereby said tube has a trans-conductance characteristic which varies in exponential relation to the voltage applied to the grid, power supply means connected to the elements of said tube and means for varying the voltage applied to one of said elements to thereby vary the trans-conductance of the tube.

24. An amplifier including an electronic tube provided with an equi-potential cathode, an anode and a irregular grid structure, said grid structure being interposed between the anode and the cathode and being substantially of uniform diameter throughout its length but having the perforations larger near the middle of the grid structure than near the ends thereof, the grid structure being sufficiently irregular with respect to the other elements of the tube to give the tube a trans-conductance characteristic which is substantially exponential in nature, and power supply means connected to the elements of the tube to energize the cathode, establish a flow of space current between the anode and the cathode, and potentialize the grid.

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