

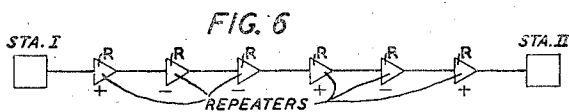
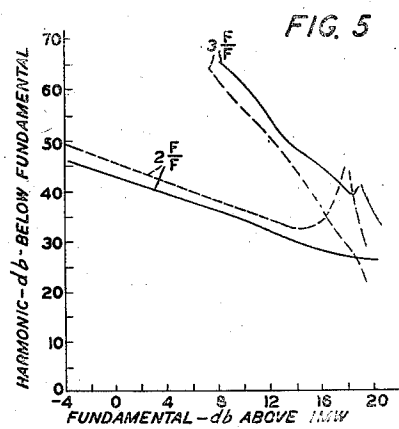
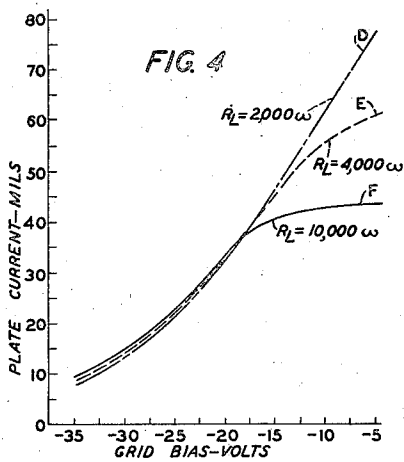
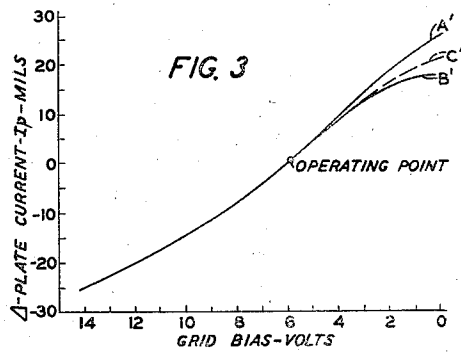
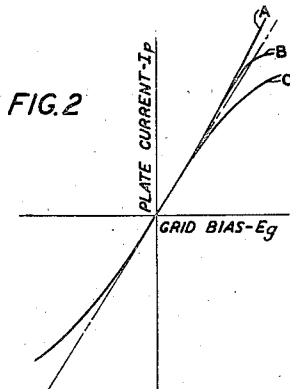
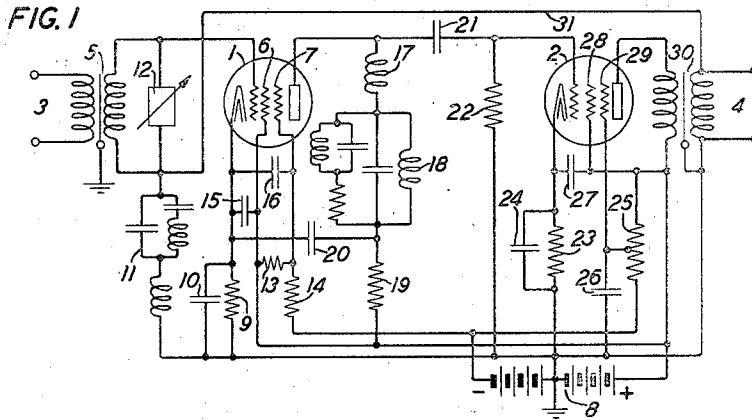
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2,250,172

ELECTRICAL WAVE AMPLIFICATION

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ELECTRICAL WAVE AMPLIFICATION

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6 Claims. (Cl. 179—171)

The present invention relates to space discharge tube circuits and methods of operating the same.

The invention has particular reference to the problem of wave amplification with minimum distortion. In broad band wave transmission in signaling systems, such as multiplex carrier wave transmission, definite limits are sometimes placed on the permissible modulation in repeaters by the structural design or operating characteristics of related parts of the system, for example, the repeater spacing, noise level or other factors. It is desirable, therefore, to be able to control and to predetermine the distortion output level of a repeater to meet given requirements.

An object of the invention is to provide a means and method for such a control.

The invention has particular application to and will be disclosed with reference to pentode tube circuits, that is, tubes incorporating a cathode, an anode, a control grid, a screen grid and a suppressor grid located between the screen grid and anode. Tubes of this type are common in the art and require no detailed description. It is not intended to limit the invention to tubes having exactly these but no other elements, for as the description proceeds it will become apparent that the invention is chiefly concerned with the control of the effectiveness of the suppression exerted by the suppressor grid or equivalent, and the nature of the tube structure not immediately concerned with such control is to be regarded as incidental rather than limiting or essential.

The chief function of the suppressor grid in the pentode tube is to permit larger plate voltage swings by preventing loss of anode current through secondary emission at low instantaneous values of plate voltage. For this purpose the suppressor grid is maintained at a lower potential than the lowest instantaneous potential reached by the plate and is usually maintained at cathode potential by connecting it to the cathode inside the tube. Secondary electrons emitted from either the plate or screen grid find themselves in a retarding field which they are unable to traverse because of their low velocity, and they are turned back to the positive electrode from which they were emitted. The suppressor grid prevents the rapid diminution of plate current by secondary emission in the low plate voltage range and allows the tube to deliver useful output up to the end of a relatively large grid swing in the positive direction corresponding to a drop in plate voltage to a relatively low point. The great

virtue of the suppressor grid is, therefore, in enabling one to secure large power output by employment of high amplitude driving voltage on the grid. For a more complete discussion of the subject, reference may be had to an article entitled "Theory of Multi-Electrode Vacuum Tubes" by H. A. Pidgeon, Bell System Technical Journal, January 1935.

Applicant has found, in accordance with the present invention, that a material improvement as regards undesired distortion in an amplifier can be effected by using a bias potential of certain value on the suppressor grid. This bias may in some cases be positive and in other cases negative. It is found that the shape of the dynamic characteristic can be changed by means of such a bias voltage in a direction and to an extent to give the improvement mentioned, as will be more fully described hereinafter.

Broad band transmission systems such as the coaxial line impose very severe requirements upon amplifier design. The coaxial line makes readily available a transmission range extending from any desired lower limit, in practice a limit expressible in kilocycles, up to several megacycles. Terminal facilities can be provided by superposing channels to any desired extent, but the broader the band the more severe are the requirements placed upon the repeaters. Since the repeaters are spaced only 5 or 10 miles apart there is a large number of repeaters in tandem between terminals, and this fact greatly increases the requirements placed upon an individual repeater.

The design of any given system determines the maximum permissible modulation of second order, third order and possibly higher order, for the repeaters. It becomes extremely important, therefore, to be able to exert a control over the amount of modulation of a given type appearing in the output of a repeater.

The best type of dynamic characteristic for even order distortion is one which is symmetrical about the operating point, sometimes called the quiescent point. By symmetrical is meant that if one half is swung about the operating point by 180 degrees it will exactly overlie the other half. There is no requirement, in this test, as to linearity of the two halves. For minimum third order distortion each half of the dynamic characteristic should be, ideally, linear; the two halves need not be in a straight line. As stated above, it has been found by experiment that the shape of the dynamic characteristic of a tube can be controlled to an extent by use of suitable bias

on the suppressor grid, toward its ideal shape for minimum distortion of particular kind. It frequently happens that a tube and circuit meets the requirements for one type of modulation, e. g. third order, with something to spare, but falls short of the requirement for second order distortion. It has been found that when a suppressor grid bias of proper value was applied, it reduced the second order distortion bringing it within the required limit. At the same time the third order could be kept within the required limit.

As will appear more fully from the detailed description to follow, the control over the shape of the dynamic characteristic can be varied at will to meet different requirements within limits. For example, it is possible under certain conditions either to increase the curvature or to straighten out the dynamic characteristic near the low-plate-voltage high-plate-current end without producing corresponding changes in the portion of the dynamic characteristic lying on the opposite side of the operating point. One effect of this is that if the dynamic characteristic to begin with gave an undesired amount of second harmonic, the curvature of the high-plate-current end could be changed so as to make the characteristic more symmetrical about the operating point and thus reduce the second order modulation. On the other hand, if the desired effect is to straighten the high-plate-current end of the dynamic characteristic so as to reduce third order modulation, this may also be done. These various effects are obtained by the use of suitable suppressor-grid bias in connection with other factors, one of which is the load impedance, as will be explained below.

The nature of the invention and its various objects will be more fully understood from the following detailed description of a typical or illustrative embodiment in connection with the accompanying drawing.

In the drawing, Fig. 1 is a schematic circuit diagram of one form of broad band amplifier used by applicant incorporating the present invention;

Figs. 2 to 5, inclusive, show curves to be referred to in the detailed description of the nature and mode of operation of the invention, and

Fig. 6 is a diagram of a repeated line with random distribution of distortion in accordance with the invention.

Referring first to Fig. 1, the amplifier shown comprises two stages including pentode tubes 1 and 2 connected in cascade with an input connection at 3 and an output connection at 4. For illustrative purposes this amplifier may be considered as a broad band amplifier such as might be used in a coaxial line system transmitting waves comprised in a band extending from, say, less than one megacycle to the order of 3 megacycles or more. It is understood that in this case the input 3 would be connected to one section of coaxial line not shown, while the output connection 4 would be connected to a second section of coaxial line not shown. The waves of the broad band of frequencies mentioned may comprise modulation side-bands representing multiplex telephone messages or a television band, or similar waves.

The control grid of stage 1 is coupled to input connection 3 by means of transformer 5. A regulating impedance 12 which may in practice be a network of suitable type is connected across the secondary winding of transformer 5. In

series with the lower terminal of this winding are a network 11 shown as consisting of a capacitive and inductive reactances and a mesh consisting of bias resistor 9 and shunting condenser 10 leading to the cathode of stage 1. The network 11 is an equalizer. The elements 9, 10 are the usual grid bias resistance-capacity network. The screen grid 6 is connected to the positive pole of the plate battery 8 and is by-passed to the cathode through condenser 15. The suppressor grid 7 is not returned to the cathode as in common practice but is in accordance with this invention connected to the junction point of resistances 13 and 14 which are connected in series across the battery 8 so that a positive or negative bias is supplied to the suppressor grid 7 of a magnitude and sign dependent on the relative values of resistances 13 and 14, battery 8 being grounded at an internal point as shown. This feature of the invention will be described more fully hereinafter. The suppressor grid 17 is by-passed to the cathode through condenser 16.

The plate of stage 1 is connected through coupling condenser 21 to the control grid of stage 2 and is supplied with space current from battery 8 through the series path including resistor 19 and network 18 including inductance 17. The network 18 may take on any one of many different forms depending upon the band width and the other elements of the circuit. An illustrative form used by applicant and consisting of both reactive and resistive components is shown. The upper end of resistance 19 is by-passed to the cathode through condenser 20. The control grid of stage 2 is connected through resistor 22 and grid bias mesh consisting of resistance 23 and condenser 24 to the cathode of stage 2. The screen grid 28 of stage 2 is connected to the positive pole of battery 8 and is by-passed to its cathode by condenser 27. The suppressor grid 29 is connected to a suitable point between the terminals of resistor 25 which is connected across the battery 8 and is by-passed to ground through condenser 26. The suppressor grid is thus supplied with a bias voltage in accordance with the invention as will be more fully described hereinafter. The plate of stage 2 is connected through the primary of output transformer 30 to the positive pole of battery 8. The secondary winding of this transformer is connected to the terminals of output circuit 4. The lower terminal of this secondary winding is connected to ground and the upper terminal is connected by way of lead 31 to the junction point between the secondary winding of input transformer 5 and the network 11 whereby a portion of the output waves is fed back to the control grid of stage 1 in a negative or gain reducing sense. The necessary phase reversal is obtained by the direction of winding of the output transformer 30 in conjunction with the circuit elements connected between the control grid of stage 1 and its cathode. This negative feedback is provided for the purpose of stabilizing the gain, reducing the distortion and influencing the impedances of the circuit in the manner generally disclosed and claimed in United States patent to H. S. Black 2,102,671 issued December 21, 1937.

The feature of the circuit of Fig. 1 with which the present invention is chiefly concerned is the feature by which the suppressor grids 7 and 29 or either of them are or is supplied with a steady bias voltage for the purpose of controlling

and particularly minimizing undesired distortion in a manner to be described presently.

Fig. 2 shows typical dynamic transfer characteristics of a pentode tube, such as tube 1 or tube 2 of Fig. 1, under different conditions of suppressor grid bias. For reference purposes, a straight broken line has been drawn through the operating point of this figure and three dynamic curves A, B and C are shown which merge together into one curve in the lower left-hand quadrant and for a short distance in the upper right-hand quadrant after which they separate into three distinct curves as shown. The curve A is a typical dynamic characteristic obtained with a low load impedance when the suppressor grid is directly connected to the cathode and therefore has no bias potential relative to the cathode. The upper end of this curve, it will be noted, has a slight curvature upward. The curve B is typical of a dynamic characteristic obtained by the use of a considerable positive bias potential on the suppressor grid, while the curve C is a typical dynamic characteristic obtained with a substantial negative bias supplied to the suppressor.

The shape of curves B and C may be accounted for in the following way. For large swings of plate voltage the instantaneous plate voltage will fall to a low value as described above and any secondary emission which is allowed to take place from the plate to the screen grid or other electrode will subtract from the plate current thus diverting a corresponding amount of current away from the plate. A positive bias on the suppressor grid provides a potential gradient within the tube adjacent the plate of such nature that secondaries emitted from the plate are attracted over to and are collected by, the suppressor grid, thus subtracting from the plate current. This is the condition represented by curve B where the suppressor is given a positive bias. It will be understood that the exact shape of curve B is a function of the amount of this bias so that the curvature and general shape of the curve B can be controlled by the amount of the bias applied to the suppressor, other things being equal. In the case of curve C corresponding to a negative bias on the suppressor grid, the action is somewhat similar to that of a negative voltage on the control grid. The effect in this case does not involve secondary emission but is due rather to the retarding field of the negatively biasing suppressor on the primary electrons traveling toward the plate. It will be noted that the curve B has greater curvature than curve C.

It was explained above that for minimum second order distortion the two halves of the dynamic characteristic should have similar shape and the characteristic as a whole should be symmetrical about the operating point. Inspection of curves B and C shows that the use of bias on the suppressor grid affords a very effective control over the shape of the upper end of the dynamic curve so that in cases typified by the curves of Fig. 2 it will generally be possible to find some value, either positive or negative, of the suppressor grid bias which permits a high degree of symmetry to be obtained in the shape of the dynamic characteristic.

While the curves of Fig. 2 may be taken as typical, or illustrative, the exact shape of the curves will differ considerably from one type of tube to another. As an illustration of this, Fig. 3 shows measured curves of a particular tube similar to the Western Electric Company type

311 pentode tube. In this particular tube the curves corresponding to those of Fig. 2 are lettered A', B' and C', respectively, and it will be noted that in this case curve C' is intermediate between curves A' and B'. In taking these curves curve B' corresponded to a suppressor grid bias of 58 volts positive, while curve C' corresponded to a suppressor grid bias of 70 volts negative, curve A' representing the zero bias condition. In these measurements the plate voltage was 130 volts, the control grid bias was 6 volts negative, while the load impedance was 3,000 ohms.

As mentioned above, the shape of dynamic characteristics of a pentode tube is also dependent upon the load resistance. Typical curves showing this are given in Fig. 4 for a Western Electric 311 type tube. The upper curve D corresponds to a load impedance of 2,000 ohms, the intermediate curve E corresponds to a load impedance of 4,000 ohms and the lower curve F corresponds to a load resistance of 10,000 ohms. These observations were taken with the suppressor grid at cathode potential and with a plate voltage of 150 volts. If these curves of Fig. 4 are scaled off it will be found that the load impedance corresponding to the best shape of curve as regards minimum second order distortion is a load resistance of slightly less than 4,000 ohms, viz. about 3,500 ohms, this being the load impedance which gives the most nearly symmetrical dynamic characteristic. This shows that if one were free to choose the load resistance an optimum value could be used which would result in minimum second order distortion.

The problem becomes much more difficult in the case of a broad band amplifier than in the case of a narrow band or single frequency amplifier.

This is partly due to the difficulty of designing an output transformer to cover the entire band with the required degree of uniformity of characteristic over the band and with sufficiently high transformer ratio, due to a large extent to the inherent shunt capacity. Usually in broad band amplifiers, the total plate-to-ground capacity limits the load impedance which may be presented to a tube, regardless of how good the transformer design may be. It has been found to be a rough working rule that the load impedance can be built up to about half the capacitive reactance at the top of the band if the impedance and reflection requirements imposed on the transformer design are quite stringent. By relaxing somewhat these requirements, it is possible to build up the load impedance to the full value of the reactance.

For example, if the plate-to-ground capacity (including tube and output coil) is 20 microfarads, this corresponds to a reactance of 4,000 ohms at 2 megacycles. If the requirements mentioned are severe, the maximum realizable output transformer impedance is taken as about 2,000 ohms on the basis of this working rule. This load impedance would correspond to the curve D of Fig. 4, which is of such shape as to result in production of undesired harmonic or distortion component. By use of a bias voltage on the suppressor grid of proper magnitude, however, the dynamic characteristic can be given such shape as to minimize the undesired distortion, despite the unfavorable value of load impedance as regards distortion production.

In very low frequency amplifiers a somewhat analogous difficulty exists due to the difficulty of

building high enough inductance to enable the best value of load impedance to be presented to the tube. In other amplifiers other effects may limit the realizable load impedance. It is clear from these illustrative cases that the invention provides an effective way of compensating the tendency of the unfavorable load impedance to produce output distortion in that the suppressor grid bias enables the shape of the dynamic characteristic to be controlled within practical limits to minimize such distortion.

As discussed above, it is generally not possible to secure a dynamic characteristic of a shape which will at the same time be optimum for both second order and third order distortion. This means that in selecting a suppressor grid bias of the right value to give a dynamic characteristic of optimum shape for second order distortion there will usually be a certain small sacrifice in the third order distortion level. Fortunately, however, there is usually a greater margin for one of these types of distortion than for the other such that a net gain in distortion can be effected. This is illustrated by the curves of Fig. 5 in which the solid line curves show in accordance with the labels the level of second and third order distortion with zero bias on the suppressor grid and with a given load resistance, while the dotted line curves show the change in distortion level produced by the use of a positive suppressor grid bias of 63 volts. In this case the plate voltage was 200, the control grid bias was 18 volts negative and the load resistance was 7,000 ohms. The tube was of the same general type as the Western Electric 311. It is noted that an improvement was obtained in the level of second order distortion with a sacrifice of about the same order in third order distortion but in this particular case the third order distortion level to begin with was so much better than the second order that the degradation of the third order distortion was unimportant.

From the description that has been given in connection with Figs. 2 to 5, inclusive, it becomes obvious how the invention may be applied to a circuit of the type shown in Fig. 1 or to pentode circuits in general to secure improved operation. The circuit connections to the suppressor grids 7 and 29 or to one or the other of them are such as to apply to the respective suppressor grid a steady bias voltage either positive or negative of a value which is optimum under the particular circuit conditions and for the type of distortion which it is desired to minimize. The exact value of this suppressor grid bias may be determined by trial and measurement. For example, dynamic characteristics of the particular tube may be obtained in the usual way but with different values of suppressor grid bias so as to obtain families of curves similar to those shown in Figs. 2, 3, and 4 and possibly curves similar to those in Fig. 5. As a result of such measurements a determination can be made of the value of suppressor grid bias which, in case second order distortion is to be minimized, gives the most nearly symmetrical dynamic characteristic for the given load resistance. Using this value as a first approximation, the circuit as a whole may then be measured for second order distortion with slight adjustments of suppressor grid bias in the neighborhood of this first approximation value to determine whether a departure from this first approximation value needs to be taken as the final value. Any method of measuring the second order distortion may be employed, such methods

being well known in the art. For example, two different frequencies may be simultaneously applied to the input of the amplifier of sufficient amplitude to simulate the conditions of use and the adjustment of the suppressor grid bias may be changed until a minimum difference frequency component is observed in the output.

As noted above the purpose of the suppressor grid in a tube is to establish a potential between the plate and screen below the minimum voltage to which the plate is to be swung, so that there is always a potential gradient toward the plate in the region between the plate and suppressor grid. The effectiveness of a suppressor grid depends on its position, turns per inch and its potential. For a given position the effectiveness of the suppressor in establishing a potential minimum will increase with the number of turns per inch and decrease as its potential is raised above that of the cathode. Ordinarily the suppressor has such an open mesh that it has practically no effect on the primary electrons. Making the pitch fine has a somewhat similar effect to applying a negative bias to it. In both cases the grid returns some of the primary electrons to the screen before they reach the plate. This action may be referred to as over-suppression.

If a tube is constructed so that the suppressor grid gives a slight amount of over-suppression, this can be counteracted by application of a small positive bias or it can be accentuated by making the suppressor more negative toward the cathode. This offers one possibility toward providing a range of adjustment of the type discussed above in accordance with this invention. If the dynamic characteristic is either straight or has slight upward curvature as illustrated by curve A in Fig. 2, an opportunity is afforded for securing desired shapes possessing different degrees of curvature to fit different requirements by the simple application of the proper voltage, either positive or negative. The upward curvature can be obtained by adjusting the plate voltage or the load impedance, preferably the latter. By making the load impedance smaller the upper end of the dynamic characteristic is raised as indicated, for example in Fig. 4.

The invention contemplates as one application the control of the effectiveness of the suppressor grid in each of a string of repeaters in a long line to provide random distribution of a given type of distortion, for example, second order distortion. Such a system is shown in diagram in Fig. 6, having terminal stations I and II with intermediate repeaters R, R, etc. The reason for desiring random distribution of a distortion product is disclosed in Patent 1,570,770 to Nyquist, January 26, 1926 and Patent 1,927,070 to Peterson, September 19, 1933 and these patents disclose methods of controlling the distortion output of repeaters so as to secure random distribution. The present invention provides, as has been disclosed, a means of control of distortion production in a repeater and this means of control affects both the amplitude and sign of the distortion. In applying the invention to a string of repeaters in a line, as in Fig. 6, the repeaters R, R, etc. would initially be arranged in accordance with any of the methods herein described to provide a considerable margin of adjustment by the suppressor grid bias. For example, the load impedance initially might be made sufficiently low to give an upwardly bending dynamic characteristic. Then in each of the repeaters an appropriate suppressor bias could

be employed to modify the shape of the dynamic characteristic in such a way as to control the magnitude and sign of a given distortion output and to provide a random distribution of given distortion product along the line.

While the invention has been described in detail in connection with a particular type of amplifier circuit, this circuit and the values that have been given are to be taken as illustrating rather than limiting, the invention being capable of general application and its scope being indicated in the claims which follow.

What is claimed is:

1. In combination, a pentode tube whose dynamic characteristic in the high-plate-current low-plate-voltage end has a slope and curvature varying with load resistance, other things being equal, a load resistance coupled to the plate circuit of said tube which, with zero bias on the suppressor grid, is of non-optimum value as regards production in the load circuit of given distortion component, and means applying a steady bias potential to the suppressor grid of optimum value as regards production in said load circuit of said distortion component but of a value too small to affect substantially the slope of the dynamic characteristic as a whole.

2. In the operation of pentodes, the method of controlling the ratio of modulation to fundamental output components comprising applying to the suppressor grid a steady bias voltage and proportioning said voltage with respect to the normal plate voltage and load resistance to the value which gives the desired radio while maintaining the gain substantially unchanged as a result of application of said bias voltage.

3. In an amplifier, a pentode tube, a load circuit coupled to said tube, means for applying waves of a broad band of frequencies to said amplifier to be amplified thereby and impressed on said load circuit, said load circuit having such

impedance over the frequency band that in the absence of a bias potential on the suppressor grid an undesired amount of distortion is produced in said amplifier, and means for reducing said distortion comprising means to impress a steady bias potential on said suppressor grid of a value sufficient to alter the shape of the tube characteristic but too small to affect substantially the amplifier gain.

4. In the operation of amplifiers employing tubes with suppressor grids, the method of controlling the ratio of distortion to fundamental output components comprising biasing the suppressor grid to control the curvature of the high-current low-voltage portion of the dynamic characteristic relative to the remainder of the characteristic for a given slope of the characteristic as a whole, whereby the optimum shape of characteristic for distortion control is secured.

5. In a broad band amplifier including a tube with a suppressor grid, a load circuit presenting an impedance to the output of said tube which is lower than optimum at some portion of the band, means to apply waves of said band of frequencies to said amplifier in such amplitude as to tend to produce distortion in the output, and means for applying to the suppressor grid a bias voltage proportioned with respect to said load impedance to such value as to counteract said tendency.

6. In a broad band system including a multiplicity of repeaters in tandem each repeater including a tube containing a suppressor grid, means to bias the suppressor grid to determine the magnitude and sign of an output distortion product, the bias means in successive repeaters being of values to produce substantially random distribution of magnitude and sign of a given distortion component independent of the repeater gain whereby the over-all distortion is reduced.

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