GATE SUPPRESSING LINEAR RESPONSE AMPLIFIER

Filed July 14, 1945 2 Sheets-Sheet 1

FIG. 1

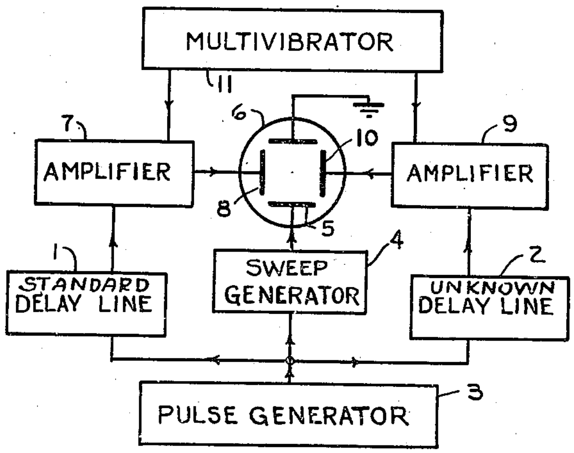


FIG. 4

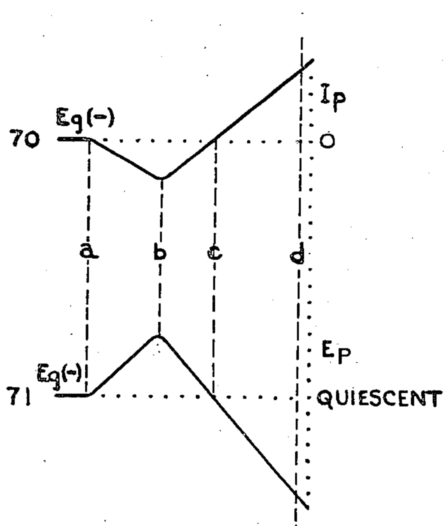
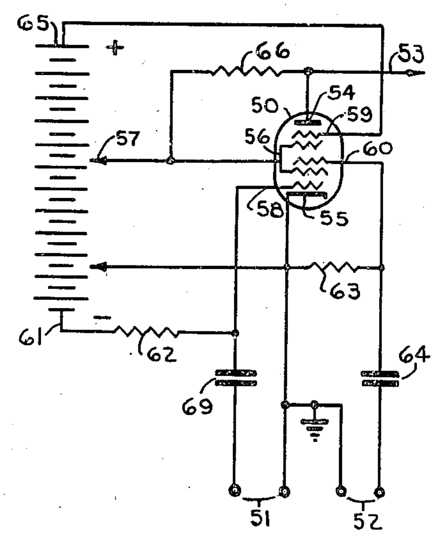


FIG. 3



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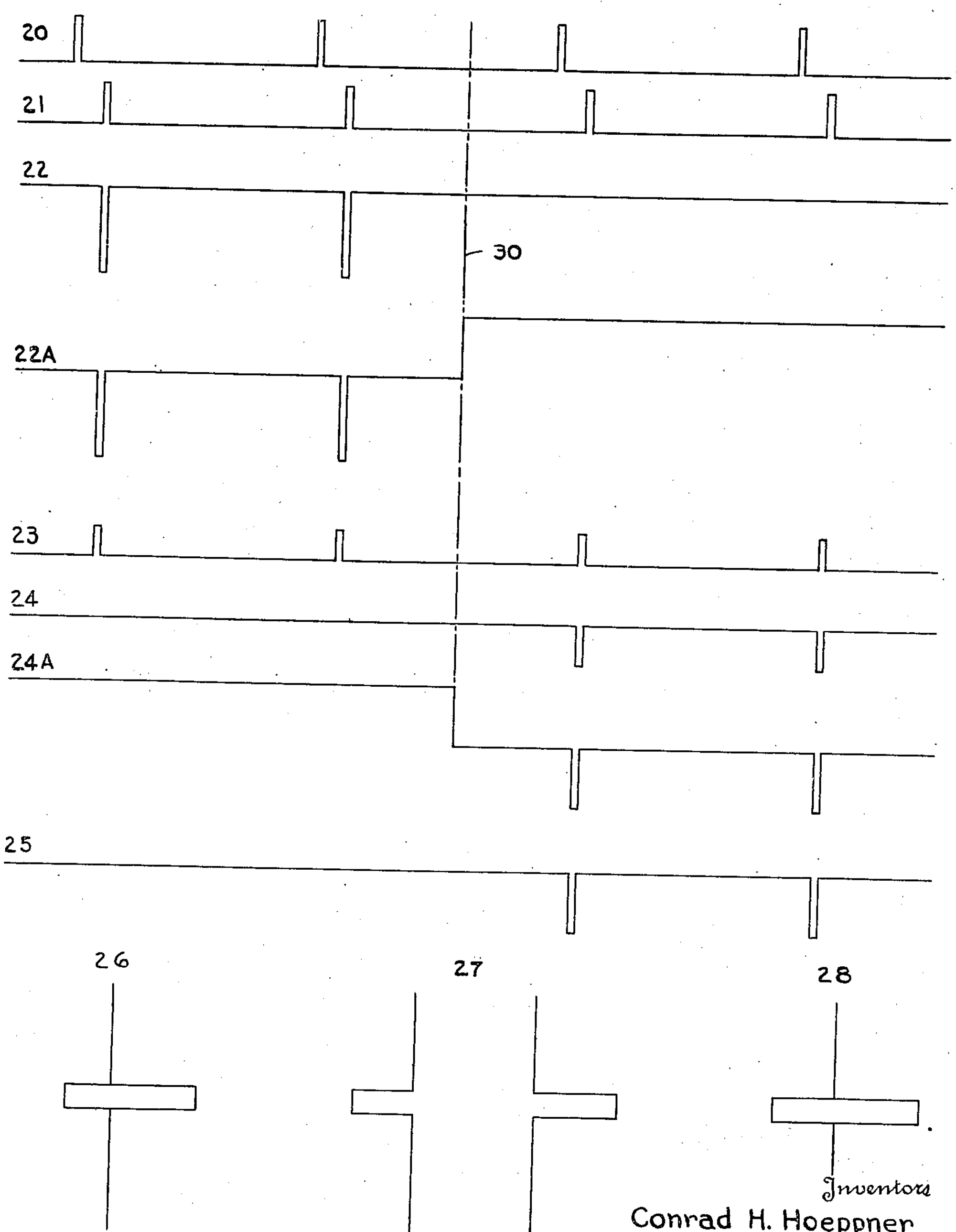
Jan. 18, 1949. M. W. ROSEN ET AL 2,459,181

GATE SUPPRESSING LINEAR RESPONSE AMPLIFIER

Filed July 14, 1945 2 Sheets-Sheet 2

FIG. 2



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GATE SUPPRESSING LINEAR RESPONSE AMPLIFIER

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8 Claims. (Cl. 315—26)

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This invention relates in general to electronic amplifier circuits and in particular to an amplifier circuit which is adapted to be electronically switched from cutoff to a linear operating condition without a corollary change in plate current flow.

Under certain circumstances it is desirable to present two unidirectional waveforms simultaneously on the face of an oscilloscope in such a manner that the waveforms are disposed in a back-to-back relationship and consist of opposing excursions from a common base line. The application of both waveforms to the same deflecting plate of an oscilloscope requires that one of them be passed through an inverting stage while application to opposite deflecting plates introduces the difficulty of maintaining a common base line.

It is an object of this invention to provide a means whereby two waveforms may be alternately applied to opposing deflecting plates in oscillographic equipment and viewed simultaneously in a back-to-back relationship.

It is another object of this invention to provide an electronic means for alternating the source of applied signals between two deflecting plates of a cathode ray tube without change in the potential between those plates.

It is another object of this invention to provide a vacuum tube amplifier which may be biased periodically from cut-off condition to linear operating condition by means of a gating voltage without causing to appear at the plate of said amplifier any variation in potential as between the two conditions of operation.

It is another object of this invention to provide an amplifier employing a single vacuum tube which, in effect, draws no plate current in its quiescent condition but which, upon receipt of signals of various amplitudes amplifies each in a substantially linear manner.

It is another object of this invention to provide an electronic circuit comprising a single vacuum tube and associated components in which the vacuum tube may be changed from a non-conducting condition to a conducting condition by application of an external control voltage without altering the output potential of the circuit and in which conducting condition signal voltages applied to the circuit cause changes in the output potential directly proportional to the amplitude of said signal voltages.

Other objects and features of this invention will become apparent upon a careful consideration of the following detailed description when taken together with the accompanying drawings of which:

Fig. 1 is a block diagram of one embodiment of this invention;

Fig. 2 is a group of waveforms illustrative of the operation of one embodiment of this invention;

Fig. 3 is a circuit diagram of one of the components illustrated in Fig. 1; and

Fig. 4 is a group of waveforms representative of the operating characteristics of the circuit shown in Fig. 3.

Reference is now had in particular to Fig. 1 wherein there is shown, in block diagram form, cathode ray oscillograph apparatus employing two linear response gate suppressing amplifiers 7 and 9 constructed according to the teachings of this invention. In this embodiment, the apparatus is designed to permit the simultaneous visual comparison of the characteristics of two delay lines when identical signals are impressed on both. There is thus provided a means whereby the performance of a delay line may be ascertained in terms of a known standard delay line. In Fig. 1, delay line 1 represents a standard delay line the delay and resolution characteristics of which are known. Delay line 2 represents a unit the corresponding properties of which are unknown. Pulse generator 3 is employed to impress upon both identical signals in order to eliminate the possibility of unreliable test results arising from the nature of the input to the lines being compared.

This pulse generator may be of any suitable type, the principal requirements being that the frequency of pulses should be such that their time spacing is somewhat greater than the delay introduced by the standard delay line and that the pulse shape should be reasonably constant and possess sufficiently steep leading and trailing edges to provide satisfactory time markers and a sufficiently rigorous test of resolution.

The pulse output of generator 3 is also applied to sweep generator 4 so as to cause it to generate and apply to vertical deflecting plate 5 of cathode ray tube 6 a linearly decreasing sweep voltage in response to each applied pulse. In this way, the cathode ray tube trace is caused to move vertically up the face of the tube at a uniform velocity each time a pulse is applied to delay lines 1 and 2. The time duration of this sweep is likewise somewhat greater than the delay introduced by the standard delay line and may be divided into suitable time intervals by calibration of the scope face or by the introduction of electronically produced marker pulses according to any one of several known methods.

The delayed pulse output of delay line 1 is applied through amplifier 7 to horizontal deflecting plate 8 of the oscilloscope while the output of delay line 2 is applied through amplifier 9 to the opposing horizontal deflecting plate 10. Since the simultaneous application of signals to both plates 8 and 10 would result in signal cancellation and a confusing trace presentation, multivibrator 11 has been provided to render the amplifiers alternately unresponsive. Thus, during one half of the multivibrator cycle, amplifier 9 is held unresponsive and amplifier 7 impresses the output of delay line 1 on the cathode ray tube. During the other half cycle, amplifier 7 is held unresponsive and amplifier 9 impresses the output of delay line 2 on the tube.

Multivibrator 11 may be of any several well known free running types with the circuit values so chosen that its cycle consists of a rectangular pulse occupying approximately half the period. Such circuits contain two points of output providing wave trains which are 180° out of phase and these two output points are utilized in the circuit of Fig. 1 to provide the alternate blocking of amplifiers 7 and 9. The frequency of this multivibrator 11 may be chosen from a wide range of values, the lower limit being fixed by the persistence characteristics of the cathode ray tube screen and the upper limit by the ability of the multivibrator to produce a reasonably sharp amplifier switching action. A frequency of 100 cycles per second is of the proper order to yield satisfactory results although a frequency as low as 10 or 20 cycles per second may be employed as in radar homing equipment for which the invention herein disclosed is admirably suited.

A typical, though not limiting, set of operating values for the components of Fig. 1 would be a frequency of 100 cycles per second for multivibrator 11, a frequency of 5 kilocycles per second for pulse generator 3, and a vertical sweep duration of 50 microseconds employed to test lines having a delay of the order of 25 microseconds. With this set of values, each amplifier responds to the output of the delay line to which it is connected for alternate periods of 5000 microseconds. This 5000 microsecond period is the equivalent of an output from pulse generator 3 of 25 pulses. This amplifier switching rate and the cathode ray tube persistence are such that the effect of optical continuity is achieved to thereby permit the simultaneous viewing of the output of both delay lines.

In the circuit shown, the output of pulse generator 3 consists of a series of positive pulses which, after passing through the delay lines, are applied to amplifiers 7 and 9 and there undergo inversion, amplification, and application to plates 8 and 10 of tube 6. Thus, signals reaching tube 6 from amplifier 7 cause a displacement of the cathode ray trace to the right while those reaching tube 6 from amplifier 9 cause a displacement to the left. In a manner described in subsequent paragraphs, the teachings of this invention permit such displacements to occur from a common vertical base line so that a true back-to-back presentation is provided. Thus, if delay lines 1 and 2 have identical characteristics, a pattern symmetrical about the common vertical trace is viewed on the tube screen. If, however, the attenuation of delay line 2 is greater than that of delay line 1 for example, this will be reflected in the form of a lesser left hand deflection in the oscilloscope pattern. Obviously, if amplifiers 9 and 10 are not operated in a linear manner, the attenuated output of delay line 2 would be subjected to a lesser amplification than the output of delay line 1. The result would be to exaggerate the difference between the attenuation characteristics of the two lines and thus render a direct comparison impossible.

An attempt to operate ordinary high vacuum tubes in the usual manner as amplifiers 7 and 9 to secure linear operation encounters an obstacle which prevents true back-to-back presentation. At a bias which provides the desired linear operation, a substantial plate current flows and a corresponding quiescent voltage is applied to the cathode ray tube deflecting plates. At a bias which renders the amplifier unresponsive, plate current no longer flows and a different quiescent voltage is applied to the deflecting plates. Thus, such an arrangement causes the vertical trace to be shifted from left to right as amplifier 7 is rendered responsive and amplifier 9 unresponsive and from right to left as this condition is reversed in accordance with the output of multivibrator 11. This trace shifting separates the patterns provided by the two amplifiers and back-to-back presentation is not obtained.

The requirement is for amplifiers 7 and 9 to apply the same quiescent potentials to the deflecting plates of cathode ray tube 6 regardless of whether they be held responsive or unresponsive by multivibrator 11.

In Fig. 2 are shown several waveforms illustrative of the conditions described above in which waveform 20 is representative of the positive pulse output of pulse generator 3. Superposed on this waveform is line 30 which indicates the instant in time in which multivibrator 11 renders amplifier 7 unresponsive and amplifier 9 responsive. Waveform 21 is representative of the delayed pulse output of standard delay line 1 which, in addition to the delay imposed, has suffered slight attenuation. The inverted and amplified output of amplifier 7 under conditions in which the switching of multivibrator 11 is not accompanied by base line shift is illustrated by the waveform 22. Since amplifier 7 is rendered unresponsive by multivibrator 11 at the instant marked by line 30, no amplifier output pulses appear after that instant. Waveform 23 is representative of the delayed pulse output of delay line 2 which, though it has been delayed the same amount as was the output of the standard line, has suffered more attenuation. The inverted and amplified output of amplifier 9 under conditions in which amplifiers 7 and 9 are operated in a non-linear fashion so as to avoid base line shift is illustrated by waveform 24. Such non-linear action resulted in the lesser amplification illustrated by the exaggerated difference in amplitude of the pulses of waveforms 22 and 24 as compared to those of 21 and 23. Such exaggeration is still more obvious on the face of the cathode ray tube as represented by oscillogram 26. If, on the other hand, amplifiers 7 and 9 are operated in a linear manner by ordinary means, their outputs appear as represented by waveforms 22A and 24A respectively. The vertical steps in these waveforms at instant 30 are caused by the abrupt changes in anode voltages of amplifiers 7 and 9 in response to the switching action of multivibrator 11. The resulting effect on the cathode ray pattern is represented by oscillogram 27. In this oscillogram the proper amplitude characteristics are portrayed but true back-to-back presentation is no longer obtained. Waveforms 22 and 25 are representative of the output of amplifiers 7 and 9 under conditions in which these amplifiers function according to the teachings of this invention. Linear amplification of the delay line outputs is provided but is not accompanied by a shift in base line. This is illustrated by oscillogram 28 which is a true, undistorted back-to-back presentation.

The advantages of this oscillogram over oscillograms 26 and 27 would be still more pronounced had the two delay lines possessed different delay characteristics so as to cause vertical displacement of the pulses with repect to each other and had the resolution characteristics of the lines been less exact.

In general, the desired comparative oscillogram is accomplished according to the teachings of this invention by providing a vacuum tube, designated as tube 50 of Fig. 3, with a point of reversal in its transconductance characteristic so as to have a negative transconductance region on one side of the point of reversal and a positive transconductance region on the other side. This reversal of transconductance characteristic makes it possible to bias the tube at a point on the linear portion of its transconductance curve in such a manner that the effect of normal electron flow to the anode is neutralized by secondary emission. Under this biasing condition, the tube is responsive and produces an output signal directly proportional in amplitude to the amplitude of the input signal even though the quiescent output voltage is the same as when the tube is unresponsive. The usual cut off biasing creates the alternate unresponsive condition in which no electron flow reaches the anode and it is held quiescent at supply potential even though input signals may be applied to the tube.

In particular, Fig. 3 is the circuit diagram of one form of a gate suppressing linear response amplifier such as amplifiers 7 and 9 of Fig. 1 constructed according to the teachings of this invention. In this form, tube 50 represents the single vacuum tube element required for the circuit and is, in this illustration, any one of several common receiving type multiple grid vacuum tubes such as 6SA7. Input pulses from the delay line are applied at input terminals 51 and gating pulses from multivibrator 11 of Fig. 1 are applied at input terminals 52. Lead 53 communicates the variations in potential at anode 54 to one of the horizonal deflection plates of cathode ray tube 6 of Fig. 1.

Cathode 55 of tube 50 is so connected to ground potential and dual screen grid 56 is so connected to positive potential 57 that a positive gradiant exists in tube 50 for the acceleration of electrons from the space charge of cathode 55. The number of electrons leaving the space charge is controlled primarily by grid 58 and the number of such electrons reaching grid 59 and anode 54 is controlled primarily by grid 60.

Grid 58 is so connected to negative potential 61 through resistance 62 that tube 50 is conducting at a rate which places the operation of tube 50 in the linear range of its characteristics as hereinafter explained. Grid 60 is so connected to ground potential through resistance 63 that, in the absence of a negative gating potential at input 52, grid 60 allows the free flow of electrons to grid 59 and anode 54. The time constant of the circuit by which such negative gating potentials are communicated to grid 60 from input 52 comprising resistor 63 and capacitor 64 is sufficiently long that capacitor 64 collects negligible charge during a half cycle of multivibrator 11. In the presence of a negative gating potential at input 52, grid 60 prevents the flow of electrons to anode 54 and thereby holds the amplifier unresponsive to signals at input 51.

Grid 59 is so connected to high positive potential 65 that a positive potential gradiant exists from screen 56 to grid 59. A negative potential gradient exists from grid 59 to anode 54 by virtue of the connection of anode 54 to lower positive potential 57 through resistance 66.

Under the conditions in which grid 60 is not held below cut-off potential by a negative gate from multivibrator 11, the electrons which leave the cathode space charge under the accelerating influence of screen 56 divide into a rather complex grouping. Certain of the electrons leave the stream by collision with the surface of one or the other of the grids. Certain of the lower velocity electrons are gathered to screen 56 by anode action. A similar group is attracted to grid 59 by anode action. Those, however, which avoid collision and the anode action of grids 56 and 59, overcome the negative gradient from grid 59 to anode 54 and therefrom collide with anode 54. This last group constitutes conventional plate current flow which travels in such a direction through resistance 66 as to lower the potential of anode 54. This conventional plate current, since it originates from the flow of primary electrons to anode 54 may be termed primary current to distinguish it from the plate current described below which flows as the result of secondary emission from anode 54.

As the primary electrons which eventually reach anode 54 pass screen 56, they emerge into the positive potential gradient existing from screen 56 to grid 59 and are thus further accelerated to the extent determined by the potentials of screen 56 and grid 59. The terminal velocity of the primary electrons is, upon collision with anode 54, sufficient to cause secondary electrons to be dislodged from the surface of that electrode. The total number of such bombardment emitted electrons is a function of the number of the primary electrons bombarding anode 54, their collision velocity, and the work function energy of the surface of anode 54. The bombardment emitted electrons emerge into a potential gradient which is positive from anode 54 to grid 59 so that, except when this potential gradient is altered as hereinafter described, all such secondary electrons travel to and are collected by grid 59.

It will be seen that the direction of plate current flow represented by the escape of secondary electrons from anode 54 is opposite to that represented by the primary electrons reaching anode 54. Thus, the potential of anode 54, as determined by plate current flow through resistance 66 is a function of the relative amounts of primary current and secondary current. If secondary current exceeds primary current, the potential of anode 54 rises above cutoff potential while a greater primary current than secondary current causes anode 54 to fall below its cutoff potential. In an amplifier circuit constructed according to the teachings of this invention, shown in one form in Fig. 3, the transconductance characteristic of tube 50 is represented by waveform 70 of Fig. 4 in which net plate current (I_p) has been plotted as the vertical coordinate against the potential grid of 58 (E_g) on the horizontal axis. At grid potential *a* and below, space current flow is negligible and net plate current flow is likewise negligible. In the grid potential range from *a* to *c* secondary current exceeds primary current in such a manner that, from *a* to *b*, the transconductance characteristic is negative. At the reversal point *b*, the difference between the two currents starts to decrease so that at grid potential *c*, the difference becomes zero and net plate current flow is zero.

Between points c and d, the difference between the primary current and secondary current increases in favor of the primary current in a manner which is linear with respect to the potential of grid 58. The reversal at point b results from the space charge effect of the electron stream traveling at high velocity toward anode 54. This space charge, which increases as the density of the electron stream increases, forces an increasing number of secondary electrons from anode 54 back to anode 54. Thus, tube 50 has been provided with a reversal point b in its transconductance characteristic and has a negative transconductance region a to b and a positive transconductance region b to d. As an example, a screen and plate supply voltage 57 of +150 and a grid 59 voltage 65 of +175 were employed to obtain a transconductance characteristic of this type. Depending upon the particular tube chosen and upon the value of grid bias desired for point c, certain changes in the electrode potentials may be made to fit particular requirements. It is not essential that the plate and screen supply voltages be the same, the principal requirement being one of establishing the voltage gradient conditions hereinbefore described.

The corresponding variations at anode 54 (E_p) have been plotted against grid 58 potential (E_g) in waveform 71. Of interest in this waveform is that fact that, regardless of whether grid 60 is biased so as to cut off the electron stream to anode 54 or at ground potential, the quiescent potential of anode 54 is the same if grid 58 is biased at point c. When, however, grid 58 is biased at point c, and grid 60 is at ground potential, tube 50 is operating in a linear region in which positive signals applied to grid 58 cause a change in the potential of anode 54 which is proportional to the signal amplitude. This means that, in the range of grid 58 potential from c to d, the response of the amplifier of Fig. 3 to positive signals is linear and corresponds to the type of operation required for correct signal presentation.

By similar, but somewhat simpler means, a reversal point may be introduced into the transconductance characteristics of other classes of vacuum tubes such as ordinary receiving type pentodes and tetrodes. In such cases, the principles are the same but the multiplicity of control grids provided by such tubes as tube 50 of Fig. 3 is not available. They may, however, be employed wherever their construction proves advantageous.

With amplifiers 7 and 9 both of the construction shown in Fig. 3, let it be assumed that the circuit of Fig. 1 is in operation and that an instant of time has been selected in which amplifier 7 is held responsive and amplifier 9 unresponsive. The anode 54 of amplifier 9 is at quiescent potential 57 since multivibrator 11 holds grid 60 at a potential which prevents the flow of electrons from screen 56 to anode 54. Anode 54 of amplifier 7 is likewise at quiescent potential 57 since multivibrator 11 holds grid 60 at ground potential and grid 58 is biased at point c of Fig. 4. Thus the potential between the two deflecting plates of cathode ray tube 6 is zero and the vertical trace is in the center of the screen. Each time a positive pulse from delay line 1 reaches amplifier 7, it is reproduced in the form of a displacement of the trace to the right. Now let it be assumed that multivibrator 11 changes states and amplifier 9 is rendered responsive and amplifier 7 unresponsive. For the reasons explained above, this action causes no change in trace position since the anodes of both amplifiers are again at potential 57. Now, pulses reaching amplifier 9 are reproduced in the form of a displacement of the trace to the left. While it is true that the transition of the amplifiers is accompanied by variations at the anodes, these transitory variations occur at such a low rate and are of such short duration that they are virtually indistinguishable even though they arrive during a vertical sweep on the tube face. In this manner, amplifiers 9 and 10 have functioned in the circuit of Fig. 1 to make the transition from a state of linear operation to a state of non-conduction and vice versa and have in so doing suppressed from the cathode ray tube presentation all but a transitory effect of the gating potential of multivibrator 11.

Should difficulty arise from such transitory effects, multivibrator 11 may be synchronized with pulse generator 3 so as to operate at a convenient subharmonic thereof and the gating so timed that it occurs between vertical sweep traces. In this manner, even the transitory gating variations may be suppressed.

The use of such of the embodiment as that illustrated in Fig. 1 need not be confined to the comparative testing of delay lines. For example, the performance of two one shot multivibrators may be compared on the oscilloscope. To those familiar with the art of oscillography will occur variations in embodiments and other applications. Further, the use of the gate suppressing, linear response amplifier herein disclosed is not confined to such uses as laboratory or field testing but may be employed to advantage in radio homing devices in which visual comparison of relative echo signals is used to determine relative bearing.

Since certain further changes may be made in the foregoing constructions and different embodiments of the invention may be made without departing from the scope thereof, it is intended that all matter shown in the accompanying drawings or set forth in the accompanying specification shall be interpreted as illustrative and not in a limiting sense.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalty thereon or therefor.

What is claimed is:

1. A method of presenting two unidirectional waveforms simultaneously on the viewing screen of a cathode ray oscilloscope comprising, amplifying one of said unidirectional waveforms in a linear manner, applying said one amplified waveform to one plate of one pair of deflecting plates of a cathode ray tube, amplifying the other of said unidirectional waveforms in a linear manner, applying said other amplified waveform to the other of said deflecting plates, applying a sweep producing voltage to the other pair of deflecting plates of said cathode ray tube, alternately preventing the amplification of said two waveforms in such a manner as to suppress from the viewing screen of the cathode ray oscilloscope any visual evidence of said amplification prevention.

2. In combination, a vacuum tube arranged so as to contain a reversal point in its transconductance characteristic, said reversal point being bounded by a negative transconductance region on one side thereof and a positive transconductance region on the other side thereof whereby two points of effective plate current cutoff are

established, one of said points being situated in a linear portion of the positive region of said transconductance characteristic, and means biasing said tube to operate at said one of said points whereby linear operating characteristics of said tube are obtainable.

3. In combination; a source of voltage, a vacuum tube having at least a plate, a cathode, a screen grid, and a control grid, means connecting the elements of said tube to said source of voltage in such a manner as to produce a reversal point in the transconductance characteristic of said tube, said reversal point being bounded by a negative transconductance region on one side thereof and a positive transconductance region on the other side thereof whereby two points of effective plate current cutoff are established, one of said points being situated in a linear portion of the positive region of said transconductance characteristic, and means biasing said tube to operate at said one of said points whereby linear operating characteristics of said tube are obtainable.

4. A gate suppressing linear response amplifier comprising, a vacuum tube arranged so as to contain a reversal point in its transconductance characteristic, said reversal point being bounded by a negative transconductance region on one side thereof and a positive transconductance region on the other side thereof whereby two points of effective plate current cutoff are established, one of said points being situated in a linear portion of the positive region of said transconductance characteristic, the other of said points being situated on the other side of said reversal point from said one point and in a region where complete suppression of input signals results, means biasing said tube to operate at said one of said points whereby linear operating characteristics of said tube are obtainable, and means for changing the point of operation of said tube to the other of said points.

5. A gate suppressing linear response amplifier comprising, a source of voltage, a vaccum tube having at least a plate, a cathode, a screen grid, and a control grid, means connecting the elements of said tube to said source of voltage in such a manner as to produce a reversal point in the transconductance characteristic of said tube, said reversal point being bounded by a negative transconductance region on one side thereof and a positive transconductance region on the other side thereof whereby two points of effective plate current cutoff are established, one of said points being situated in a linear portion of the positive region of said transconductance characteristic, the other of said points being situated on the other side of said reversal point from said one point and in a region where complete suppression of input signals results, means biasing said tube to operate at said one of said points whereby linear operating characteristics of said tube are obtainable, and means for changing the point of operation of said tube to the other of said points.

6. In an electrical circuit where input signals are to be alternately suppressed and amplified, the combination of; a vacuum tube amplifier arranged so as to contain a reversal point in its transconductance characteristic, said reversal point being bounded by a negative transconductance characteristic on one side thereof and a positive transconductance characteristic on the other side thereof whereby two points of effective plate current cut-off are established, one of said points being situated in a linear portion of the positive region of said transconductance characteristic where linear amplification may take place, the other of said points being situated on the other side of said reversal point from said one point and in a region where complete suppression of input signals results, and an electronic switching device for alternately switching the operating bias for said tube between said two points.

7. A cathode ray oscillograph apparatus comprising, a cathode ray tube means, means generating and applying a sweep producing voltage to one pair of deflecting plates of said cathode ray tube, a first amplifier means receiving and amplifying input signals, means applying said amplified signals to one of the deflecting plates of the other pair of deflecting plates of said cathode ray tube, a second amplifier means receiving and amplifying input signals, means applying last said amplified signals to the other deflecting plate of last said pair of deflecting plates, said first and second amplifier means each comprising a vacuum tube arranged so as to contain a reversal point in its transconductance characteristic, said reversal point being bounded by a negative transconductance region on one side thereof and a positive transconductance region on the other side thereof whereby two points of effective plate current cutoff are established, one of said points being situated in a linear portion of the positive region of said transconductance characteristic where linear amplification may occur, the other of said points being situated on the other side of said reversal point from said one point and in a region where complete suppression of input signals results, and means arranged to bias said amplifier means alternately to operate at said one of said points so established in said linear portion of said tubes and at said other of said points in such a manner that said first and second amplifier means alternately apply received input signals to last said pair of deflecting plates of said cathode ray tube.

8. The method of operating a vacuum tube so as to produce linear amplification thereby, which comprises, producing a reversal point in the transconductance characteristic of said vacuum tube, said reversal point being bounded by a negative transconductance region on one side thereof and a positive transconductance region on the other side thereof whereby two points of effective plate current cutoff are established, one of said points being situated in a linear portion of the positive region of said transconductance charactertistic, and biasing said tube to operate at said one of said points whereby linear operating characteristics are provided.

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