June 25, 1935. B. KREUZER 2,006,052

AMPLIFIER

Filed Sept. 30, 1933 2 Sheets-Sheet 1

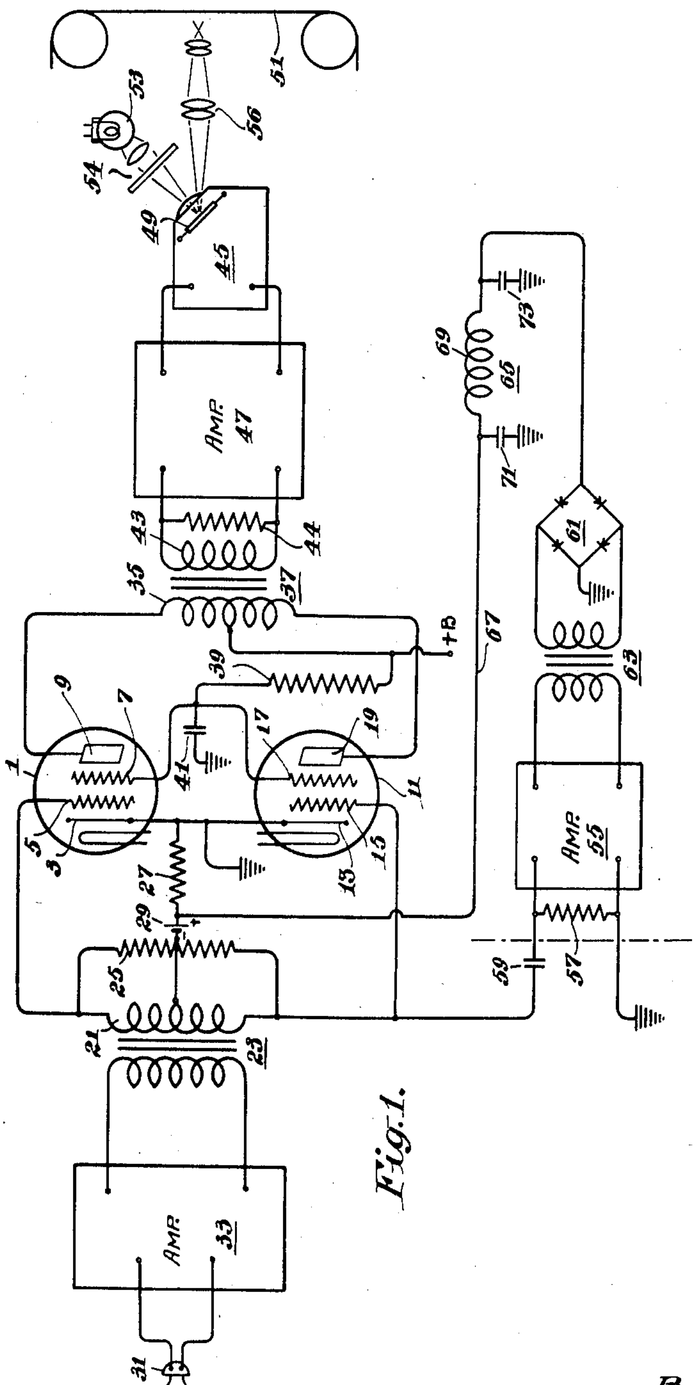

Fig.1.

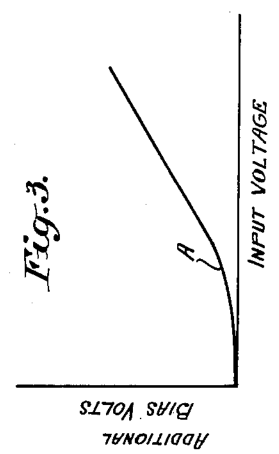

Fig.3.

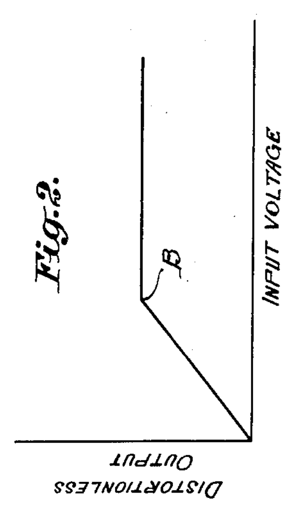

Fig.2.

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Fig. 4.

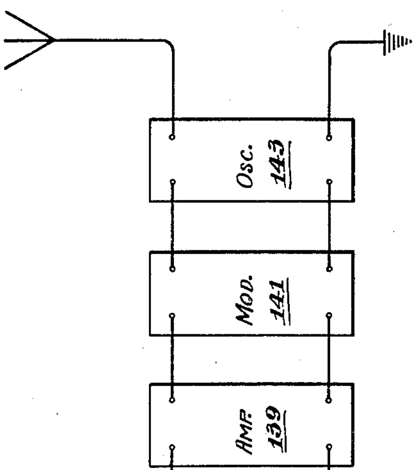
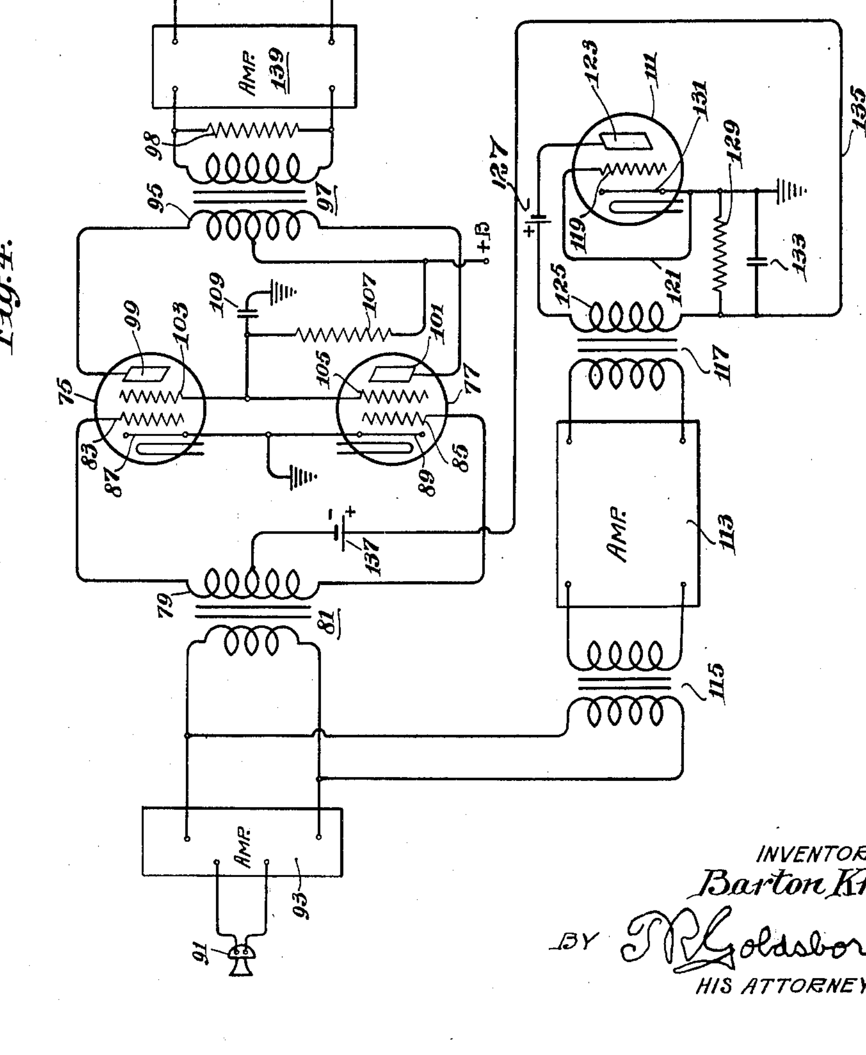
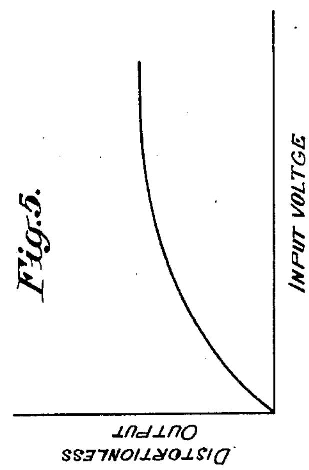



Fig. 5.



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Patented June 25, 1935 **2,006,052**

UNITED STATES PATENT OFFICE

2,006,052

AMPLIFIER

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Application September 30, 1933, Serial No. 691,596

17 Claims. (Cl. 179—171)

My invention relates to audio frequency amplifiers and particularly to means for obtaining improved volume control in such amplifiers when utilized in sound recording or radio apparatus.

In both sound recording apparatus and radio transmitters certain precautions must be taken or the input to the audio-frequency amplifiers will become too great and distortion will result. Part of this distortion is produced in the amplifier itself but the greater part of it is produced elsewhere in the system. In sound recording, if the amplifier output exceeds a certain value, "over-shooting" of the sound record will result. "Over-shooting" of the record is especially likely to occur in news-reel recording where it is impossible to give sufficient attention to the volume control. When "over-shooting" does occur, the record, when reproduced, becomes very disagreeable because of harmonic distortion.

In a radio transmitter, when the audio frequency amplifier output becomes too great, over-modulation results and a badly distorted signal is produced.

In both sound recording and radio transmitting it is the general practice to control the volume manually. This requires a well trained operator and has obvious disadvantages. Various systems have been devised to control the volume automatically, but for various reasons they are not generally completely satisfactory. Most of these systems provide logarithmic recording or modulation so that the normal volume range is compressed. This produces a compression of the upper volume range such that true realism in reproduction is prevented. Also, such systems are generally too restricted in application since they provide only a limited volume range without introducing distortion.

I have discovered that a satisfactory system for automatic control of an audio frequency amplifier can be designed by the use of exponential or "variable mu" electric discharge devices, such as the RCA 235 tubes, with a relatively wide range of normal operation. While this type of electronic tube is well known, it has been used chiefly in radio frequency circuits, and its use in audio frequency amplifiers has been considered undesirable since the characteristic curve of the tube has substantially no straight line portion. An inspection of the amplifying characteristics of the exponential tube would indicate that if used in an audio frequency circuit, the tube would introduce a large amount of distortion.

The distortion introduced by an exponential tube when utilized in a radio frequency or intermediate-frequency amplifier is not detrimental since such amplifier circuits are tuned to the desired frequency range, whereby the harmonic and other frequencies which appear in the distorted wave or waves are filtered out. For example, the second and third harmonics of a radio frequency signal will lie beyond the range of frequencies to be passed by the tuned radio frequency circuit, and as a result, such harmonic frequencies will not appear in the output of the radio frequency amplifier. If two radio frequency signals differing only by a small amount in their frequencies are amplified by an exponential tube, additional distortion may be created in the form of sum and difference frequencies of the two original signals. These also will, under normal conditions, be excluded by the tuned radio frequency circuit.

In an audio frequency amplifier, on the other hand, the harmonics of a given audio frequency will lie within the range of speech or music frequencies. Similarly, sum and difference tones produced by two audio frequency signals may lie in the frequency range of the amplifier and accordingly also produce distortion. Since it is impossible to filter out such harmonic and other frequencies, the audio frequency amplifier must be so designed that it has an undistorted output. In the past, this has been accomplished only to a limited extent by employing vacuum tubes having an output which is directly proportional to the input voltage.

An object of my invention is to provide an audio frequency amplifier so designed that its input may be varied over a wide range without producing distortion.

A further object of my invention is to provide a self-controlled audio frequency amplifier which will amplify a signal without appreciable distortion over a relatively wide range of input potentials, yet which will have an output which never exceeds a certain value.

A still further object of my invention is to provide an improved amplifier which will prevent "over-shooting" of a sound record, or over-modulation of a radio frequency signal.

In practicing one embodiment of my invention, I connect two exponential tetrodes in push-pull or balanced relation to form a push-pull amplifier stage, and connect this amplifier or amplifier stage between the signal source and the sound recording or radio transmitter apparatus. A control circuit is connected to the input circuit of the push-pull amplifier for supplying a variable bias to the control grids of the exponential tubes.

Other features and advantages of my invention will appear from the following description taken in connection with the accompanying drawings in which

Figure 1 is a circuit diagram of an embodiment of my invention applied to sound recording equipment;

Fig. 2 is a curve showing an operating characteristic of the system illustrated in Fig. 1;

Fig. 3 is a curve showing an operating characteristic of a rectifier employed in my improved amplifier;

Fig. 4 is a circuit diagram of another embodiment of my invention applied to a radio transmitter; and

Fig. 5 is a curve showing an operating characteristic of the amplifier illustrated in Fig. 4.

Referring to the embodiment shown in Fig. 1, the self-controlled amplifier comprises an exponential tetrode 1 having an indirectly heated cathode 3, a control-grid 5, a screen grid 7, and an anode 9, and a second exponential tetrode 11 having a cathode 13, a control grid 15, a screen grid 17, and an anode 19.

The tubes 1 and 11 are connected in push-pull relation. The input circuit comprises the secondary 21 of an audio frequency transformer 23, each half of the secondary being loaded by a resistor 25 shunted thereacross. One end of the secondary 21 is connected to the control grid 5, while the other end of the secondary 21 is connected to the control grid 15. The cathodes 3 and 13 are connected to ground and to the mid-points of the secondary winding 21 and the resistor 25 through a source of fixed grid biasing potential, such as a battery 29.

An audio frequency signal source, such as a microphone 31 is connected to the audio frequency transformer 23 through an amplifier 33. In some cases it may be desirable to omit the amplifier 33 and connect the microphone 31 directly to the input transformer 23. When the amplifier 33 is employed, in general it will be a low power amplifier, since the input to the exponential tubes should be kept fairly low in order to minimize the output of odd harmonics.

The plate circuit of the push-pull amplifier includes the primary winding 35 of an audio frequency transformer 37. One end of the winding 35 is connected to the anode 8, while the other end of the winding is connected to the anode 19, the mid-point of the winding 35 being connected to the positive terminal of the plate supply.

The screen grids 7 and 17 are connected to the positive terminal of the plate supply through a resistor 39 which lowers the voltage to the proper value for the screen grids. The resistor is shunted by the usual by-pass condenser 41.

The secondary winding 43 of the transformer 37 is connected to the sound recording apparatus 45 through a suitable amplifier 47. The secondary 43 is loaded by a resistor 44 shunted thereacross. The sound recording apparatus 45 includes a galvanometer mirror 49 which vibrates in accordance with the output of the amplifier 47 to throw a vibrating beam of light upon a moving film 51. The beam of light is supplied from a lamp 53 and focused upon the mirror 49 and film 51 by a suitable lens system indicated at 54—56.

The control circuit for the push-pull amplifier includes an audio frequency amplifier 55 which is connected to the input circuit of the amplifier in any suitable manner. In the circuit illustrated, the input circuit of the amplifier 55 includes a resistor 57 which is connected to ground at one end. The other end of the resistor 57 is coupled to one end of the secondary winding 21 through a coupling condenser 59.

The output of the amplifier 55 is impressed upon a full-wave copper oxide or other suitable rectifier 61, through an audio frequency transformer 63. One output terminal of the rectifier 61 is connected to ground, while the other output terminal is connected through a low pass filter 65 and a conductor 67 to the grid biasing resistor 27 of the push-pull amplifier.

The low pass filter 65 comprises an inductance coil 69, in series with the conductor 67, and shunting condensers 71 and 73 connected to ground at each end of coil 69. The low pass filter 65 is designed with large values of inductance and capacity so that the decrease in control bias will be rather slow. The path of the biasing current from the control circuit may be traced from the rectifier 61, through the filter 65, through the conductor 67 and biasing resistor 27 to the cathodes 3 and 13, and from the cathodes through ground to the grounded terminal of the rectifier 61.

When properly adjusted, the push-pull amplifier circuit, shown in Fig. 1, will have the characteristic curve shown in Fig. 2. This characteristic may be obtained by employing a rectifier having the characteristic shown in Fig. 3. It will be noted that there is very little rectifier output until the input voltage reaches a certain value. Beyond this value, the output of the rectifier is proportional to the input voltage. A copper oxide rectifier will have substantially this characteristic since it will pass very little current until the input voltage reaches a certain value. The curve will be substantially a straight line if the internal impedance of the rectifier is a small percentage of the total circuit impedance.

The point A at which the rectifier begins to pass an increased amount of current is a point corresponding to the point B in Fig. 2 where the curve becomes horizontal.

From these curves it will be seen that almost no additional biasing voltage is supplied to the push-pull amplifier by the control circuit until the volume of the input signal exceeds a predetermined magnitude. Beyond that value the rectifier 61 supplies an additional biasing voltage which increases as rapidly as the increase in signal strength so that the output of the push-pull amplifier never exceeds a certain value.

From the above description it will be understood that so long as the signal volume is less than a certain value, that is, so long as it remains within the "normal range", the control circuit does not function, and there is no compression of the volume range. It is only when the signal strength becomes so great that distortion would be produced that the gain of the amplifier is reduced by the control circuit.

To obtain satisfactory operation with the type of self-controlled amplifier circuit illustrated, it is necessary to use exponential tubes in order to obtain the necessary range in gain control. While the usual audio frequency amplifier tubes would operate over a certain volume range, the range would be so limited that the circuit would be of but little value. Beyond this limited range the amplifier using ordinary tubes would introduce serious distortion because such tubes have a definite cut-off so that they will rectify the signal after the bias has been increased beyond a certain point. Exponential tubes, on the other hand, have no definite cut-off point until the grids are biased to a negative value which would never be reached in the operation of the amplifier.

Calculations have shown that the distortion produced by an exponential tube is due mainly to the second harmonic and the sum and difference frequencies. In one case, for example, with a peak grid swing of one volt and with two frequencies of equal magnitude, the second harmonic was 4.5% and the sum and difference frequencies were each 9%. The third harmonic was only .1%. Since a push-pull amplifier balances out all even order frequency signals, as well as the sum and difference frequency signals, it is apparent that by connecting exponential tubes in push-pull relation, the distorting signal frequencies of any appreciable magnitude are balanced out.

In Fig. 4 there is shown a variation of the self-controlled amplifier illustrated in Fig. 1, which is applied to a radio transmitter. The amplifier comprises two exponential tubes **75** and **77** connected in push-pull or balanced relation. The input circuit includes the secondary **79** of an audio frequency transformer **81**, the upper end of which is connected to the control grid **83** of the tube **75** and the lower end of which is connected to the control grid **85** of the tube **77**. The cathodes **87** and **89** of the tubes **75** and **77**, respectively, are connected to ground. A signal source such as a microphone **91** is connected to the transformer **81** through an amplifier **93**.

The plate circuit of the push-pull amplifier includes the primary winding **95** of an audio frequency transformer **97**, the upper end of the winding being connected to the plate **99** of tube **75**, and the lower end being connected to the plate **101** of the tube **77**. The mid-point of the winding **95** is connected to the positive terminal of the plate supply.

The screen grids **103** and **105** of the tubes **75** and **77**, respectively, are supplied with the proper positive potential through a resistor **107** which is shunted by a by-pass condenser **109**.

The control circuit for the push-pull amplifier comprises a diode rectifier **111** which is connected to the output circuit of the amplifier **93** through an audio frequency amplifier **113** and coupling transformers **115** and **117**. The rectifier **111** is a conventional three-element vacuum tube which has its grid **119** connected to the cathode **131** through a conductor **121**. The plate **123** of the rectifier tube **111** may be connected to the upper terminal of the secondary **125** of the audio frequency transformer **117** through a biasing battery **127**, the purpose of which is described hereinafter. The lower terminal of the secondary **125** is connected through a biasing resistor **129** to the cathode **131** of the tube **111**.

The biasing resistor **129** is shunted by a condenser **133** which, with the biasing resistor **129**, forms a filter. The resistor **129** is connected through a conductor **135** and a biasing battery **137** to the mid-point of the secondary winding **79** so that an additional biasing potential is supplied to the control electrodes **83** and **85** when the rectifier **111** passes current. In one embodiment of my invention where the amplifier is employed in a news-reel recording system instead of in a radio transmitter, the resistor **129** has a value of 3 megohms and condenser **133** has a capacity of 2 microfarads. When applied to a radio transmitter, as illustrated, the resistance of the resistor **129** is preferably made somewhat less than the value mentioned in order to lower the time of discharge of condenser **133**.

The output circuit of the push-pull amplifier is connected by means of transformer **97** to the audio frequency amplifier **139**, the modulator **141**, and oscillator **143** of a conventional radio transmitter. The secondary **96** of transformer **97** is preferably loaded by means of a resistor **98**.

When employing my self-controlled amplifier in a radio transmitter circuit, a characteristic curve similar to the one shown in Fig. 5 is preferred. To obtain this characteristic, the rectifier **111** is so adjusted by means of biasing battery **127** that it will not pass current until the signal strength reaches a certain level, but this level is lower than in the adjustment for the circuit shown in Fig. 1. With this adjustment, the upper region of the normal volume range is compressed a certain amount, but the compression is not great enough to be objectionable. When the output of the push-pull amplifier reaches a level such that a further increase in output would cause over-modulation, the gain of the push-pull amplifier is reduced in proportion to the increase in signal strength, so that the output of the amplifier never exceeds a definite value.

It will be understood that either self-controlled amplifier circuit illustrated may be used with a radio transmitter or with a recording system, and that the particular rectifiers illustrated are interchangeable.

For some applications it may be preferred to connect the gain control circuit to the output circuit of the push-pull amplifier instead of to its input circuit. With the control circuit so connected, the amplifier characteristic curve will resemble the curve shown in Fig. 5.

In order to obtain amplifier characteristics such as shown in Figs. 2 and 5, the rectifier may have the output characteristic shown in Fig. 3 as hereinbefore described. The characteristic curve of the amplifier may be controlled to a large extent by the fixed biasing voltage applied to the control grids of the exponential tubes, by the screen grid and plate voltages, and by the impedance of the plate circuit. If desired, the rectifier may be so adjusted that its output increases in direct proportion to the input voltage beginning with zero input, or linearly with respect to the input voltage, and the control grids of the exponential tubes may be given a negative bias of such magnitude that the additional bias at first applied by the rectifier will have very little effect upon the amplifier characteristic. The linear rectifier characteristic may be obtained by biasing the grid **119** of rectifier **111** negatively with respect to cathode **131**. Also the amplifier **55** may be biased to cut off so that its input voltage must reach a predetermined value before voltage is applied to the rectifier.

With regard to the impedance in the plate circuit of the push-pull amplifier, an exponential tube should have a load impedance which is less than one-half its plate impedance in order that the gain of the amplifier shall be proportional to the mutual conductance of the tube, that is, in order that the gain shall have an exponential characteristic.

From the foregoing description it will be seen that while exponential tubes may ordinarily not be adapted for audio frequency amplification because of certain harmonic and other distortions hereinbefore pointed out, if utilized in push-pull or balanced relation this undesirable distortion may substantially be eliminated. Accordingly, in accordance with the invention, a pair of high mu or exponential tubes are operated in push-pull or balanced relation and are furthermore controlled in gain only above a certain high value of input potential through the use of a suitable bias control circuit which operates in response to signal potentials which are sufficiently higher than the average level that in an ordinary amplifier, overloading or distortion would result.

With this type of control, and preferably one embodying a bias rectifier substantially as shown, there is no "squeezing" or condensing of the normal volume range. Therefore, emphasis should be placed upon the fact that sounds of normal volume level are recorded in true volume perspective, but extra loud sounds which would ordinarily be "over shot" or, at best, held down by volume control manipulation, are in this case self controlled and are recorded or amplified undistorted at full modulation level. In this manner no compression of the normal volume range occurs and no loss of gain is suffered which is of particular importance in connection with a recording amplifier, for example.

It should be noted that in a self controlled amplifier, such as shown in Figs. 1 and 4, where in the control voltage is derived from the incoming signal or is responsive to changes in the average signal amplitude, there must be a definite time interval between the start of a signal and the establishment of the control voltage. In the circuits shown and described, preventive means are employed for preventing the control voltage from varying with the amplitude of the individual signal peaks, and in the circuit of Fig. 1 includes the filter **65** and the bias supply resistor **27**, while in the circuit of Fig. 4 it includes the bias supply resistor **129** and the shunt condenser **133**. In this connection it will be noted that the condenser **71** is connected in shunt relation to the bias supply resistor **27** in the circuit of Fig. 1.

The filter system, including the rectifier device, must supply a bias which is proportional to the general level of the signal, while smoothing out the individual peaks or sounds, and which bias potential should increase to a maximum value for any given signal in as short an interval of time as possible.

Experience with such a circuit in noise reduction recording has shown conclusively that distortion of the first few cycles of any sound is not perceptible if the time interval is not too large, since in general, most sounds do not start with their full amplitude but build up from a low amplitude until a maxima is reached.

The bias may be made to assume a proportionality to the general volume level by impressing the rectified signal upon a capacitor whose rate of discharge is fixed by a parallel resistor.

In the present example, the rate of change of the bias or additional control potential for the balanced exponential amplifier stage is controlled by the shunt resistor and condenser combinations above pointed out, and their relative values may be adjusted for different requirements in the amplifier characteristic.

In noise reduction recording, the discharge time is made only sufficiently slow so that individual peaks of the lowest frequency to be recorded are not followed. This accomplishes a minimizing of noise between individual sounds. Were a self controlled amplifier to function in this manner the gain would change so rapidly that a difference in noise might become apparent and minor downward changes in a high volume level, such as the inflection of a speaker's voice would be lost. For these reasons the discharge time in the self controlled amplifier is made much slower.

It is in the following particulars that self control differs most from previous systems of automatic volume control. For example, in a self controlled system of the type for recording sounds such as hereinafter described, all sounds are not recorded at the same level. All ordinary sounds are recorded with a linear characteristic up to a level which would ordinarily "over-shoot" the film. Above this level the gain is automatically reduced to record these sounds at full modulation of the film, but even at this high level minor downward variations of the level are actually recorded because of the slowness of discharge of the control circuit which will hold the gain temporarily at the value determined by the last loud sound. At the same time, the growth of control bias in this circuit is so rapid that still louder sounds are immediately held below the full modulation limit.

The preferred charge and discharge rates for the filter condenser or condensers will be different when the amplifier is employed for speech than when employed for music. In the phonograph recording referred to above, the time for the charge of the condenser should be about the same as the time for its discharge, one second having been found suitable.

In the case of news-reel recording, on the other hand, where most of the sound recorded is speech, it has been found that the charging rate of the filter should be made rapid, .13 of a second for example, while the discharge time should be much longer, possibly as long as six or eight seconds. With such a filter adjustment, the additional biasing voltage from the control circuit will be applied to the grids of the push-pull amplifier so rapidly that the gain of the amplifier will be reduced before the sound has increased to too great a magnitude. At the same time, the discharge rate is such that downward variations in volume will be recorded.

Where manual control may be desirable, in phonograph recording, for example, to compress the volume range when recording, and to expand it during reproduction, the control circuit, which includes the rectifier may be controlled either manually or from a volume control channel separate from the input circuit of the amplifier.

Various other modifications may be made in my invention without departing from the spirit and scope thereof, and I desire, therefore, that only such limitations shall be placed thereon as are necessitated by the prior art and set forth in the appended claims.

I claim as my invention:

1. An audio-frequency amplifier comprising a pair of exponential amplifier tubes connected in balanced relation to each other, means for impressing a signal voltage upon the input circuit of said tubes, and means for applying a biasing voltage to the grids of said tubes which varies with the average amplitude of said signal voltage.

2. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in balanced relation, means for impressing a signal voltage upon the input circuit of said tubes, and means for applying a volume control voltage to the grids of said tubes.

3. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in balanced relation, means for impressing a signal voltage upon the input circuit of said

tubes, and means for decreasing the gain of said tubes in response to an increase in said signal voltage.

4. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in balanced relation, means for impressing a signal voltage upon the input circuit of said tubes, and means for decreasing the gain of said tubes when said signal voltage exceeds a predetermined value.

5. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in push-pull, a rectifier, and means including said rectifier for applying a biasing potential to the grids of said tubes.

6. An audio frequency amplifier comprising a pair of exponential electric-discharge tubes connected in push-pull, means for applying an audio-frequency signal to the input circuit of said amplifier, and a control circuit for varying the gain of said amplifier, said control circuit including means for impressing a biasing voltage upon the grids of said tubes.

7. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in push-pull, a rectifier, a signal source, means for connecting the input circuit of said tubes to said signal source, means for connecting the input circuit of said rectifier to said signal source, and means including said rectifier for applying a negative biasing potential to the grids of said tubes.

8. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in push-pull, a rectifier, a signal source, means for connecting the input circuit of said tubes to said signal source, means for connecting the input circuit of said rectifier to said signal source, and means including said rectifier for applying a negative biasing potential to the grids of said tubes after the strength of said signals exceeds a predetermined value.

9. An audio-frequency amplifier comprising a pair of exponential tubes connected in push-pull, said tubes having control-electrodes, means for impressing an audio frequency signal voltage upon said control electrodes, and means for applying a biasing potential to said control-electrodes so related to said signal voltage that the gain of said tubes decreases with an increase in signal strength.

10. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in balanced relation, means for impressing an audio frequency signal upon the input circuit of said tubes, and means for so controlling the gain of said tubes that their output never exceeds a predetermined value.

11. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in push-pull, said tubes having control-electrodes, means for impressing an audio frequency signal voltage upon said control electrodes, and means for applying a biasing potential to said control-electrodes so related to said signal voltage that the output of said tubes never exceeds a predetermined value.

12. A self controlled audio frequency amplifier comprising in combination, a pair of exponential electric discharge amplifier devices, means providing a balanced input circuit and a balanced output circuit for said devices, means for supplying a biasing potential to the input electrodes of said devices, said means including a rectifier biased to respond to signals applied to the amplifier above the predetermined average amplitude, a resistor connected in circuit with said rectifier to receive its output as a source of biasing potentials, and a condenser connected in parallel with said resistor to provide a filter having a predetermined time constant.

13. A self controlled audio frequency amplifier comprising in combination, a pair of exponential electric discharge amplifier devices, means providing a balanced input circuit and a balanced output circuit for said devices, means for supplying a biasing potential to the input electrodes of said devices, said means including a rectfier biased to respond to signals applied to the amplifier above the predetermined average amplitude, a resistor connected in circuit with said rectifier to receive its output as a source of biasing potentials, and a condenser connected in parallel with said resistor to provide a filter having a predetermined time constant, said condenser having a value such that its discharge time is relatively slow with respect to the lowest frequency of the signals to be transmitted by said amplifier.

14. A self controlled audio frequency amplifier comprising in combination, a pair of exponential electric discharge amplifier devices, means providing a balanced input circuit and a balanced output circuit for said devices, means for supplying a biasing potential to the input electrodes of said devices, said means including a rectifier biased to respond to signals applied to the amplifier above the predetermined average amplitude, a resistor connected in circuit with said rectifier to receive its output as a source of biasing potentials, a condenser connected in parallel with said resistor to provide a filter having a predetermined time constant, a second amplifier, and means for supplying signals from said input circuit to said rectifier through said last-named amplifier.

15. A self controlled audio frequency amplifier comprising in combination, a pair of exponential electric discharge amplifier devices, means providing a balanced input circuit and a balanced output circuit for said devices, means for supplying a biasing potential to the input electrodes of said devices, said means including a rectifier biased to respond to signals applied to the amplifier above the predetermined average amplitude, a resistor connected in circuit with said rectifier to receive its output as a source of biasing potentials, a condenser connected in parallel with said resistor to provide a filter having a predetermined time constant, and an inductive filter interposed in circuit between said rectifier and said bias supply resistor.

16. An audio-frequency amplifier comprising a pair of exponential vacuum tubes connected in balanced relation and having an input circuit and an output circuit, and a load connected across said output circuit, the load impedance of the output circuit being less than one-half the plate impedance of either one of said tubes.

17. An audio-frequency amplifier comprising a pair of exponential electric-discharge tubes connected in push-pull, each of said tubes having a control electrode, means for impressing an audio-frequency signal voltage upon said control electrodes, and means for applying a negative bias to said control electrodes which increases in value in response to an increase in the strength of said audio-frequency signal.

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