June 3, 1941. K. W. JARVIS 2,244,066

SIGNAL AMPLIFICATION METHOD AND CIRCUITS

Filed April 12, 1938 2 Sheets-Sheet 1

Fig. 1.

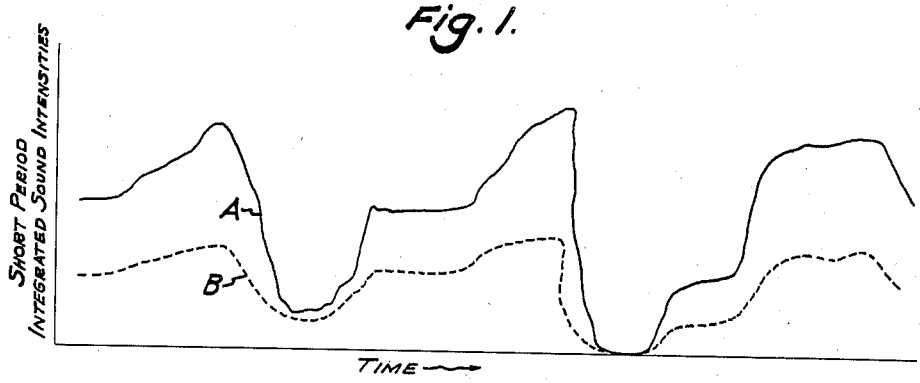


Fig. 2.

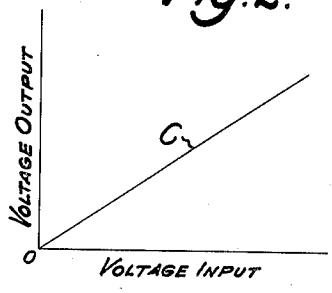


Fig. 3.

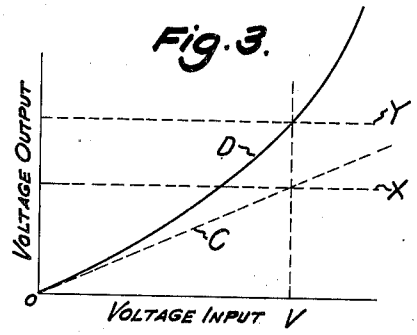
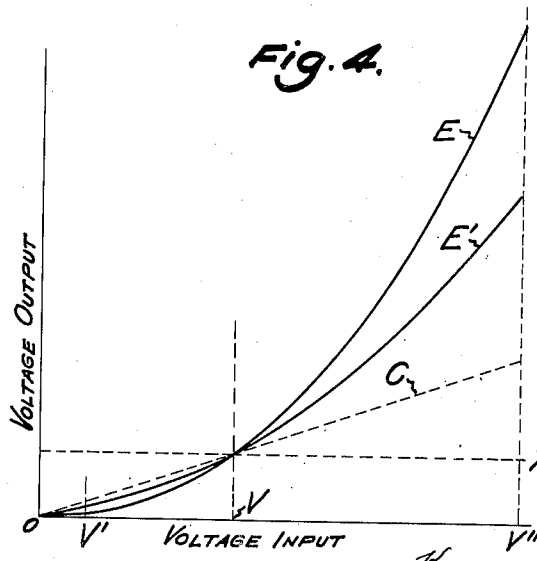


Fig. 4.



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Fig. 5.

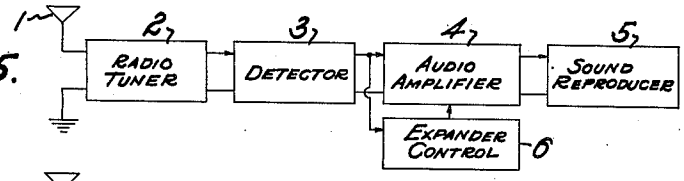


Fig. 7.

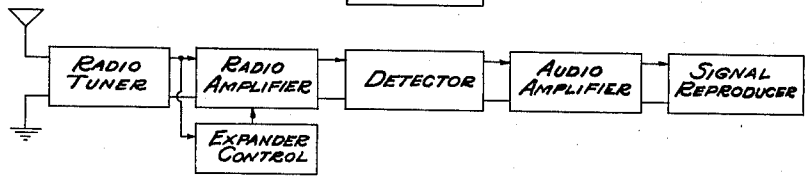


Fig. 6.

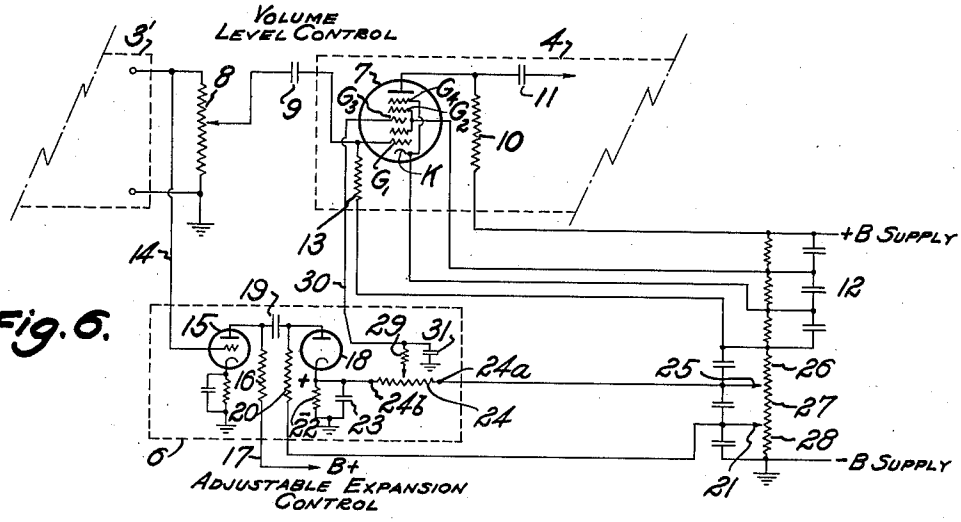
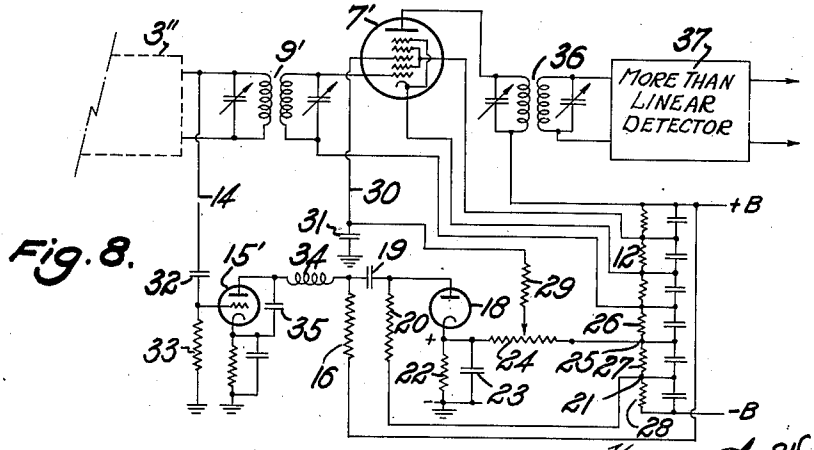


Fig. 8.



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SIGNAL AMPLIFICATION METHOD AND CIRCUITS

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8 Claims. (Cl. 250—20)

This invention relates to signal amplification methods and circuits, and more particularly to amplification methods and circuits which compensate for the compression of the volume range of a recorded or transmitted signal.

The range in sound intensity in various productions may be so great as to impose impractical or impossible demands upon the transmitting or translating medium. The ratio between the maximum and minimum volume passages of a symphony orchestra may be as high as 3000 to 1 and it has been the practice to reduce this volume range, at the broadcasting or recording studio, by a purely manual control exercised by the monitor operator, by automatic controls or by desired combinations of manual and automatic control. Transmission and reproduction of such a "volume compressed" signal by the usual linear systems result in a great decrease in the brilliance, definition and lifelikeness of the music and make the reproduction much less desirable than the original performance. Compensating amplification systems have been developed to provide an output voltage, for reproduction, that is not in proportion to the compressed input voltage but rises rapidly with increasing input voltage. These amplification systems, commonly known as "volume expanders," are quite effective in restoring the high quality characteristics to a compressed signal but are open to one serious objection when designed, as has been customary, to permit adjustment of the degree of expansion by the operator. This adjustment is desirable due to the lack of uniformity in the degree of compression of the signal on different programs from the same or different broadcasting stations, and lack of uniformity in various mechanical and optical translating systems.

The objectionable feature of the prior systems has been the change in average volume level of reproduction with any change in the degree of expansion. An increased degree of expansion has been accompanied by an increase in output level or volume which, to the average listener, is much more pronounced than the increased ratio of intensities of notes or sounds of different volume. The increased output level masks the desired expansion characteristics and satisfactory reproduction can be had only by adjusting the degree of expansion, restoring the average volume level by an adjustment of an auxiliary control, and then repeating these operations in alternation until the desired degree of expansion is obtained at the desired average output volume.

Objects of this invention are to provide methods of and circuits for volume expansion that are free from the objectionable features of the prior volume expansion systems. Objects are to provide volume expansion methods and circuits that are characterized by an independent control of the degree of volume expansion and the average output level or volume. An object is to provide a volume expansion system which affords an increased fidelity of reproduction while maintaining the average volume constant. A further object is to provide a volume expansion system which affords a substantially distortionless volume expansion.

These and other objects and advantages of the invention will be apparent from the following specification when taken with the accompanying drawings in which:

Fig. 1 is a curve sheet showing the integrated intensity, over a small time period, of a sound source at any particular instant;

Figs. 2 to 4 are curve sheets representing the relation of input to output voltage for different amplification and/or transmission characteristics;

Fig. 5 is a block diagram of a radio receiver embodying the invention;

Fig. 6 is a circuit diagram of the novel features of a radio receiver such as shown schematically in Fig. 5;

Fig. 7 is a block diagram of a radio receiver in which the invention is incorporated in the radio amplifier; and

Fig. 8 is a circuit diagram of a radio amplifier and volume expansion control applicable for use in a receiver such as shown in Fig. 7.

In Fig. 1 of the drawings, the curve A shows the variations of the sound intensity of an audio frequency source over a short time interval that may be of the order of from 0.05 to 0.5 second. The sound intensity is determined by integrating the instantaneous intensities over a time period longer than the lowest fundamental frequency of the sound, but short in comparison to the time interval of observation. It is assumed that the maximum to minimum sound intensities constitute a range that exceeds the operating possibilities of the transmission system, and that volume compression is therefore necessary. Curve B indicates the sound intensity-time characteristic of the audio signal after compression.

This compressed rendition of the original performance is generally impressed upon a linear system having an input voltage-output voltage relationship such as indicated by curve C of

Fig. 2. The output of such a system is a linear copy of the input voltage and retains the compressed relationship of the sound intensities of the transmitted signal, and a reproduction of this output voltage lacks the brilliance of the original production. A linear transmission and reproduction such as indicated by curve C is of course appropriate in the case of a signal such as indicated by curve A of Fig. 1, and considerable study has been given to the development of systems that afford a close approximation to the true linear characteristic shown by the right line C.

The initial compression of audio signals for recording or transmission has resulted in the development of volume expander systems having an output-input voltage relation such as shown by curve D of Fig. 3. The output voltage is not a linear function of the input voltage, as the changing slope of curve D shows that the increment in output voltage, for a given increment of input voltage, increases progressively with the magnitude of the input voltage. The curve C of linear output-voltage relation is a straight line lying below curve D.

Maximum fidelity of reproduction of a program that covers only a normal sound intensity range is obtained when the receiver is adjusted for zero volume expansion and the receiver is operated on curve C of Fig. 3. The volume level may be set to provide an output voltage for operating the reproducer as indicated by line X corresponding to an average input voltage level V. When the received program changes to the compressed volume type, a non-linear transmission according to curve D provides a more faithful reproduction of the original production. Adjustment of the volume expander for operation on curve D results in a rise in the output voltage level, for the average input voltage V, to the output voltage level indicated by line Y. The operator of the receiver will usually immediately readjust the gain or output level control after shifting to the volume expansion curve D to lower the average output level. This reduces the average output level to line X, but calls for a further change in the adjustment of the degree of expansion which, in turn, calls for a further adjustment of the average output volume control.

In accordance with this invention, the average output level X for a preselected average input voltage V is maintained constant for all adjustments of the degree of volume expansion. Curves E and E' of Fig. 4 indicate the non-linear output-input voltage relation for two degrees of expansion of the received or input compressed voltage. It will be noted that the non-linear curves E, E' and the linear curve C cross at the average input voltage value V. The significance of these curves and the characteristic feature of this invention is that the average volume level of reproduction is not affected by regulation of the degree of volume expansion. This is a new, and for practical operation, an extremely useful result, for it means that the average volume and the degree of expansion may be independently set to the desired point without distressing interaction. This is accomplished by gradually shifting from the linear curve C of Fig. 4 to a solid curve E, E' of Fig. 4. It may be observed that the average volume level X is the same for both the expanded and the linear conditions. As the expansion control is increased in effectiveness, the gain of the amplifier is gradually reduced below the input value V, and gradually increased above the input value V. As a practical case, I have found that the average volume stays practically constant if the amplifier gain for very low input voltages is reduced in the same proportion as the amplifier gain is increased for maximum voltage inputs. Thus let the gain of the amplifier at the input level V be called K, which is to remain constant regardless of the degree of expansion. Then the gain at the lower input voltage V' is approximately K/N, and the gain at the maximum input value V'' should be approximately KN, where N^2 is the value of the expansion desired. Values of N up to 3 or 4 (N^2=9 to 16) are quite often desired in common practice. It may easily be seen that without this characteristic of my invention of maintaining the average volume constant for all degrees of expansion, the increase in volume with such large degrees of expansion would be the most obvious effect, and might even cause over-load and distortion.

In Fig. 5 is shown a block diagram of a radio receiver with the various elements indicated. In illustrating this application, it is to be understood that the invention is equally applicable to mechanical or optical systems, such as phonographs, talking movies, television, etc. Here the input to the expander control is of audio frequencies, and the control is exercised on the audio frequency amplifier. The antenna 1 is followed by a tuner-amplifier system 2 that works into the detector 3 which passes an audio frequency output to the audio amplifier 4 that works into the sound reproducer 5. The volume expander control unit 6 has an audio frequency input from the detector 3 and delivers a control voltage to the audio amplifier 4, as is indicated by the arrow lines connecting these portions of the block diagram.

The novel features of the adjustable expansion control of the invention are shown diagrammatically in Fig. 6, and the relationship of the volume expander to sections of the radio receiver of Fig. 5 is indicated by the dotted line blocks 3', 4 and 6 which enclose certain of the circuit elements. Block 3' indicates a source of audio frequency voltage corresponding to a compressed signal, this source being the detector 3 of a radio receiver, an audio amplifier stage, or the like. Only the audio amplifier tube 7 is shown in the "amplifier" block 4 as any subsequent audio amplifier stages that precede the reproducer are or may be of conventional design.

The usual voltage divider 8 for manual regulation of the amplifier output level constitutes the input impedance of the amplifier 4, the sliding tap of the voltage divider being connected through coupling condenser 9 to the control grid G1 of the tube 7. The illustrated tube is of the type known as 6L7 but other tubes capable of performing the same functions may be used. The amplified voltage is developed across the plate circuit load 10 and transferred through the coupling condenser 11 to the succeeding tube or reproducer. The cathode K and suppressor grid G4 are connected to each other and returned to an intermediate point of the voltage divider 12 which is connected across the direct current source, not shown, which is indicated by the legends "B supply." Control grid G1 is connected to the voltage divider 12 through the resistor 13, and the plate and screen grid G2 are connected to points of appropriate positive potentials on the voltage divider 12.

The circuit connections of the amplifier tube 7 in which the volume expansion takes place are, so far as described above, more or less conventional and may be varied if desired without affecting the invention. As in the prior volume expanders, the invention contemplates the application of a signal-produced voltage to the auxiliary control grid G3 to regulate the gain of the tube 7 as a function of the intensity of the compressed audio-output from the source 3'.

The full output voltage of the source 3' is impressed through lead 14 upon the grid of the amplifier tube 15 of the volume expander 6. The amplified audio voltage is developed across the plate load resistor 16 that is connected by lead 17 to the +B terminal of the voltage divider 12, and the amplified voltage is transferred to the diode 18 by the coupling condenser 19 and the resistor 20 which serves as a coupling element and is returned to the point 21 on the voltage divider 12. Rectification takes place in the diode and the direct current voltage thus developed across the cathode resistor 22 is used to produce the desired expansion or increase in the amplifier gain with increasing audio frequency intensity. The resistor 22 is preferably shunted by a condenser 23 to filter out any audio frequency component of the rectified voltage.

The cathode of the diode 18 is connected through the potentiometer resistance 24 to the point 25 on the voltage divider 12; the point 25 being at a more negative potential than the bias connection to grid G1 of amplifier 7 by the drop across section 26 of the voltage divider 12, and more positive than point 21 by the drop across section 27, and point 21 which places a steady potential on the anode of diode 18 is more positive than the —B terminal by the drop across the resistance section 28. The tap on the potentiometer resistor 24 is connected through the resistor 29 and lead 30 to the auxiliary control grid G3 of tube 7, the resistor 29 being by-passed for fundamental audio frequencies by the condenser 31. Various conventional elements such as by-pass condensers are shown in Fig. 6 but need not be described in detail.

The operation of the volume expander may be best understood by first assuming that the tap of potentiometer 24 is set at the terminal 24*a* which has the potential of point 25 on the voltage divider 12. This is the adjustment for no volume expansion and the various energizing potentials applied to the elements of the tube 7 are those corresponding to normal amplification and the output level is controlled as desired by adjustment of the potentiometer 8 to supply a fraction of the available source voltage to the control grid G1 of tube 7.

Now it will be observed that the series resistances 24 and 22 are connected in parallel to the series resistances 27 and 28. Let the values of resistors 27 and 28 be very low compared to those of resistors 24 and 22. Also let these units be in the following proportion: 27:24::28:22.

Now take the case when there is no audio input, and no rectified voltage developed across the diode output resistor 22. At this time the voltage drop across the resistor 24 is the same as the voltage drop across the resistor 27. The terminal 24*b* is then at the same potential as the point 21 to which the diode plate is connected through resistor 20. Thus, with no input, the plate of the diode has the same potential as its own cathode, even though not directly connected. It will therefore begin to rectify as soon as any audio frequency potential is impressed across it. This is necessary, for if the resistor 20 should be returned to ground potential, the diode plate would be biased negatively by the voltage drop across the resistor 22, and the diode would not begin to rectify until the audio frequency intensity was greater than such a bias. In general, this is undesired. It should be noted, however, that in at least one practical instance, such a delayed action characteristic was desired, and then the resistance 28 and its by-pass condenser were simply omitted, and the point 21 grounded.

Now let an audio signal be impressed. The diode 18 rectifies it and develops a voltage across the resistor 22. The voltage drop across the resistor 24 gradually decreases with increasing audio frequency potentials impressed. Finally a point is reached where the potential drop across the resistor 22 is exactly equal to the potential across the resistors 27 and 28. At this time, the potential drop across the potentiometer 24 is zero, and no matter where the expansion control adjustment of the variable arm on the potentiometer 24 be placed, the potential on the auxiliary control grid G3 does not vary. This corresponds to an input voltage equal to V on the curves of Figs. 3 and 4. That is, with this input chosen as the average volume, the output stays constant regardless of the degree of expansion chosen. Now let the audio input be still further increased. The voltage developed across the resistor 22 increases, and the voltage across the potentiometer 24 reverses in sign, the potential of point 24*b* becoming more positive than that of point 24*a*. If the tap or slider of potentiometer 24 be moved to point 24*b*, the audio gain will increase, for this makes the control grid G3 of tube 7 less negative with respect to the cathode K. This corresponds to the right hand portion of the solid curve in Fig. 4. An increase in volume over normal linearity is thus produced at high audio intensities.

Assume that the tap of potentiometer 24 remains on the terminal 24*b* of resistor 24 and that the audio input falls to zero. When this happens, there is no potential across the resistance 22 due to rectification, and the point 24*b* falls to a potential equal to that at the point 21 on the potential divider 12. Thus the control grid G3 goes more negative with respect to the cathode K than it was in the normal condition, by an amount equal to the drop in the resistor 27. This lowers the gain below normal linearity, as shown by the solid curve to the left of the voltage input V in Fig. 4.

Adjustment of the tap along the resistor 24 determines the fraction of the rectified voltage, as developed across resistor 22, which is impressed upon the control grid G3 to regulate the degree of volume expansion. The same characteristic operation is obtained at all adjustments of the tap since that average input voltage V which makes the potential drop across the diode output resistor 22 equal to the potential drop across the voltage divider sections 27 and 28 produces a zero drop of potential across the potentiometer 24. In other words, the tap on the expansion control resistor 24 may be adjusted from zero to maximum expansion without affecting the output level for the average input voltage. Similarly, the output level may be varied by the adjustment of the voltage divider 8 without affecting the degree of expansion as determined by the setting of the tap of expansion control resistor 24.

The invention is also applicable to radio frequency amplifiers to control the amplification of

a signal at rates which vary with the degree of modulation on the carrier wave. A system of this type is shown schematically in Fig. 7 in which the several components of the radio receiver are shown as blocks that carry identifying legends.

Many parts of the volume expander for radio amplification, as shown in Fig. 8, are identical with those shown in Fig. 6 and are identified by corresponding reference numerals but will not be described in detail. The coupling between the source 3'' of a radio or intermediate frequency signal may take the form of a tuned transformer 9', a coupling condenser 32 is included in the lead 14 to the tube 15' which now serves as a rectifier of the impressed modulated signal, and the grid of tube 15' is returned to ground through the resistor 33. The choke 34 and by-pass condenser 35 serve to filter out any radio or intermediate frequency components from the modulation frequency output voltage which is passed to the diode 18. The amplified radio voltage from tube 7' is passed by the tuned coupling transformer 36 to the detector 37 which may be, and preferably is, a square law detector. The operation of the circuit will be obvious from the description of the expansion control as applied to an audio amplifier.

It is frequently advantageous to apply the volume expansion to the radio or intermediate frequency signal to avoid the introduction of audio frequency distortion. Furthermore, when the detector is of the square law type an additional degree of expansion is obtained in the detector. A desired high degree of expansion may thus be obtained by controlling the carrier amplification as a function of the modulation intensity, and the novel characteristic of maintaining the average output level for all adjustments of the expansion control prevents an overloading of the detector before the desired high expansion rate is obtained.

The circuits herein shown and described are illustrative of my invention, but it is to be understood that they are subject to modification and that various changes that may occur to those familiar with the design of vacuum tube circuits fall within the spirit of my invention as set forth in the following claims.

I claim:

1. In the operation of a volume expanding system of the type having a resistor across which is developed a direct current voltage that varies with the magnitude of an incoming signal, and a tap adjustable along the resistor to regulate the degree of volume expansion; the method of preventing variation of the average output level with changes in the adjustment of the tap which comprises impressing across said resistor a direct current potential equal and opposite to the direct current voltage developed by an incoming signal of preselected magnitude.

2. In combination, an amplifier circuit having input and output terminals, said input terminals being adapted to have varying amplitude signals applied thereto, manually controlled means for adjusting the volume level at the amplifier output terminals, and volume expanding means adjustable independently of said manually controlled means for varying the degree of non-linear amplification of said amplifier circuit, said volume expanding means including means maintaining the input terminals-to-output terminals gain of the amplifier circuit at a preselected average signal input independent of the adjustment of said volume expanding means.

3. In a signal amplifying system, the combination with a detector having a more than linear characteristic, of an amplifier for impressing a modulated carrier wave upon said detector, means for varying the gain of the amplifier in accordance with the degree of modulation of the carrier wave input to said amplifier, said means being adjustable to control the degree of volume expansion, and means for maintaining the output voltage level of said amplifier constant at a preselected input level for all adjustments of said gain varying means.

4. In a volume expanding signal amplifying system, the combination with a source of signal voltage, an output circuit, and an amplifier tube connected between said source and said output circuit, of means for varying the gain of said amplifier tube as a function of the intensity of the signal voltage emanating from said source, said gain-varying means being adjustable manually to control the degree of volume expansion, and means maintaining the gain of the amplifier tube constant for a preselected average voltage input at all adjustments of said gain-varying means.

5. In a volume expanding signal amplifying system, the combination with a source of signal voltage, an output circuit, an amplifier tube connected between said source and said output circuit, and means for varying the gain of said tube; said means including a rectifier and a resistor across which said rectifier develops a direct current voltage that varies with the magnitude of the incoming signal voltage, and a tap adjustable along the resistor to vary the rate of volume expansion; of means maintaining the output level for a signal input of preselected average magnitude constant for all adjustments of said tap, said last means comprising means establishing across said resistor a direct current potential equal and opposite to the direct current voltage developed across the resistor by said rectifier at the signal input of preselected average volume.

6. In a signal amplifying system, the combination with a multi-element vacuum tube having a first control grid and an auxiliary control grid cooperating with a cathode and a plate, an input circuit between said first control grid and said cathode, an output circuit between said plate and said cathode, a source of signal voltage coupled to said input circuit, rectifier means coupled to said source for developing a direct current voltage that fluctuates with the intensity of the signals emanating from said source, a resistor upon which said direct current voltage is impressed, a tap adjustable along said resistor and connected to said auxiliary control grid, and means establishing across said resistor a direct current potential of predetermined magnitude and in opposition to the direct current voltage developed by said rectifier means, whereby the voltage level at said output circuit is independent of the adjustment of said tap at that signal voltage for which the voltage developed by said rectifier means has the same magnitude as said direct current potential.

7. In a signal amplifying system, the combination with a source of signal voltage and an amplifier tube having a gain control electrode, of adjustable expansion control apparatus connected between said source and said gain control electrode; said apparatus comprising a vacuum tube having an input electrode connected to said source, an output circuit for said vacuum tube, a rectifier coupled to said output circuit and having an output resistor across which a direct cur-

rent voltage is developed, a voltage divider resistor connected to the high potential end of said output resistor and having an adjustable tap connected to said gain control electrode of the amplifier tube, and mean establishing across said voltage divider resistor a potential drop equal and opposite to the direct current voltage developed across said output resistor by said rectifier at a preselected voltage output of said source, whereby the voltage impressed upon said gain control electrode for the preselected output voltage of said source is independent of the adjustment of said tap on the voltage divider resistor.

8. In a signal amplifying system, the invention as claimed in claim 7 wherein said source develops a modulated carrier wave, and said vacuum tube of the expansion control apparatus is a rectifier of the modulated carrier wave, in combination with a detector having a more than linear characteristic coupled to said amplifier tube, whereby the volume expansion in said amplifier tube is accentuated by the non-linear detector.

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