Nov. 12, 1940. K. H. F. SCHLEGEL 2,221,681

VOLUME CONTROL SYSTEM

Filed April 5, 1938 3 Sheets-Sheet 1

Fig. 1.

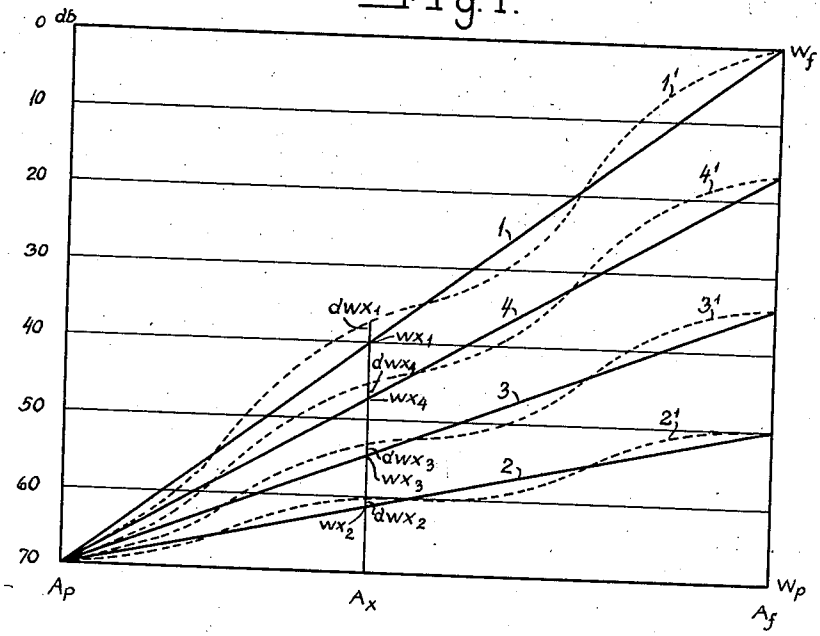
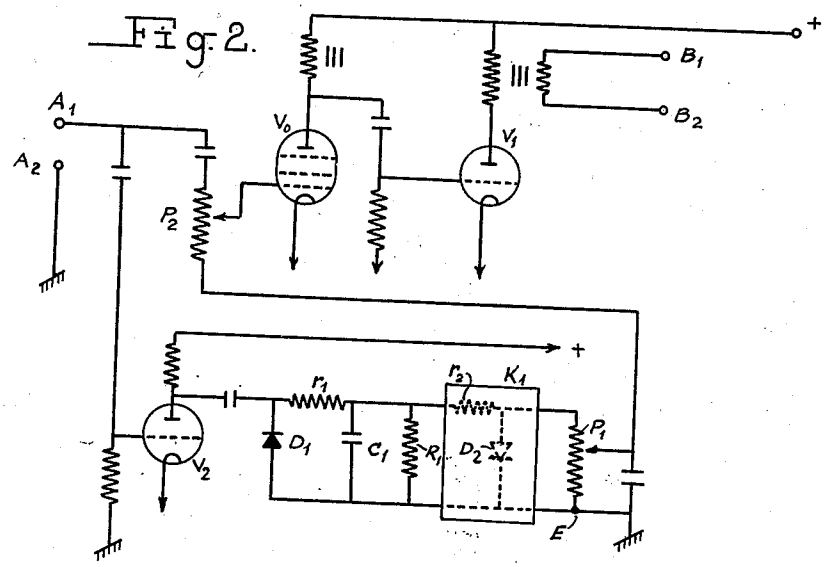


Fig. 2.



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Fig. 4

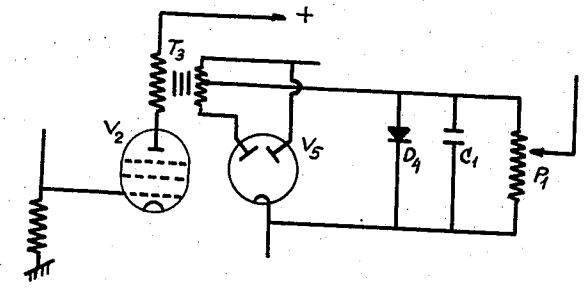


Fig. 3.

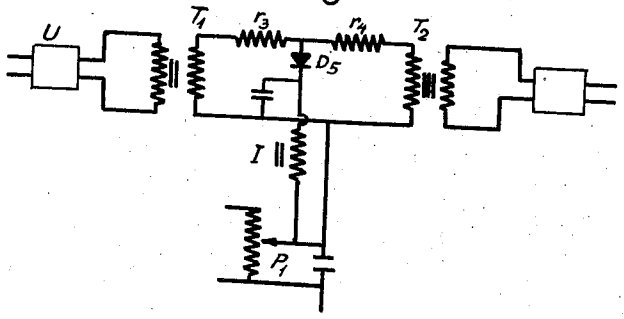
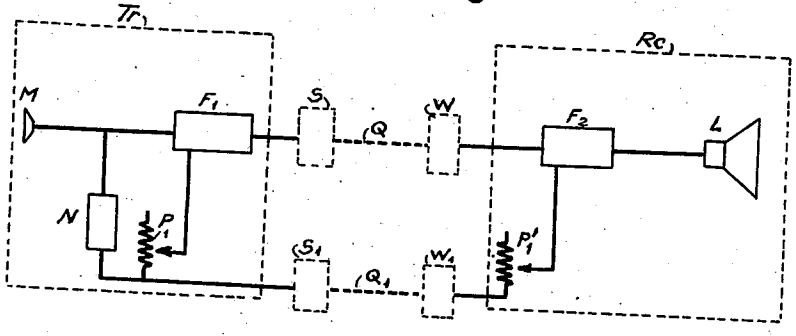


Fig. 5.



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Fig. 6.

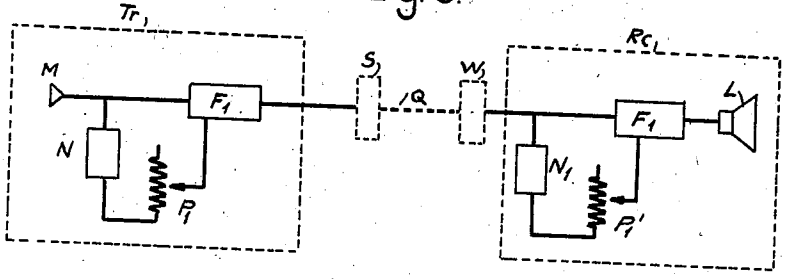
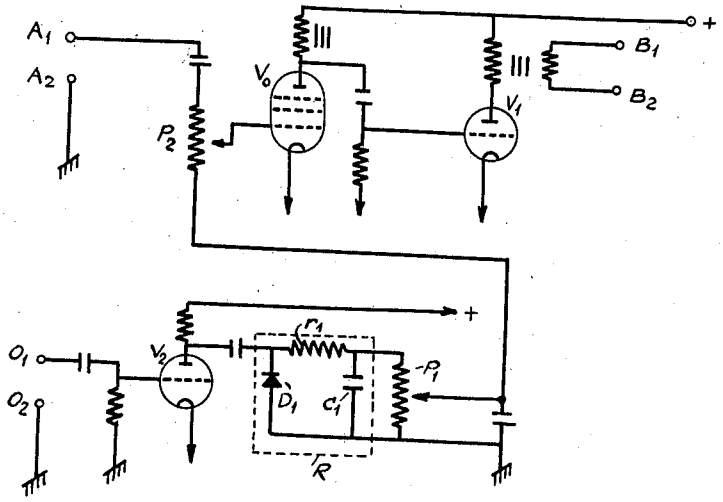


Fig. 7.



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2,221,681

VOLUME CONTROL SYSTEM

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Application April 5, 1938, Serial No. 200,277
In Denmark April 8, 1937

10 Claims. (Cl. 179—100.3)

The invention relates to volume control systems for expanding or compressing the volume range of electric oscillations, and more particularly the invention relates to systems for controlling the volume range of electric oscillations in the recording and reproduction of sounds.

It is commonly known to compress the volume range of sounds during the recording process and to undertake a complementary expansion of the volume range during the reproduction of the recorded sounds, and further it is well known to effect the said compression and the said expansion by varying the gain of the recording amplifier and the gain of the reproducing amplifier.

The compression of the volume range of oscillations to be recorded on a photographic film is necessary for the reason that, owing to the size of the grains in the sensitive layer on the film, the maximum ratio of the amplitudes of the record should preferably not exceed the value of about 10:1, whilst the maximum ratio of the amplitudes of sounds developed by an orchestra, the volume range of which normally amounts to about 70 decibels, would approximately be 3160:1. Therefore a reduction of the volume range to a value of about 20 decibels, corresponding to an amplitude ratio of 10:1—or with other words a compression of the volume range of the sound from 70 decibels to 20 decibels, i. e. a compression amounting to 50 decibels—is desirable.

In this connection it should be remarked that it is not impossible to prepare photographic sound records, in which the maximum amplitude ratio is about 100:1 corresponding to a volume range of 40 decibels of the recorded oscillation, however in order to secure in the reproduction of different musical items by way of photographic sound records a good quality of the reproduction a maximum ratio of approximately 10:1 in the record is preferred. The present invention is, however, not limited to the maintenance of this preferred amplitude ratio of the compressed oscillations.

According to the definition of the decibel unit the difference expressed in decibels between the volume of a sound oscillation having the amplitude a_1 and a sound oscillation having the amplitude a_2 is

$$20.\log \frac{a_1}{a_2}$$

Now, according to the Weber-Fechner rule, the psychological impression created by the different sounds is proportional to the sound volume expressed in decibel units within the average interval of sound frequencies and, therefore, in order to obtain the maximum quality of the sounds as perceived by the human ear during the reproduction, the compression of volume range effected during the recording operation should be wholly or partly compensated during the reproduction operation in such a manner that the logarithm of the ratio between any two different amplitudes w_1 and w_2 of the reproduced oscillations is proportional to the logarithm of the ratio between the corresponding amplitudes a_1 and a_2 respectively of the original sound oscillations, or in other words that:

$$K.\log \frac{a_1}{a_2} = \log \frac{w_1}{w_2} \quad \text{----------(1)}$$

where K is a constant.

If r_1 and r_2 are two amplitudes of the recorded oscillations, corresponding to the amplitudes a_1 and a_2 respectively of the original sound oscillation, then

$$k_1.\log \frac{a_1}{a_2} = \log \left(\frac{r_1}{r_2}\right) \quad \text{---------- (2)}$$

where k_1 is a constant, which is called the compression coefficient, and further:

$$k_2.\log \frac{r_1}{r_2} = \log \frac{w_1}{w_2} \quad \text{----------(3)}$$

where k_2 is a constant, which is called the expansion coefficient.

From the Equations 1 and 2 and 3 it would appear that

$$K = k_1 \cdot k_2$$

If $K=1$ the expansion is complete, i. e. the sound will be reproduced with the full natural volume range.

However, under practical conditions, for instance during the reproduction of sound films in a picture theatre, it may not always be possible to reproduce the sounds with complete expansion. If, by way of example, a number of different performers or musical items are recorded on the same film, then some parts of the performance, for instance speech or solo instruments may be reproduced with full natural volume range, while other items such as the music played by a large symphony orchestra must be reproduced with a volume range which is reduced with respect to that of the original sounds.

It is therefore desirable to be able to adjust the degree of expansion during the reproduction

of the sound so as to suit the various sound items occurring during the performance, and similarly it is often desirable to be able to adjust the compression of the volume range during the recording operation to suit the various volume ranges of the different musical items to be recorded.

The object of the present invention is to provide means whereby the degree of compression and expansion of the volume range of electric oscillations in the recording and reproduction respectively may be conveniently adjusted at any desired value, i. e. means for arbitrary adjusting the value of the coefficients k_1 and k_2 in the Equations 2 and 3.

Now any of the three Equations 1 and 2 and 3 corresponds to the general equation:

$$k.\log\left(\frac{i_1}{i_2}\right)=\log\left(\frac{u_1}{u_2}\right) \quad \text{----------(4)}$$

where k is a constant and i_1 and i_2 are amplitudes of the input oscillations of a device for converting the said oscillations into output oscillations of a different volume range, in which u_1 and u_2 are amplitudes corresponding to i_1 and i_2 respectively. If the value of the coefficient k in Equation 4 is less than 1, then the volume range of the output oscillations is compressed relatively to the input oscillations, and if $k_1>1$, the output oscillations are expanded relatively to the input oscillations.

According to the invention the coefficient k—and consequently the compression coefficient k_1 and the expansion coefficient k_2 according to the Equations 2 and 3—may be varied by deriving from the input oscillations a control voltage e, which varies proportionally to the variation—expressed in decibel units—of the amplitudes of the input oscillations, which means that, if $e_1 \div e_2$ is the variation of the control voltage e corresponding to a variation of the amplitude of the input oscillations from i_1 to i_2, then $e_1 \div e_2$ is expressed by

$$c_1.(e_1 \div e_2)=\log\frac{i_1}{i_2} \quad \text{----------(5)}$$

where c_1 is a constant.

By means of a potentiometer an adjustable portion $e_1' \div e_2'$ of the variation $e_1 \div e_2$ of the control voltage is applied to control the gain of an amplifier for amplifying the input oscillations, so that the gain expressed in decibel units is caused to vary proportionally to the variations of the control voltage.

Thus, if p is the ratio of adjustment of the potentiometer and f_1 and f_2 are the value of the said gain corresponding to the amplitudes f_1 and f_2 respectively, then

$$e_1 \div e_2 = p.(e_1' \div e_2')$$

and

$$\overset{+}{\div} c_2.(e_1' \div e_2')=\log\left(\frac{f_1}{f_2}\right) \quad \text{--------(6)}$$

In Equation 6 $e_1' \div e_2'$ is the numerical value of the voltage variation irrespectively whether the said variation is positive or negative and, consequently, the constant c_2 is negative, if $f_1>f_2$, i. e. if compression of the volume range is aimed at.

Now

$$i_1=f_1.u_1 \text{ and } i_2=f_2.u_2 \text{----------(7)}$$

and consequently

$$\log\frac{i_1}{i_2}+\log\frac{f_1}{f_2}=\log\frac{u_1}{u_2} \quad \text{----------(8)}$$

From the Equations 5, 6, 7 and 8 it would appear that:

$$\log\frac{i_1}{i_2}\left(1 \pm p.\frac{c^2}{c_1}\right)=\log\frac{u_1}{u_2} \quad \text{--------(9)}$$

which equation is seen to be equivalent to Equation 4, if

$$k=\left(1 \overset{+}{\div} p.\frac{c_2}{c_1}\right) \quad \text{----------(10)}$$

From this it would appear that the coefficient k—and consequently the coefficients k_1 and k_2—may be adjusted to any desired value by varying the ratio of adjustment p of the said potentiometer.

If on a sound record representing sound oscillations, the volume range of which has been compressed by the recording, there is recorded an auxiliary track representing the variations—expressed in decibels—of the amplification of the sound responsive current, into which the sound was converted for the purpose of being recorded. then a separate auxiliary input current produced by way of the said auxiliary track is caused to produce the above mentioned control voltage $e_1 \div e_2$.

The manner in carrying the invention into practice would be more readily understood from the explanation set forth below with reference to the drawings, on which

Fig. 1 is a graphic representation of adjustment of the volume range of sound oscillations.

Fig. 2 is a circuit diagram of a system for compressing or expanding the volume range of electric oscillations.

Fig. 3 shows a modification of a detail of the systems according to Fig. 2.

Fig. 4 shows a modification of another detail of the systems according to Fig. 2.

Fig. 5 shows diagrammatically a transmitting system illustrating the manner in effecting a compression and a complementary expansion of the volume range of a sound responsive current.

Fig. 6 shows diagrammatically a modification of a transmitting system according to Fig. 3.

Fig. 7 is a circuit diagram of a modified system serving the purpose of expanding the volume range of electric oscillations, when reproduced, by means of a separate control current.

In the diagram in Fig. 1 the variations w of the volume, expressed in decibel units, of reproduced sounds are plotted against the variations a of the volume, also expressed in decibels, of the original sounds. w_f and w_p correspond to the maximum and the minimum values respectively of the reproduced variations and a_f and a_p correspond to the maximum and the minimum value respectively of the original sound variations. It is assumed that the volume range of the original sounds is 70 decibels and that the volume of the recorded variations used for the purpose of reproducing the sounds is 20 decibels.

If the sound is reproduced with the full natural volume range, i. e. when the compression undertaken by the recording is completely compensated by an expansion during the reproduction, then the relation between the original sounds and the reproduced sounds is represented by the straight diagonal line 1 in Fig. 1. If, on the other hand, no expansion is effected during the reproduction, the said relation is represented by the line 2 in Fig. 1, which consequently also represents the relation between the volume of the original sounds and the compressed volume of the recorded sounds. The intermediate lines

3 and 4 represent two different degrees of partial compensation according to the Equations 3 and 10 of the compression represented by the line 2, which compensation is effected by adjustment of the potentiometer ratio p referred to above.

A straight-lined compression characteristic as shown at 2 in Fig. 1 and corresponding to the relation according to Equation 2 above between the original oscillations and the compressed oscillations may be obtained in a recording or transmitting system, in which a sound responsive current used for effecting the recording or transmitting is amplified to a variable degree, controlled by a rectified portion of the said current or by a separate current, which is caused to pass a logarithmic compressor to produce a control voltage according to Equation 5. A circuit diagram for a system of this kind is shown in Fig. 2 and described below.

It should be remarked that the arbitrary adjustment of the degree of expansion according to the invention may also be effected, even if the compression characteristic is not exactly a straight line but merely a fairly good approximation to this preferred condition. Thus, for instance, a characteristic as shown by the dotted curve 2' in Fig. 1 may be obtained by manually controlled volume compression by a skilled operator.

It will be appreciated that even in this case it is desirable to effect the expansion according to the Equation 3 as in this circumstance any deviation dw_{x2} from the amplitude w_{x2} of the straight line 2, corresponding to an amplitude a_x of the original sound variations, will remain constant at any degree of expansion, which means that

$$\frac{dw_{x2}}{w_{x2}}=\frac{dw_{x1}}{w_{x1}}=\frac{dw_{x3}}{w_{x3}}=\frac{dw_{x4}}{w_{x4}}$$

or in other words, a tolerable inaccuracy that may have occurred during the compression will not become more conspicuous, if the expansion is increased to the full natural volume range.

In the system according to Fig. 2 A_1 and A_2 are the input terminals of an amplifier represented by the two valves V_0 and V_1, from which the valve V_0 is a variable-mu valve. A device, not shown, for converting sound oscillations into a sound responsive electric current is to be connected across the terminals A_1 and A_2, so that the sound responsive current is amplified by the said amplifier. The amplified electric oscillations are tapped at the output terminals B_1 and B_2 and utilized for any desired purpose, for instance for recording or reproducing purposes.

A portion of the sound responsive current is diverted from the input circuit of the valve V_0 and amplified in a valve V_2. The output of this valve is rectified in a rectifier D_1, which is associated with a smoothening device r_1, C_1, R_1. A so-called logarithmic compressor K_1, comprising for instance a metal rectifier D_2 in combination with a resistance r_2 is connected across the resistance R_1 of the smoothening device and serves the purpose of converting the variations of the loss of voltage across the resistance R_1 into a voltage across the resistance of a potentiometer, P_1, which latter voltage varies substantially proportional to the logarithm of the variations of the voltage across the resistance R_1 and, consequently, proportional to the variations of the input current expressed in decibel units in accordance with Equation 5 above.

The valve V_0 is coupled to the input terminals A_1 and A_2 by means of a potentiometer P_2 having one end connected to the adjustable terminal of the potentiometer P_1, and being adapted to adjust the amplification in the said valve independently of the variations of the said amplification, which are caused by that portion of the voltage across the resistance of the potentiometer P_1, which is tapped by the adjustable terminal of this potentiometer. This control voltage causes the gain of the valve V_0 to vary according to the rule expressed by Equation 6, since the variation of the gain—expressed in decibel units—of a variable-mu valve is proportional to the corresponding variation of the voltage impressed upon the control grid of the valve.

It will be appreciated that instead of the variable-mu valve V_0 any other well known device, such as a heat sensitive conductor, or a dry cell rectifier, having a logarithmic characteristic similar to that of a variable-mu valve, may be used. Fig. 3 shows an example of such a device, comprising two transformers T_1 and T_2 connected in series with two resistances r_3 and r_4 and a dry cell rectifier D_5 connected across the common circuit of said resistances and said transformers in series with an impedance I and the potentiometer P_1, corresponding to the potentiometer P_1 in Fig. 2. The electric oscillations to be transmitted are fed—if desired after suitable amplification in an amplifier U—to the transformer T_1, and the rectifier D_5 would due to the influence of the control voltage derived from the potentiometer P_1 cause the impedance of the circuit interconnecting the two transformers to vary in such a manner that the transmission coefficient of the said circuit would vary in such dependence of the variations of the said control voltage that the volume range of the transmitted oscillations is expanded or compressed according to Equation 9.

Similarly the rectifier D_1 and the logarithmic compressor K_1, Fig. 2, may be replaced by any other known device having a similar effect. Fig. 4 shows by way of example a device to substitute the control circuit, including the rectifier D_1, the said compressor and the potentiometer according to Fig. 2.

In Fig. 4 the valve V_2 for amplifying the portion of the current derived from the input circuit of the system according to Fig. 2 is a valve having a large internal resistance for instance a pentode. The output circuit of this valve is by means of a transformer T_3 coupled to a double-rectifying valve V_5, and a metal rectifier D_4 is connected across the output circuit of this valve. The impedance of the rectifier D would vary considerably in dependence of the amplitude of the currents rectified by the valve V_5, so that the loss of voltage across the rectifier D_5 and consequently the difference of potential between the ends of the resistance of the potentiometer P_1 connected across the rectifier D_5, would vary substantially proportional to the logarithm of the variations of the grid potential of the valve V_2. Consequently, the control voltage tapped at the adjustable terminal of the potentiometer P_1 in Fig. 4 would vary in dependence of the amplitudes of the input currents according to Equation 5.

Fig. 5 illustrates diagrammatically the manner, in which a compression of the volume range of a sound responsive current in a transmitter Tr and a subsequent expansion of the compressed volume range in a receiver Rc may be adjusted according to the invention. Sounds are converted in a sound responsive current by way of a

microphone M and the volume range of the said current is compressed in an amplifier F_1 in the manner described above in connection with Fig. 2. N in Fig. 5 represents the rectifier and logarithmic compressor in combination, used according to Fig. 2 for producing the control voltage. P_1 is the potentiometer for adjusting the portion of the said control voltage supplied to the amplifier F_1 in order to effect the compression of the volume range of the amplified currents.

The output oscillations of the amplifier F_1 is in any suitable well-known manner, for instance through a transmitting line Q or in a wireless way or after having been recorded in a proper recording device S, Fig. 2, transferred to the amplifier F_2—or if recorded to a reproducing device W being coupled to the amplifier F_2—in the receiver Rc and the control voltage produced in the device N in a similar manner, i. e. either by a transmitting line Q_1 or by wireless transmission or by recording in a recording device S_1 and reproduction in a reproducer W_1 on the receiver station Rc transferred to a potentiometer P_1' adapted to adjust the portion of the said voltage, which by means of the potentiometer P_1' is supplied to the amplifier F_2 for the purpose of expanding the volume range of the received oscillations to a degree, which may be adjusted by way of the potentiometer P_1'. L is a loud speaker for reproducing the sounds.

In the system according to Fig. 5 the logarithmic compressing device N for securing a control voltage varying proportionally to the variation, expressed in decibel units, of the volume of the input current is common to the compressing and expanding system.

If as shown in Fig. 6 the said control voltage is not transferred from the transmitting or compressing system Tr to the receiving or expanding system Rc a separate control voltage may in the manner described above in connection with Fig. 2 be produced in the receiving or expanding system by way of a separate device N_1 for rectifying and logarithmically compressing a portion of the transmitted oscillations.

Fig. 7 shows a circuit diagram of a system for expanding the volume range of sound responsive electric oscillations which have been recorded on a photographic film together with a separate control track representing the variations, expressed in decibel units, of the gain of the amplifier—for instance the amplifier F_1 in Fig. 5—in the recording system, which means that the said control track is assumed to represent the variations of the control voltage produced in the device N in Fig. 5.

The said sound responsive current is in a well known manner not shown reproduced by way of the sound record and is supplied to the input terminals A_1 and A_2 in Fig. 7. The variations represented in the control track are in a manner known per se converted into corresponding variations of the intensity of an alternating current of a constant relatively high frequency, which current is supplied to the input terminals O_1 and O_2 of the valve V_2. The output of this valve would after suitable rectification and smoothening in a rectifier R produce across the potentiometer P_1 a loss of voltage varying proportionally to the said variation of the input current of the valve V_2. A portion of this voltage is tapped by the adjustable terminal of the potentiometer P_1 and supplied to the control grid of the valve V_0 to secure a partial or complete expansion of the compressed volume range of the oscillations amplified by this valve.

It should be remarked that, though the invention is described above mainly in connection with systems for recording sounds on photographic films and for reproducing sounds from such records, the invention is not limited to such use, but is also applicable for compressing and expanding electric oscillations to be transmitted from a transmitter to a receiver through telephone lines or by wireless radiation, irrespectively whether or not the oscillations are transmitted and reproduced without being recorded, or are recorded either at the transmission station or at the receiving station in any desired well known manner, for instance on film, plates, wires or the like.

Having now particularly described and ascertained the nature of my invention and in what manner the same is to be performed I declare that what I claim is:

1. A system for converting electric oscillations of a given volume range into electric oscillations of a different volume range, comprising an amplifier for amplifying the first mentioned oscillations, means for deriving from these oscillations a control voltage substantially proportional to the decibel values of the amplitudes of the first mentioned oscillations, and means for varying the decibel value of the gain of the said amplifier substantially proportional to the variations of the said control voltage.

2. A system for converting electric oscillations of a given volume range into electric oscillations of a different volume range, comprising an amplifier for amplifying the first mentioned oscillations, means for deriving from these oscillations a control voltage substantially proportional to the decibel values of the amplitudes of the first mentioned oscillations, means for arbitrarily adjusting the said control voltage, and means for varying the decibel value of the gain of the said amplifier substantially proportional to the variations of the said control voltage.

3. A system for converting electric oscillations of a given volume range into electric oscillations of a different volume range, comprising an amplifier for amplifying the first mentioned oscillations, means for deriving from these oscillations a control voltage substantially proportional to the decibel values of the amplitudes of the first mentioned oscillations, a potentiometer for arbitrarily adjusting the said control voltage, and means for varying the decibel value of the gain of the said amplifier substantially proportional to the variation of the said control voltage.

4. A system for converting electric oscillations of a given volume range into electric oscillations of a different volume range, comprising an amplifier including a variable-mu valve for amplifying the first mentioned oscillations, means for deriving from these oscillations a control voltage substantially proportional to the decibel values of the amplitudes of the first mentioned oscillations, a potentiometer for arbitrarily adjusting the said control voltage, and means for supplying the control voltage to the control circuit of the said variable-mu valve.

5. A system for converting electric oscillations of a given volume range into electric oscillations of a different volume range, comprising an amplifier including a variable-mu valve for amplifying the first mentioned oscillations, a control circuit including means for rectifying a portion of

oscillations to be amplified and to compress the volume of the said portion logarithmically to produce voltage variation proportional to the decibel values of the amplitude of the oscillations to be amplified, a potentiometer to derive from the said voltage variations an adjustable control voltage, and means to supply the control voltage to the control grid of the variable-mu valve.

6. A system for converting sound oscillations into electric oscillations the volume range of which is compressed relatively to the volume range of the sound and for recording the said oscillaitons comprising a microphone to convert the sounds into a sound responsive electric current, an amplifier including a variable-mu valve for amplifying said current, a control circuit including means for rectifying a portion of the said current and for compressing the volume of same logarithmically to produce voltage variations proportional to the decibel values of the amplitudes of the said sound responsive current, a potentiometer arranged to supply an adjustable portion of the said voltage variations to the grid circuit of the said variable-mu valve so as to control the decibel value of the gain of the said amplifier, and means for recording the output oscillations of the said amplifier.

7. A system for converting sound oscillations into electric oscillations the volume range of which is compressed relatively to the volume range of the sound and for recording the said oscillations comprising a microphone to convert the sounds into a sound responsive electric current, an amplifier including a variable-mu valve for amplifying said current, a control circuit including means for rectifying a portion of the said current and for compressing the volume of same logarithmically to produce voltage variations proportional to the decibel values of the amplitudes of the said sound responsive current, a potentiometer arranged to supply an adjustable portion of the said voltage variation to the grid circuit of the said variable-mu valve so as to control the decibel value of the gain of the said amplifier, means for recording the output oscillations of the said amplifier, and means for separately recording the said voltage variations.

8. A system for expanding the volume range of the output oscillation of an amplifier relatively to the volume range of the input oscillations of the amplifier, comprising in combination with the said amplifier, including a variable-mu-valve, a control circuit, including means for rectifying and compressing logarithmically a portion of the said input oscillations to produce a control voltage varying substantially proportional to the decibel values of the amplitudes of the input oscillations, a potentiometer for supplying an adjustable portion of said voltage to the grid circuit of the variable-mu valve to control the decibel value of the gain of the said amplifier, and in the output circuit of the said ampilfier means for reproducing the amplified oscillation.

9. A system for reproducing sounds from a record on which the sounds are recorded as variations the volume range of which is contracted relatively to the volume range of the sounds comprising means for producing an oscillatory current responsive to the recorded variations, an amplifier including a variable-mu valve for amplifying said current, means for rectifying and compressing logarithmically a portion of the said current to produce a control voltage varying substantially proportional to the decibel values of the amplitudes of the said current, a potentiometer for supplying an adjustable portion of said voltage to the grid circuit of the variable-mu valve so as to cause the said valve to expand the volume range of the said current during the amplification of same, and a loud speaker for reproducing the sounds from the output oscillations of the said amplifier.

10. A system for reproducing sounds records, including an auxiliary track the amplitudes of which vary approximately proportional to the gain, expressed in decibel, of the amplifier used by the recording of the sound, comprising means for converting the recorded sound responsive variations into a corresponding oscillatory electric current, an amplifier including a variable-mu valve for amplifying said current, an auxiliary circuit, including means for producing by way of the said auxiliary track, an oscillatory control current, responsive of the variations represented by the auxiliary track, means to rectify the said current to produce a voltage varying substantially proportional to the variations of the said control current, a potentiometer for supplying an adjustable portion of the said voltage to the grid circuit of the said variable-mu valve to cause the said valve to expand the volume of the first mentioned oscillatory electric current during the amplification of same, and a loud speaker for reproducing the sounds from the expanded output oscillation of the said amplifier.

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