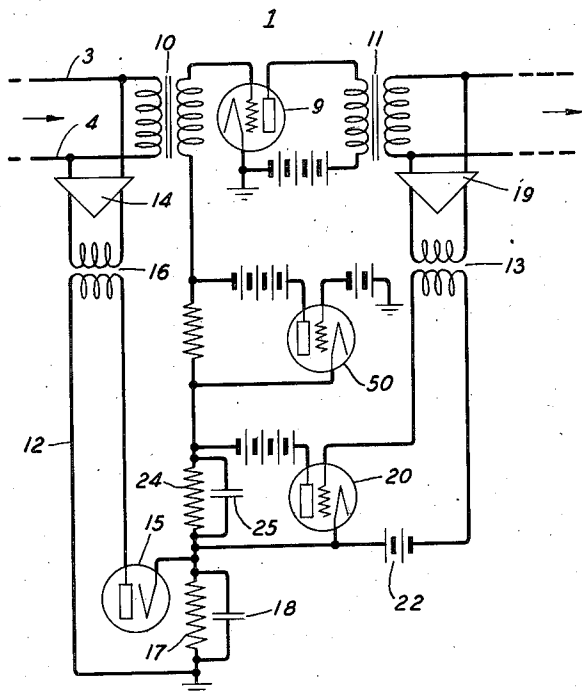
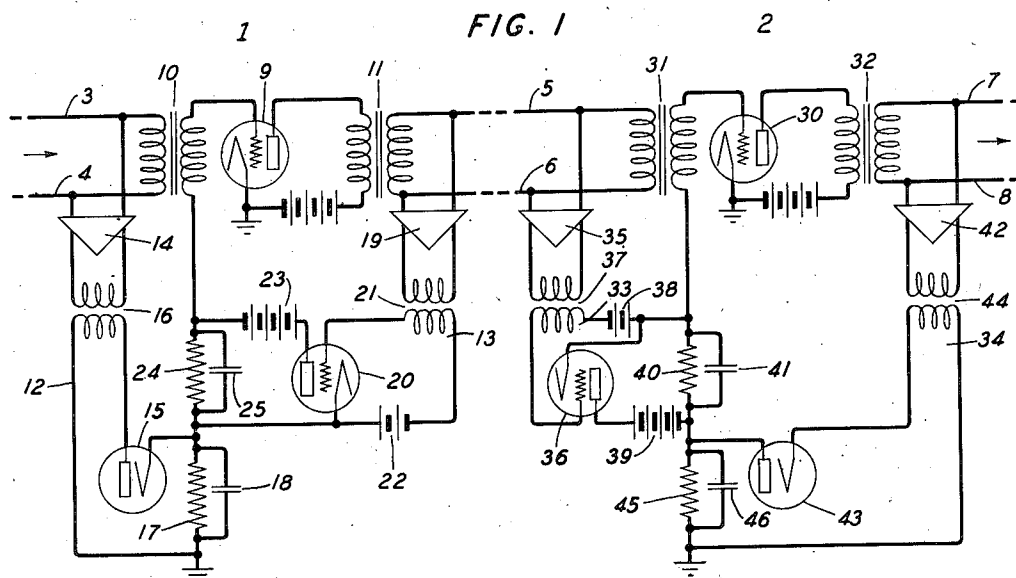


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VOLUME CONTROL CIRCUIT
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VOLUME CONTROL CIRCUIT

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This invention relates to volume control circuits and particularly to volume control circuits for effecting compression and expansion of signal waves.

5 One object of the invention is to provide a variable gain control device with forward-acting and backward-acting circuits that shall govern the gain control device to vary the volume range of signal waves according to a fixed ratio.

10 Another object of the invention is to provide a variable gain control device with a forward-acting circuit having a linear rectifier and a backward-acting circuit having a non-linear rectifier that shall govern the gain control device to compress signal waves according to a fixed ratio.

15 Another object of the invention is to provide a variable gain control device with a forward-acting circuit having a non-linear rectifier and a backward-acting circuit having a linear rectifier that shall govern the gain control device to expand signal waves according to a fixed ratio.

A further object of the invention is to provide volume control circuits with a compressor having a variable gain control device and forward-acting and backward-acting circuits for compressing received signal waves according to a fixed ratio and with an expander connected to the compressor and having a variable gain control device and forward-acting and backward-acting circuits for expanding the signal waves received from the compressor to the original range.

25 In the transmission of speech and in the transmission of radio broadcast programs having a very wide volume range it is often necessary to compress the volume range in order to effect satisfactory transmission without distortion. The signals comprising speech or a radio broadcast program are limited as to the volume range which can be satisfactorily transmitted over a transmission line. Satisfactory transmission of signals has an upper limit to avoid distortion overloading line apparatus such as repeaters and interference with other circuits and has a lower limit by interference from the noises. Similar problems are encountered in recording sound on films or phonograph records.

40 According to the present invention the volume range of the signals comprising speech or broadcasting programs is compressed before transmission or recording and is expanded after transmission or upon reproduction. The compression and expansion of the signals are accomplished according to the envelope of the signal waves.

In one form of the invention the compressor comprises a variable gain space discharge device of the three-element type. It is to be understood, however, that the invention is not limited to this type of space discharge device as other types of discharge devices may be employed if so desired. 5 A forward-acting control circuit comprising a linear rectifier is connected to the input circuit of the variable gain device and a backward-acting control circuit comprising a non-linear rectifier is connected to the output circuit of the variable gain device. A resistance element shunted by a condenser is connected across the output circuit from the linear rectifier. A second resistance element shunted by a condenser is 10 connected across the output circuit of the non-linear rectifier. The two resistance elements across the output circuits of the rectifiers are joined together so that the potential drops across the resistance elements oppose each other. The difference between the potential drops across the two resistance elements is applied to the grid of the variable gain device for so controlling the device as to compress the volume of the signals on the line. The condensers across the resistance elements act as filters and insure that the variable gain device is controlled in accordance with the envelope of the waves supplied to the variable gain device. If so desired, a direct current amplifier may be provided in the connection between 25 the grid of the variable gain device and the resistance element in shunt to the rectifiers.

The linear rectifier is so connected to the grid of the variable gain device as to tend to impress positive voltage on the grid whereas the non-linear rectifier which is shown in the form of a square law detector tends to impress negative voltage on the grid. Thus the linear rectifier tends to increase the gain of the variable gain device whereas the non-linear rectifier tends to decrease the gain. It is apparent that if the rectifiers in the forward-acting and in the backward-acting circuits are respectively linear and square law devices a variable gain control device operates as a device whose output is proportional 45 to the square root of the input thereto. It is apparent that if so desired the detector in the backward-acting circuit may be operated according to the cube law instead of the square law if so desired. In a compressor having a square law detector the output voltage range from the variable gain device measured in decibels is one-half the range of the input voltage applied thereto.

An expander at the receiving end of the transmission line is very similar to the compressor at the transmitting end except that the forward-acting circuit is provided with a non-linear rectifier, the output from which increases with output volume at a more rapid rate than that of a linear device, and the backward-acting circuit is provided with a linear rectifier. In an expander so connected and provided with a non-linear rectifier operating according to the square law, the output from the variable gain device in the expander will have an output range measured in decibels which is twice the input range thereto.

In the compression expansion system above described the bias impressed on the grid of the variable gain device of the compressor may be,

$$B = -g_2(K_0V_0^m - K_1V_1^n) \quad (1)$$

where

V_0 is the output voltage from the variable gain device,

V_1 is the input voltage to the variable gain device,

g_2 is a term proportional to amplification produced by a direct current amplifier between outputs of the rectifiers and the grid of the variable device,

K_0 and K_1 are constants,

m is an exponent having a value according to a characteristic of the backward-acting circuit,

n is an exponent having a value according to a characteristic of the forward-acting circuit,

$K_0V_0^m$ is the output voltage from the rectifier associated with the backward-acting circuit, and

$K_1V_1^n$ is the output voltage from the rectifier associated with the forward-acting circuit. The gain g of the variable gain device may be expressed as a function of the biasing voltage B .

$$g = f(B) \quad (2)$$

or

$$B = F(g) \quad (3)$$

The expression (3) gives the bias of the variable gain device required as a function of the gain g , and may be regarded substantially as a vacuum tube characteristic. This characteristic, of course, depends also upon the load impedance.

Equating the two values of B in Equations (1) and (3) and remembering that

$$V_0 = gV_1 \quad (4)$$

I obtain

$$-\frac{F(g)}{g_2} = (K_0g^mV_1^m - K_1V_1^n) \quad (5)$$

To show what happens when g_2 is made sufficiently large, assume that g_2 is increased until it becomes infinite. In practice, the bias voltage $F(g)$ would be maintained finite, so that the left-hand portion of Equation (5) and therefore the right-hand portion of the equation will approach zero.

Accordingly,

$$g = \left(\frac{K_1}{K_0}\right)^{1/m} V_1^{n-m} \quad (6)$$

Since K_1 , K_0 , n and m are finite, g will remain finite for finite values of V_1 .

If for all values within the required range of g , $F(g)$ is finite, has a positive first derivative with respect to g , and includes within its range the value of g required by the solution, the foregoing solution for g holds and

$$g\alpha V_1^{n/m-1} \text{ and } V_0\alpha V_1^{n/m} \quad (7)$$

If $m=2$ and $n=1$

$g\alpha V_1^{-1/2}$ as required in the compressor

If $m=1$ and $n=2$

$g\alpha V_1$ as required in the expander.

It is apparent that the characteristic of either rectifier may be changed so as to give other values.

If $m=3$ and $n=1$

$g\alpha V_1^{-2/3}$ in the compressor

and if $n=3$ and $m=1$

$g\alpha V_1^2$ in the expander.

In the accompanying drawing:

Fig. 1 is a diagrammatic view of a compression expansion system constructed in accordance with the invention;

Fig. 2 is a diagrammatic view of a compressor similar to the compressor shown in Fig. 1 and provided with a direct current amplifier connected to the grid of the variable gain device.

Referring to Fig. 1 of the drawing a compressor 1 and an expander 2 are shown connected to a transmission line having input conductors 3 and 4 connected to the compressor 1, conductors 5 and 6 between the compressor and expander and output conductors 7 and 8. The signal waves supplied over the conductors 3 and 4 to the compressor 1 are, for example, within the voice frequency range and may be speech or radio broadcasting programs.

The compressor 1 comprises a variable gain space discharge device 9 which may be of the three-element type. It is to be understood, however, that other types of space discharge devices may be employed if so desired. The grid circuit of the variable gain device 9 is connected to the conductors 3 and 4 by means of a transformer 10. The plate circuit of the variable gain device 9 is connected to conductors 5 and 6 by means of a transformer 11. The grid of the device 9 is controlled by means of a forward-acting circuit 12 and a backward-acting circuit 13.

The forward acting circuit 12 comprises an amplifier 14 which is connected across the primary winding of the transformer 10 and a two-element space discharge rectifier 15. The rectifier 15 is connected to the amplifier 14 by means of a transformer 16. A resistance element 17 shunted by condenser 18 is provided in the circuit of the rectifier 15 for supplying potential to control the grid of the variable gain device 9.

The backward acting control circuit 13 comprises a space discharge amplifier 19 connected across the secondary winding of the transformer 11 and a non-linear rectifier 20. The non-linear rectifier 20 is shown in the form of a three-element detector which is operated on its characteristic curve so as to function as a square law detector. The input circuit of the detector 20 is connected to the amplifier 19 by means of a transformer 21. A biasing battery 22 is provided in the input circuit to the non-linear rectifier 20 and the battery 23 is provided in the plate circuit of the detector 20. A resistance element 24 shunted by a condenser 25 is provided in the output circuit of the detector 20.

The resistance element 17 in the circuit of the linear rectifier 15 and the resistance element 24 in the output circuit of the non-linear rectifier 20 are connected oppositely so that the voltage drop across the resistance element 17 opposes the voltage drop across the resistance element 24. The resistance elements 17 and 24 have one end thereof connected to the grid of the variable gain device 9 and the other end thereof grounded as shown in Fig. 1 of the drawing. When the resistance elements are so connected the drop across

the resistance element 24 will tend to impress a negative potential upon the grid of the variable gain device to lower the gain. The drop across the resistance element 17 will tend to impress a positive potential on the grid of the variable gain device to increase the gain. The condensers 18 and 25, respectively connected in shunt of the resistance elements 17 and 24 serve to filter out speech components from the feedback circuits and provide a time constant for controlling the variable gain device 9 in accordance with the envelope of the signal waves.

If the rectifier 15 in the forward acting control circuit is operated as a linear rectifier and the rectifier 20 in the backward acting control circuit is operated as a square law detector, it is apparent in accordance with the Equation (7) given above that the output from the variable gain space discharge device 9 will have a volume range measured in decibels which is one-half the volume range of the signals supplied to the compressor. If the non-linear rectifier 20 is designed to serve as a cube law detector, then the output from the variable gain device 9 measured in decibels will have a range one-third the range of the signals supplied to the variable gain device. It is also apparent that the non-linear rectifier 20 may be varied to obtain an output volume with respect to the input volume which varies according to other fixed ratios.

The expander 2 comprises a variable gain space discharge device 30 having the grid circuit thereof connected to the conductors 5 and 6 by means of a transformer 31 and the plate circuit thereof connected to the output conductors 7 and 8 by means of a transformer 32. Although a three-element space discharge device is employed as the variable gain device, it is to be understood that other types of space discharge devices may be employed, if so desired.

A forward acting control circuit 33 and a backward acting control circuit 34 are provided for governing the potential impressed on the grid of the variable gain device 30. The forward acting control circuit 33 comprises an amplifier 35 and a non-linear rectifier 36. The non-linear rectifier 36 is shown as a three-element space discharge detector operating according to the square law. This rectifier 36 in the forward acting circuit of the expander 2 should be similar in construction and operation to the rectifier 20 employed in the backward acting circuit of the compressor 1. The amplifier 35 has its input circuit connected across the primary winding of the transformer 31. The output circuit of the amplifier 35 is connected by a transformer 36 to the grid circuit of the non-linear rectifier 36. A battery 38 is provided for biasing the grid of the non-linear rectifier 36. A battery 39 is provided in a plate circuit of the non-linear rectifier. A resistance element 40 which is shunted by condenser 41 is provided in the plate circuit of the non-linear rectifier 36.

The backward acting control circuit 34 comprises an amplifier 42 and a linear rectifier 43. The input circuit of the amplifier 42 is connected across the secondary winding of the transformer 32. The output circuit of the amplifier 42 is connected by a transformer 44 to the linear rectifier 43. A resistance element 45 shunted by condenser 46 is connected in the circuit of the rectifier 43. The two resistance elements 45 and 40 are connected together so that the resistance drops across the resistance elements oppose each other. The grid of the variable gain device 30 is connected to one terminal

of the resistance 40 and the free terminal of the resistance 45 is grounded. The resistance elements 45 and 40 are so connected to the grid of the variable gain device 30 that the drop across the resistance element 40 tends to increase the gain whereas the drop across the resistance element 45 tends to reduce the gain. In brief, the resistance element 40 tends to impress a positive potential on the grid of the variable gain device whereas the resistance element 45 tends to impress a negative potential on the grid of the variable gain device. If the forward acting control circuit is provided with a square law detector and the backward acting control circuit has a linear rectifier, then $n=1$ and $m=2$ in Equation (7), as set forth above and the range of output from the variable gain device 30 is double the input and the range of the signals beyond the expander is the same as the range of the signals supplied to the compressor. It is, of course, apparent that the design of rectifiers may be altered so as to have different characteristics from those in the foregoing illustration. Thus in accord with Equation (7), the decibel range of V_0 is n/m times that of V_1 , making it possible to obtain different degrees of compression, and different values of m and n to obtain the same ratio n/m .

Referring to Fig. 2 a compressor similar to the compressor shown in Fig. 1 is provided with a direct current amplifier 50. The compressor shown in Fig. 2 is similar to the compressor shown in Fig. 1 and like parts have been indicated by similar reference characters. A detailed description of the compressor shown in Fig. 2 is deemed unnecessary. The input circuit of the direct current amplifier 50 has the input circuit thereof connected across the resistance elements 17 and 24. The output circuit is connected to the grid of the variable gain device 9.

Modifications in the system and in the arrangement and location of parts may be made within the spirit and scope of the invention and such modifications are intended to be covered by the appended claims.

What is claimed is:

1. In a signal system, a variable gain space discharge device having input and output circuits, a linear rectifier, a non-linear rectifier, the circuits of said device being connected to said rectifiers, and means for controlling said device according to the difference in the voltage outputs of said rectifiers.

2. In combination, a variable gain space discharge device having input and output circuits and a control element, and means comprising a forward acting circuit and a backward acting circuit for governing said control element to vary the output volume of said device with respect to the input volume according to a fixed ratio.

3. In combination, a variable gain space discharge device having input and output circuits and a control element, a two-element linear rectifier and a three-element non-linear rectifier connected to the circuits of said device, and means for governing said control element according to the difference in the voltage output of said rectifiers.

4. In combination, a variable gain space discharge device having input and output circuits and a control element, a linear rectifier connected to the input circuit of said device, a non-linear rectifier connected to the output circuit of said device, and means for governing the control element of said device according to the dif-

ference in voltage outputs of said rectifiers to compress the input volume supplied to said device according to a fixed ratio.

5. In combination, a variable gain space discharge device having input and output circuits and a control element, a two-element space discharge linear rectifier connected to said input circuit, a three element space discharge non-linear rectifier connected to the output circuit of said device, and means for governing said control element according to the difference in voltage outputs of said rectifiers to compress the input volume supplied to said device according to a fixed ratio.

6. In combination, a variable gain space discharge device having input and output circuits and a control element, a linear space discharge rectifier connected to said input circuit, a non-linear space discharge rectifier connected to said output circuit, and means for governing said control element according to the difference in voltage outputs of said rectifiers to compress the volume input to said device one-half when measured in decibels.

7. In combination, a variable gain space discharge device having input and output circuits and a control element, a linear rectifier connected to said output circuit, a non-linear rectifier connected to said input circuit, and means for governing said control element according to the difference in voltage outputs of said rectifiers to expand the volume input supplied to said device according to a fixed ratio.

8. In combination, a variable gain space discharge device having input and output circuits and a control element, a non-linear space discharge rectifier connected to said input circuit, a linear space discharge rectifier connected to said output circuit, and means for governing said control element according to the difference in voltage outputs of said rectifiers to expand the volume input to said device to twice the original volume when measured in decibels.

9. In combination, a variable gain space discharge device having input and output circuits and a control element, a two-element space discharge linear rectifier connected to said output circuit, a three-element space discharge non-linear rectifier connected to said input circuit, and means for governing said control element according to the difference in voltage outputs of said rectifiers to expand the input volume supplied to said device according to a fixed ratio.

10. In combination, a signal transmission line having transmitting and receiving stations,

means at the transmitting station comprising a variable gain space discharge device and forward and backward acting control circuits for controlling said device to compress the volume input to said device according to a fixed ratio, and means at the receiving station comprising a variable gain space discharge device and forward and backward acting control circuits for controlling said second device to expand the volume input to said second device according to a fixed ratio.

11. In combination, a signal transmission line, a transmitting station on said line, a variable gain space discharge device connected in the line at said station and having input and output circuits, a linear rectifier connected to said input circuit, a non-linear rectifier connected to said output circuit, means for controlling said device according to the difference in voltage of said rectifiers to compress the volume at the transmitting station according to a fixed ratio, a receiving station on said line, a variable gain space discharge device connected in the line at the receiving station and having input and output circuits, a non-linear rectifier connected to the input circuit of said second device, a linear rectifier connected to the output circuit of said second device, and means for controlling said second device according to the difference in voltage output of the rectifiers connected to the second device for controlling said second device to expand the volume of the signals at the receiving station according to a fixed ratio.

12. In combination, a signal transmission line, a transmitting station on said line, a variable gain space discharge device on the line at said station having input and output circuits, means comprising a forward acting control circuit having a linear rectifier connected to said input circuit and a backward acting control circuit having a non-linear rectifier connected to said output circuit for controlling said device to compress the volume of the signals at the transmitting station one-half when measured in decibels, a receiving station on said line, a variable gain space discharge device connected to the line at the receiving station having input and output circuits, and means comprising a forward acting control circuit having a non-linear rectifier connected to the second device and a backward acting control circuit having a linear rectifier connected to said second device for controlling the second device to expand the volume of the signal at the receiving station to the original volume at the transmitting station.

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