

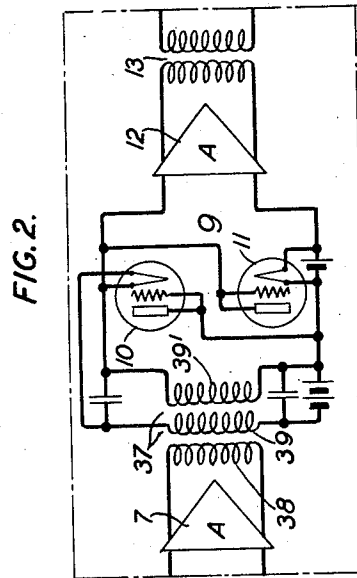
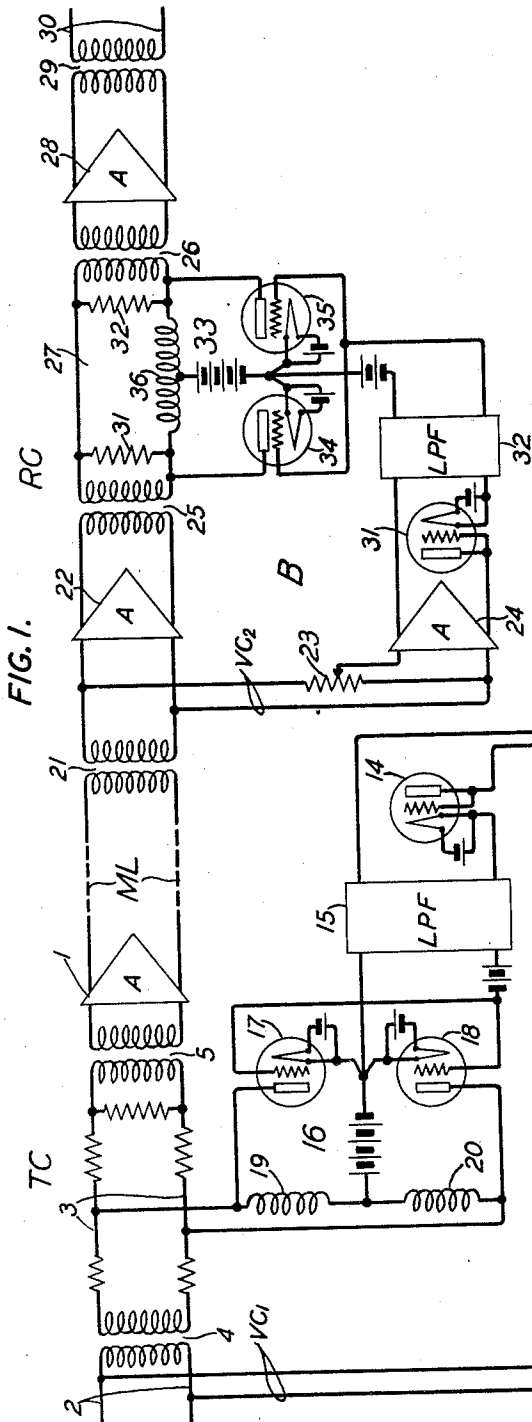
Aug. 15, 1933.

N. C. NORMAN

1,922,602

VOLUME CONTROL CIRCUITS

Filed Jan. 27, 1931



INVENTOR
N. C. NORMAN
BY *H. A. Burgess*
ATTORNEY

UNITED STATES PATENT OFFICE

1,922,602

VOLUME CONTROL CIRCUITS

Nathaniel C. Norman, New York, N. Y., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a Corporation of New York

Application January 27, 1931. Serial No. 511,504

9 Claims. (Cl. 178--44)

This invention relates to signal wave transmission systems and particularly to means for controlling the volume range of the signals transmitted thereover.

5 An object of the invention is to improve the operation of means for automatically controlling transmission in a signal transmission system.

In the transmission of signals representing speech or music having a wide variation in volume, such as is obtained, for example, in connection with the broadcasting of orchestra and public address programs, over telephone lines or radio telephone systems, it is desirable to maintain the power level of the transmitted signals within definite limits. An upper limit for the power level of the program to be transmitted is necessary to prevent overloading of line apparatus, such as vacuum tube repeaters, and to reduce objectionable cross-talk, while a lower limit is necessary so that the noise inherent in the apparatus used or in the line will not be troublesome.

The U. S. Patent 1,757,729, issued May 6, 1930 to R. C. Mathes discloses a system for effectively transmitting signals having a wide range of volumes over a system inherently capable of transmitting only a narrower range of volumes. This is accomplished by introducing at each end of the transmission system in the path of the signals a variable loss which is a function of the signal power level and not of its frequency, so as to compress the volume range of the signals at the input end within the transmission limits of the system by causing the loss introduced thereat to increase as the input level increases, and to correspondingly expand the volume range of the received signals at the output end by a converse operation thereat. According to the specific method disclosed by Mathes, a small portion of the signal energy is diverted from the main signal channel at each end of the system into an auxiliary control circuit and rectified therein. The rectified current, which will have an envelope representing the fluctuations in the power level of the signals at the input to the control circuit, at each end is applied simultaneously to the grids of two vacuum tubes having their plate circuits bridged across the signal channel by a transformer so as to insert a shunting impedance therein. The ratio of input current intensity to the output current intensity for the overall control circuit becomes some function of the input intensity. At the input of the system the control circuit is arranged so that the recti-

fied current applies positive voltages on the grids of the shunt tubes causing the value of the shunt impedance in the main signaling channel at the transmitting station to decrease with increased input and thus to compress the volume range of the signals transmitted to the other end of the system. At the output of the system the control circuit is arranged so that the rectified current applies negative voltages on the grids of the shunt tubes causing the value of the shunt impedance in the receiving signal channel to increase with increased input and thus to expand the volume range of the received signals.

The Mathes patent also discloses the use of a low pass filter in the control circuit at each end of the system to filter out the speech frequency components so that only the envelope of the rectified currents actuates the shunting device.

The circuits of the present invention are in the nature of improvements over the volume control circuits of the Mathes patent described above, the improvements mainly residing in the modification of these circuits to produce a linear relation between the range of signal volumes at the input to the compressor and the range of signal volumes at any point in the system between the compressor and expander regardless of whether the signal intensity at the input to the compressor is high or low, or whether the intensity range being transmitted is large or small.

In view of the desirability of restoring at the output of the system the electrical energy representing the speech or music to its original volume range at the input by means of a device similar in construction to the compressor at the input of the system, a law of compression in accordance with Equation (1) below was selected.

$$Y = \frac{X}{2} + K_1 \quad (1)$$

where X is the input in transmission units above an arbitrary zero level (which in the circuit of the invention was about 0.09 volt), Y is the output in the same transmission units referred to the same zero level, and K₁ is the loss in the same transmission units in the compressor when X is at the arbitrary zero level. The arbitrary zero is the point at which the compressor begins to function in accordance with Equation (1), which holds only when X is positive.

The root mean square output voltage, E_o, the

root mean square input voltage, E_i , and the voltage, E_z , at which the compressor begins to function in accordance with equation (1), are related by the equation:

$$E_0 = k_1(E_z)^{1/2}(E_i)^{1/2} \quad (2)$$

for all values of E_i equal to or greater than E_z which is 0.09 volt. If Equation (1) is written in the form:

$$20 \log \frac{E_0}{E_z} = 20 \log \frac{(E_i)^{1/2}}{(E_z)^{1/2}} + K_1$$

it is seen that Equation (2) is identical with Equation (1) provided

$$K_1 = 20 \log k_1 \quad (3)$$

A compressor having the characteristics given by Equations (1) and (2) is obtained in accordance with the invention by inserting in front of the rectifier in the control branch of a compressor, such as disclosed in the Mathes patent, a vacuum tube device which will produce in its output, voltages proportional at any instant to the square root of the voltages impressed upon its input. The net result of incorporating this device in the control circuit of the compressor is to produce a linear relation between the input and output energy in transmission units for the compressor. This insures that any effect on the output of the system caused by a change in the line equivalent will remain the same for all values of signal intensity at the input.

The loss L in a line having terminating impedances Z_o and a variable shunt impedance Z_s is given by the equation

$$L \text{ (in transmission units)} = 20 \log \frac{Z_s}{Z_s + Z_o} \quad (4)$$

which, if written in form

$$L = 20 \log \frac{1}{1 + \frac{Z_o}{Z_s}}$$

shows that if variation of Z_s is to cause an appreciable variation in loss in the line, Z_o must be larger than the highest value of Z_s . In the compressor circuit of the invention, therefore, the portion of the main signaling channel across which the plate circuits of the control tubes are bridged, is designed to have a higher impedance than the maximum impedance of the plate circuits of the control tubes, so that variations in the plate impedances of the tubes will produce a wide variation in the loss introduced into the signaling channel.

To restore the electrical energy representing speech or music to its original range of intensity variation after it has been compressed in accordance with Equations (1) and (2), it must be sent through a device having a law of expansion in accordance with the following equation:

$$Y = 2X + K_2 \quad (5)$$

where X is the input of the expander in decibels above the same arbitrary zero level (about 0.09 volt); Y is the output of the expander in decibels; and K_2 is the loss in decibels in the expander when X is at the arbitrary zero level. The arbitrary zero level is the input at which the device begins to function as an expander, and for any lower input, it is assumed that it functions as an ordinary repeater and that the output is related to the input by the equation

$$Y' = X' + K_2 \quad (6)$$

where X' is the input in transmission units below the arbitrary zero level, and Y' is the corresponding output in the same transmission units.

The root mean square voltage relation corresponding to Equation (5) is given by the equation

$$E_0 = \frac{k_2(E_i)^2}{E_z} \quad (7)$$

where E_i is the root mean square input voltage above the voltage E_z (which is 0.09 volt) at which the expander begins to function in accordance with Equation (5), and E_0 is the root mean square output voltage. k_2 is related to K_2 by the equation

$$K_2 = 20 \log k_2 \quad (8)$$

The root mean square voltage relation corresponding to Equation (6) is given by the equation

$$E_0 = k'_2 E_i \quad (9)$$

where E_i is the input in volts below E_z and E_0 is the output in volts. K'_2 is related to k'_2 by the equation

$$K'_2 = 20 \log k'_2 \quad (10)$$

An expander obeying the law of expansion expressed by Equations (5) and (7) above is obtained in accordance with the invention by a circuit similar to the compressor circuit of the invention described above except that the vacuum tube "rooter" device is eliminated in the former, the relation between applied voltages to the grids of the control tubes and the input voltages to the control circuit of the expander being necessarily linear because of the previous action by the compressor, and that the plate impedances of the control tubes in the expander are connected in series with instead of in shunt with the main signaling channel as in the compressor. The series connection requires that the portion of the main signaling channel, in which the plate impedances of the control tubes are connected in series, be designed to have a low impedance in comparison with the minimum value of the plate impedance of the control tubes in order that a wide variation in loss in the main signal channel may be obtained with variation in the plate impedances of the control tubes in the expander.

The various features and advantages of the circuits of the invention will be better understood from the following detailed description thereof when read in connection with the accompanying drawing in which:

Fig. 1 illustrates diagrammatically a system for broadcasting electrical energy representing speech and music, and embodying the volume control circuits of the invention; and

Fig. 2 illustrates diagrammatically a modification of a portion of the circuit of Fig. 1.

The transmission system of Fig. 1 comprises a sending station A and a receiving station B connected by a transmission medium ML of limited volume range capacity, such as a telephone cable. The circuits of the sending station A comprise an auxiliary control circuit VC₁ and a main signal transmission circuit TC. The main circuit TC includes the one-way amplifying device 1 having its output connected to the input of the transmission medium ML, and its input connected to the circuit 2 leading to the source of signals to be broadcast, through a section of line 3 of high impedance, which may be a resistance network as indicated, and transformers 4 and 5.

The auxiliary control circuit VC₁ has its input connected across the incoming circuit 2 and the input of the main signal transmission circuit TC so as to divert a portion of the incoming signal energy from the latter. In the circuit VC₁ the input of the one-way amplifying device 7 is connected to the circuit 2 across the potentiometer 6, and the output of the amplifying device 7 feeds into the input of the vacuum tube "rooter" device 9 through the transformer 8. The output of the vacuum tube "rooter" device 9, which comprises the vacuum tubes 10 and 11, is connected to the input of the one-way amplifying device 12, the output of which is fed through the transformer 13 to the input of the linear rectifying device 14. The low pass filter 15 is connected between the output of the rectifying device 14 and the input of the variable impedance element 16 comprising the three-electrode space discharge devices 17 and 18, the grid-filament circuits of which have a portion in common so as to be fed in parallel from the output of filter 15, and the plate-filament circuits of which are connected in push-pull relation. The retardation coils 19 and 20 in the respective plate-filament circuits of tubes 17 and 18, are bridged in series across the high impedance portion 3 of the main signal transmission circuit TC.

At the receiving station B, the output of the transmission medium ML is associated by the repeating coil 21 with the input of the one-way amplifying device 22 in the main receiving signaling path RC, and also across the potentiometer 22 with the input of the one-way amplifying device 24 in the auxiliary control circuit VC₂.

The output of the one-way amplifying device 22 in the circuit RC through transformer 25, the section of line 27, and transformer 26 is connected to the input of the one-way amplifying device 28, the output of which is connected by the output transformer 29 to the outgoing circuit 30.

The output of the one-way amplifying device 24 in the control circuit VC₂ feeds into the input of a linear vacuum tube rectifying device 31, the output of which is connected through the low pass filter 32 symmetrically to the grid-filament circuits of the two three-electrode space discharge devices 34 and 31 forming the variable impedance device 33. The plate-filament circuits of the two three-electrode space discharge devices 34 and 35 are connected in push-pull relation, and, through the coil 36, equal portions of which are contained in the two plate-filament circuits, are connected in series with the secondary winding of transformer 25 and the primary winding of transformer 26 in the portion 27 of the main signal receiving path RC. The portion 27 of the receiving circuit RC by means of resistances of suitable value connected respectively across the secondary winding of transformer 25 and the primary winding of transformer 26, is designed to have an impedance which is low in comparison with all values of the output impedance of the variable impedance device 33.

Any device which will produce in its output voltages proportional to the square root of the alternating current voltages impressed upon its input may be utilized for the device 9 in the control circuit VC₁ at the sending station A. The device illustrated is similar to that employed in the main signaling channel in the volume control circuits illustrated and described in the U. S. Patent No. 1,737,330, issued December 3, 1929 to G. Crisson. It comprises two three-electrode vacuum tubes 10 and 11, each having its plate and grid strapped together so as

to be equivalent to a two-electrode tube, which are connected in parallel with each other across the input of the amplifying device 12 but in series with the secondary winding of the input transformer 8. The connection is such that the input currents of one polarity pass through the tube 10 and the input currents of opposite polarity through the tube 11. The input terminals of the amplifier 12 are connected directly across the points X and Y in this circuit.

The device 9 in the control circuit VC₁ operates as follows: As the voltage at the output of transformer 8 increases with increasing signal current input to the compressor, the impedance between the cathode and anode of the two-element tubes 10 and 11 decreases, causing the loss in transmission units between the output of amplifier 7 and the input to amplifier 12 to increase. When the voltage at the output of transformer 8 decreases, the cathode to anode impedance of the tubes 10 and 11 increases, causing the loss between amplifiers 7 and 12 to decrease. Thus the loss between amplifiers 7 and 12 varies with the signal current input to the compressor, and by proper selection of values of the component parts of the "rooter", it is possible to cause this loss to vary with signal current input to the compressor in such a way that the voltage as measured at the output of amplifier 12 is the square root of the voltage applied to the "rooter" device 9.

The device 14 in the control circuits VC₁ at the sending station A, and the corresponding device 31 in the control circuit VC₂ at the receiving station B may be any suitable device for producing a linear rectification of the voltages impressed upon its input, for example, a three-electrode vacuum tube having its grid and plate strapped together to produce an equivalent two-element tube as illustrated.

The low pass filter 15 in the control circuit VC₁ at the sending station A, and the low pass filter 32 in the control circuit VC₂ at the receiving station B, are provided for the purpose of effectively suppressing from the rectified currents transmitted therethrough any voice frequency components which might result in distortion being produced in the main signal transmission circuit if applied to the grids of the tubes in the variable impedance devices 16 and 33, respectively. Each low pass filter preferably is designed to have a cut-off at about 40 cycles per second. These filters may be designed in accordance with the principles set forth in the U. S. patents to Campbell, Nos. 1,227,113 and 1,227,114, issued May 22, 1917.

The operation of the system of Fig. 1 will now be described. The main portion of the electrical energy corresponding to the speech or music program to be broadcast, received over the circuit 2 is impressed by the transformer 4 upon the main signal transmission circuit TC and is transmitted through the high impedance portion 3 thereof and impressed by the input transformer 5 upon the input circuit of the amplifier 1.

A portion of the electrical energy received over the circuit 2 is diverted into the input of the control circuit VC₁ and impressed by the potentiometer 6 upon the input circuit of the amplifying device 7 therein. The resulting amplified voltages in the output of the amplifying device 7 are impressed by the transformer 8 upon the input circuit of the vacuum tube "rooter" device 9, which, in the manner described above, will cause to be produced in the output circuit of that device alternating current voltages which are

proportional at any instant to the square root of the impressed voltages. These square root voltages will be amplified in the amplifying device 12 and impressed by the transformer 13 upon the linear rectifying device 14. The resulting rectified energy in the output of the device 14 will then be transmitted through the low pass filter 15 which will effectively suppress therefrom the frequency components which are above its cut-off frequency.

The rectified variations in the output of the filter 15, which, because of the previous action of the "roter" device 9, will vary in direct proportion to the square root of the input voltages impressed on the input of the control circuit VC₁ from the incoming circuit 2, are then supplied to the input circuit of the variable impedance device 16 comprising the three-electrode vacuum tubes 17 and 18. The rectified variations are applied to the grid-filament circuits of tubes 17 and 18 in such manner that like rectified control potentials are applied to the grids of the two tubes symmetrically. These rectified control potentials cause like variations in the grid voltages of each tube and consequently equal variations in the plate impedances of the two tubes. As the output circuit of the variable impedance device 16 is coupled by means of the series retard coils 19 and 20 directly across the portion 3 of the main signaling channel TC, a loss corresponding to the sum of the plate impedances of the tubes 17 and 18 in series is thus effectively inserted in shunt to the signaling path TC. The push-pull arrangement of the output circuits of the tubes 17 and 18 provides that, while their impedances are responsive to changes in the control potential applied to their grids, their combined impedance as seen from the main transmission path TC is substantially independent of the magnitude of energy passing over that path.

The poling of the grids of the tubes 17 and 18 with respect to that of the rectifier 14 is selected so that the values of the output impedances of these tubes will decrease with increase in the amplitude of the signals at the input to the signaling channel TC, and, therefore, the loss inserted in the signaling channel TC will increase with increase in the input level and decrease with decrease in input level. As the portion 3 of the main signaling circuit TC across which the plate impedances of the tubes in the variable impedance device 16 are connected is designed to have an impedance which is large in comparison with all values of the impedance of the output of the device 16, a wide variation in the loss inserted in the voice channel is obtained with variation in the plate impedances of the tubes 17 and 18. The value of the output impedance of device 16 varies inversely with the voltage applied to the grids of tubes 17 and 18, which voltage, due to the action of the roter device 9, is substantially proportional to the square root of the input voltage to the control circuit VC₁ (the compressor). Due to the well known grid-voltage plate impedance characteristic of a three-electrode vacuum tube, it is apparent then that the value of the output impedance of the device 16 will be a function of the input voltage to the control circuit VC₁, hence the compressor characteristic may be made such that the volume range in decibels of the signals delivered to the input of the amplifier 1 in path TC, is half the volume range in decibels of the signals received from the circuit 2. It will be evident that by proper

choice of the values of the elements in the variable impedance device 16 and those in the portion 3 of the signaling path TC the loss varying with input level in the signaling path TC may be made such as to compress the volume range of the variations impressed by transformer 4 upon any portion 3 of that channel within any range capable of being transmitted satisfactorily by the transmission system from that point to the receiving station B. The compressed signals will be impressed by the transformer 5 upon the input of the amplifying device 1 and amplified thereby to a desired average level depending upon the length and the transmission characteristics of the line ML. The resulting amplified energy is transmitted over the transmission medium ML to the receiving station B where it will be impressed by the transformer 21 upon the input circuit of the amplifier 22 in the main receiving circuit RC; and upon the input circuit of the amplifying device 24 in the control circuit VC₂ across the potentiometer 23.

The amplified signals in the output of the amplifying device 22 in channel RC are supplied through the transformer 25 to the low impedance section 3 of the receiving circuit RC.

Meanwhile, in the control circuit VC₂ the diverted input energy is amplified by the amplifier 24 and then rectified by the linear rectifying device 31. The rectified currents in the output of the rectifying device 31 pass through the low pass filter 32 which effectively suppresses the frequency components which are above its cut-off frequency. The rectified voltages in the output circuit of the filter 32 are then supplied symmetrically to the grid-filament circuits of tubes 34 and 35 in the variable impedance device 33, and, in the manner described above in connection with the similar device 16 in the control circuit VC₁ at the sending station A, will vary the output impedance of the two tubes 34 and 35, and, therefore, the loss inserted in the signal receiving circuit RC through the output coil 36 in accordance with the power level of the signals at the input of the circuit RC. The poling of the grids of the tubes 34 and 35 with respect to that of the rectifier 31 is made such that the output impedance of the tubes 34 and 35 in series in the portion 27 of the receiving circuit RC will decrease with increase in the amplitude of the signals impressed upon the control circuit VC₂, and, therefore, the loss in the channel RC will increase with decrease in the signal input level and decrease with increase in the signal input level. This will have the effect of expanding the volume range of the signals transmitted over the circuit RC beyond the portion 27 thereof. By proper choice of the values of the elements in the variable impedance device 33 and those in the section of line 3 this expansion may be made such as to restore the signals to their original volume range at the input of the system. The loss introduced in the receiving circuit RC by tubes 34 and 35 of the variable impedance device 33, due to the operation of the compressor at station A, will be such a function of the voltage impressed on the control circuit VC₂ that no "roter" device is required therein to make the expander (control circuit VC₂) restore the signals to the original volume range which they had at the input of the system.

The expanded signals from the line section 27 of the receiving circuit RC are impressed by

transformer 26 upon the input circuit of the amplifying device 28 in which they are amplified to any desired average level. The amplified signaling energy in the output of the amplifying device 28 is impressed by the transformer 29 upon the outgoing circuits 30.

In the compressor portion of the system of Fig. 1 only two ungrounded filament batteries are employed. This is not particularly objectionable from an operation and maintenance standpoint inasmuch as these two batteries are filament heating batteries for the tube 10 in the "rooter" device 9 and for the linear rectifier tube 14 in the control circuit VC₁ at the sending station A, and which may be dry cells. However, the number of ungrounded filament batteries may be reduced to one as indicated in the circuit of Fig. 2 by employing in place of the ordinary input transformer 8 for the "rooter" device 9 a special input transformer 37 having a primary winding 38 and two secondary windings 39 and 39' connected in parallel aiding, and feeding the battery current to the ungrounded filament of tube 10 in series through the two secondary windings. No saturation of the transformer 37 by the filament current of tube 10 can occur, since the direct current from the battery flows in opposite directions in the two secondary windings.

In a practical circuit corresponding to Fig. 1 which has been constructed, in order to make the input to the control circuit of the expander rise to as high a value as the maximum input to the compressor control circuit, when the expander is operated by the output of the compressor, it was found necessary to amplify the compressor output about 24 decibels since the loss in the compressor was about 24 decibels at maximum input. If speech energy whose peak intensities just reach 40 decibels above the arbitrary zero level (0.09 volt) is sent into the compressor and then through a 24 decibel amplifier, the peak intensities at the output of the 24 decibel amplifier will be the same as in the speech energy before compression, but the low intensities of the speech will be brought up with respect to the high intensities in accordance with Equations (1) and (2). That is, the difference between the strong sounds of speech and the weak sounds will be only half as great, in decibels, as before compression, and as a result of the amplification, the weak sounds will be twice as loud with respect to the strong sounds, in decibels, as without compression. The strong sounds are, however, no stronger than they were before compression and therefore will not overload any repeater in a line over which the speech might be sent, unless they would be overloaded by the original speech anyway.

But to a listener at the other end of a line over which speech is sent, the speech sounds appear much louder when compressed and amplified as described above before going over the line than the same speech coming over the line without compression. Since the weak sounds of speech are also the important sounds for articulation, it would be expected that the use of the compressor alone might improve the articulation of a telephone line. Actual tests indicate that considerable improvement in this respect is obtained.

Let it be supposed that there is a definite noise level on a telephone line at 30 decibels below the overloading point of the line repeaters, and speech varying over a range of 40 decibels is to be sent over this line. The weakest sounds of the speech will then be 10 decibels below the noise

level if the strongest sounds are just at the overloading point of the repeaters. But if the speech is compressed by a circuit such as shown at station A in the system of Fig. 1, and is then amplified 24 decibels by amplifier 1 before going over the line, the weakest sounds will be 10 decibels higher than the noise level, and so will no longer be masked by the noise. So the compressor of the invention alone may be used to reduce interference from noise on telephone lines. It may be used in a similar manner in connection with a radio telephone circuit to reduce interference from static; in connection with a circuit for making phonograph records to reduce the surface noise; in connection with talking motion picture reproducing circuits for reducing film noise; and, in fact it may be used in any circuit where interference with speech or music comes from a source such that the compressor can be inserted between the point where the speech or music is changed from sound waves, light waves, or any other form of energy, into electric currents, and the point where the interfering currents enter the circuit.

Recent tests have brought out an important field of usefulness for the expander alone in connection with a long cable circuit, such as between New York and Chicago. It was found that one of the effects of the 3600 mile cable was to introduce a higher loss to high speech levels than to low speech levels, so that the cable acted as a partial compressor, the effect varying slightly with the frequency. When the loss through the cable circuit was plotted as a function of the speech intensity, the shape of the curve indicated that if the expander described in this specification could be made to function according to Equations (6) and (9) over the first 10 decibels as the input increases and in accordance with Equations (5) and (7) as the input further increases, the compressing action of the cable for strong speech currents would be almost fully corrected. The same method might be applied to different lengths of cable to correct other degrees of compression. The regulation of the input of the corrective expander would in all cases be determined by the compressing characteristic of the cable.

As stated above, where high quality transmission is desired, making it desirable to restore the electrical energy representing speech or music to the original volume range, the expander would be used in addition to the compressor. The expander described, however, varies the volume of the interfering noise as well as that of the energy corresponding to the speech or music. If the noise level on a telephone line, for example, were at the arbitrary zero input level of the expander, that is, at the level at which the expander begins to function according to Equations (5) and (7) it would be about 6 decibels (the loss in the expander for maximum input) below the arbitrary zero level as heard by a listener at the output of the expander, when maximum speech is coming over the line. But, if the speech now comes over the line and into the expander at the arbitrary zero level, the loss in the expander increases from 6 to 26 decibels and the noise accordingly drops 20 decibels as heard in the output of the expander. The noise, then, as heard by a listener at the output of the expander, varies with the speech envelope and is always less than the noise received when speech in the same level is received by direct transmission except when the speech intensity is maximum.

Voice operated control devices, for example, echo suppressors, must operate at a low speech level in order to prevent clipping and at the same time must be insensitive enough so that they will not be operated by the noise, static, or other stray currents. When the volume range of the speech is halved, as by compression in a circuit such as shown at the sending station A in Fig. 1, and the weak sounds are then lifted above the noise level by amplification, the sensitivity of the voice operated devices can be correspondingly decreased without "clipping" the speech. This, of course, applies only to voice operated devices connected in the circuits beyond the point where the noise enters.

Only one stage of compression and one stage of expansion have been shown in the system of Fig. 1. However, it is to be understood that in accordance with the invention, this system is not limited to one stage of compression and one stage of expansion, but by adding additional apparatus similar to that shown several stages of compression and expansion may be obtained.

The applications illustrated and described of the invention should be considered as typical and not as limiting the invention, the scope of which is defined in the appended claims.

What is claimed is:

1. In a signal transmission system, a source of alternating current signals, a transmission medium supplied with said signals, a three-electrode space discharge device having a grid circuit and a plate-filament circuit, said plate-filament circuit being connected effectively in shunt with said medium so as to insert an electrical loss therein the value of which is dependent on the value of the impedance of said plate-filament circuit, and which determines the volume range of the signals transmitted over said medium, and means to produce a linear relation between the range of signal volumes in said medium beyond the point of connection of said plate-filament circuit thereto and the range of signal volumes at the input of said medium, said means comprising means for impressing on the grid circuit of said device rectified voltages which are substantially proportional to the square root of the alternating current signal voltages at the input to said medium to control the value of the impedance of the plate-filament circuit of said device.

2. The system of claim 1 and in which the last-mentioned means comprises a control circuit connected to the input of said medium so as to receive a portion of the signals impressed thereon, said control circuit comprising a linear rectifier and a device which will produce in its output voltages substantially proportional to the square root of voltages impressed on its input.

3. In a signal transmission system, a source of alternating current signals comprising a plurality of frequency components, a transmission medium supplied with said signals, a three-electrode space discharge device comprising a grid circuit and a plate-filament circuit, said plate-filament circuit being so connected with said medium as to insert an electrical loss therein the value of which is dependent on the value of the impedance of said plate-filament circuit, a control circuit connected to the input of said medium so as to receive a portion of the signals impressed thereon, and comprising linear signal rectifying means, means for impressing the signal voltages rectified thereby on said grid circuit to control the value of the impedance of the

output circuit of said device, and means for making the rectified voltages impressed on said grid circuit such a function of the signal voltages received by said control circuit as to make the range of signal volumes expressed in decibels in said medium beyond the point of connection of said device thereto substantially half the range of signal volumes expressed in decibels at the input of said medium.

4. The system of claim 3 and in which the last mentioned means comprises means for making the rectified voltages impressed on said grid circuit substantially proportional to the square root of the signal voltages received by said control circuit from said medium.

5. The system of claim 3 and in which the last mentioned means comprises means for making the voltages impressed on said rectifying means substantially proportional to the square root of the alternating current signal voltages impressed on said control circuit, and means for effectively suppressing from the rectified voltages before impressing them on said grid circuit, a portion of said frequency components.

6. In a signal transmission system, a source of alternating current signals comprising frequencies within the speech and music frequency range, a three-electrode space discharge device having a grid circuit and an output circuit, said output circuit being connected effectively in shunt with said medium so as to insert an electrical loss therein dependent on the value of the impedance of said output circuit, a control circuit connected to the input of said medium so as to receive a portion of the signals impressed thereon, and comprising vacuum tube means for producing from the received signals voltages substantially proportional to the square root of the signal voltages, a linear rectifier for rectifying said square root voltages, a low pass filter for effectively suppressing from the rectified voltages certain audio frequency components, and means for impressing the filtered voltages on the grid circuit of said device in such sense as to make the value of the impedance of said output circuit decrease with increase in the amplitude of the signals at the input of said medium.

7. In a signal transmission system, a source of alternating current signals within the speech and music frequency range, a transmission medium upon which said signals are impressed, a pair of three-electrode space discharge devices having grid circuits and plate-filament circuits, said plate-filament circuits being connected in push-pull relation with each other and in bridge with said medium so that an electrical loss, the value of which is dependent on the value of the sum of the impedances of said plate-filament circuits, is effectively inserted in said medium, means for picking off a portion of the signals from the input of said medium and for producing therefrom voltages which are substantially proportional to the square root of the picked-off voltages, means for linearly rectifying said square root voltages, a low pass filter for suppressing from the rectified voltages certain audio frequency components, and means to impress the resulting rectified voltages simultaneously upon the grid circuits of said devices in such sense as to make the value of the impedances of their plate-filament circuits decrease with increase in the amplitude of the impressed rectified voltages.

8. In combination in a signal transmission system, a source of alternating current signals, a transmission circuit supplied with said signals, a

three-electrode space discharge device having a grid circuit and a plate-filament circuit, said plate-filament circuit being connected in shunt with a portion of said transmission circuit so as effectively to insert an electrical loss therein dependent on the value of the impedance of said plate-filament circuit, and means to impress on said grid circuit, rectified voltages substantially proportional to the square root of the alternating current signal voltages supplied to the input of said medium, and in such manner as to make the value of the impedance of the plate-filament circuit of said device decrease with increase in the signal amplitudes at the input of said transmission circuit, said portion of said transmission circuit being designed to have an impedance the value of which is large in comparison with all values of the impedance of the plate-filament circuit of said device.

9. In combination in a signal transmission system, a source of alternating current signals, a long transmission circuit supplied with said signals, a receiving circuit connected to the output of said transmission circuit, a three-electrode space discharge device having a plate-filament circuit and a grid circuit, said plate-filament circuit being connected effectively in series with a portion of said receiving circuit so as to insert an electrical loss in said receiving circuit the value of which is dependent on the impedance of said output circuit, means to pick off from the input of said receiving circuit a portion of the signaling voltages received over said transmission circuit, means to linearly rectify the picked-off voltages, a filtering circuit for suppressing from said rectified voltages certain frequency components, and means for applying the filtered rectified voltages to the grid circuit of said device in such sense as to make the value of the impedance of its plate-filament circuit decrease with an increase in the amplitude of the signals at the input of said receiving circuit, said portion of said receiving circuit being designed to have an impedance which is low compared to all values of the impedance of the plate-filament circuit of said device.

NATHANIEL C. NORMAN.

25	100
30	105
35	110
40	115
45	120
50	125
55	130
60	135
65	140
70	145
75	150