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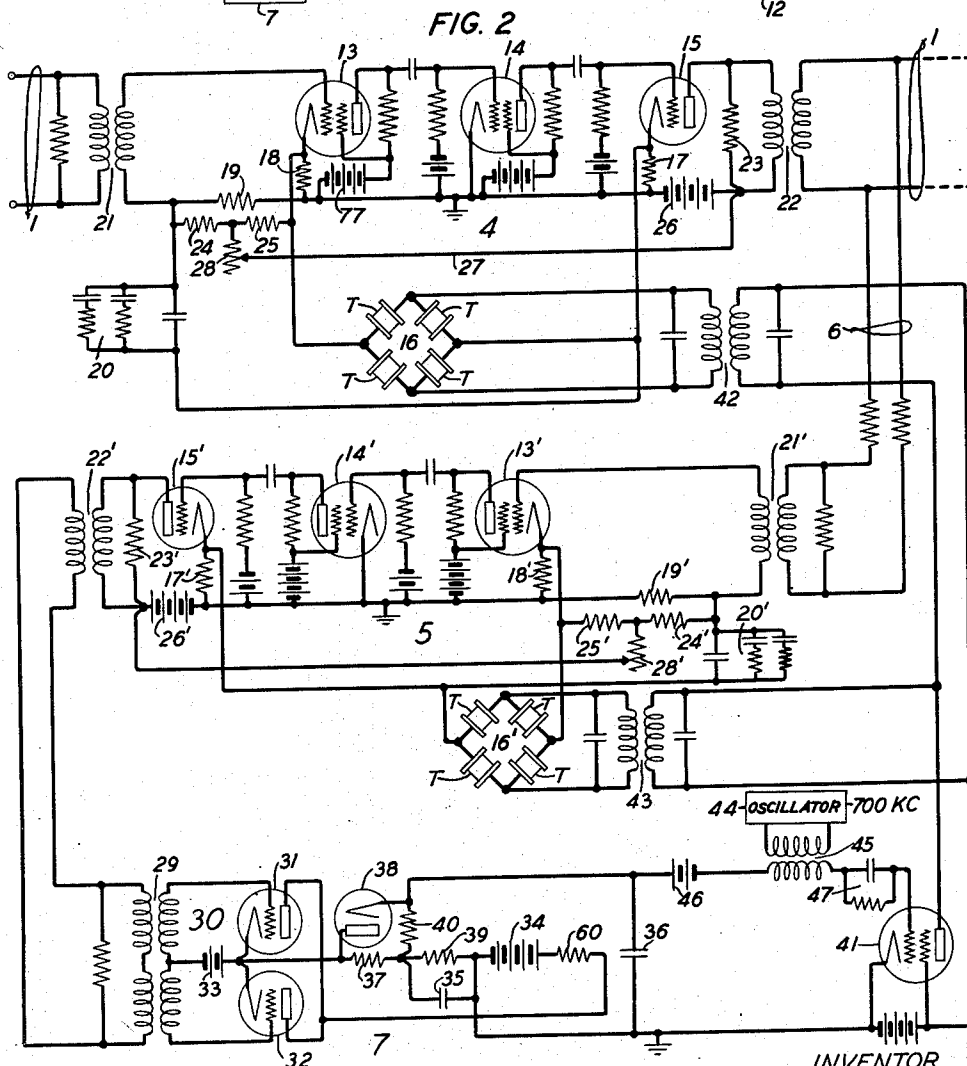
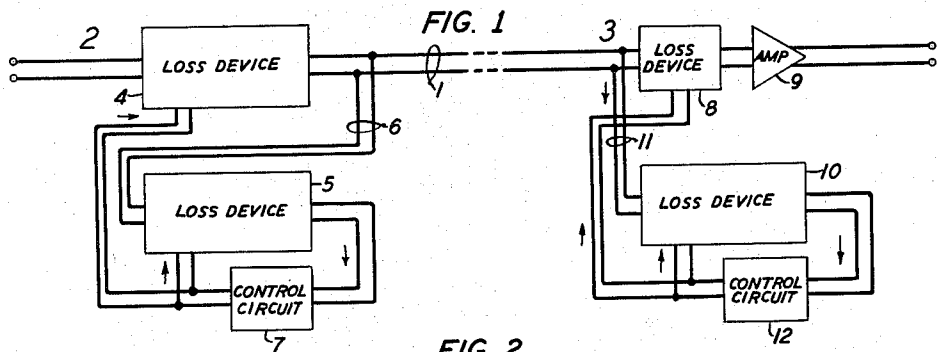
S. DOBA, JR

2,087,316

VOLUME CONTROL SYSTEM

Filed Dec. 11, 1935

2 Sheets-Sheet 1



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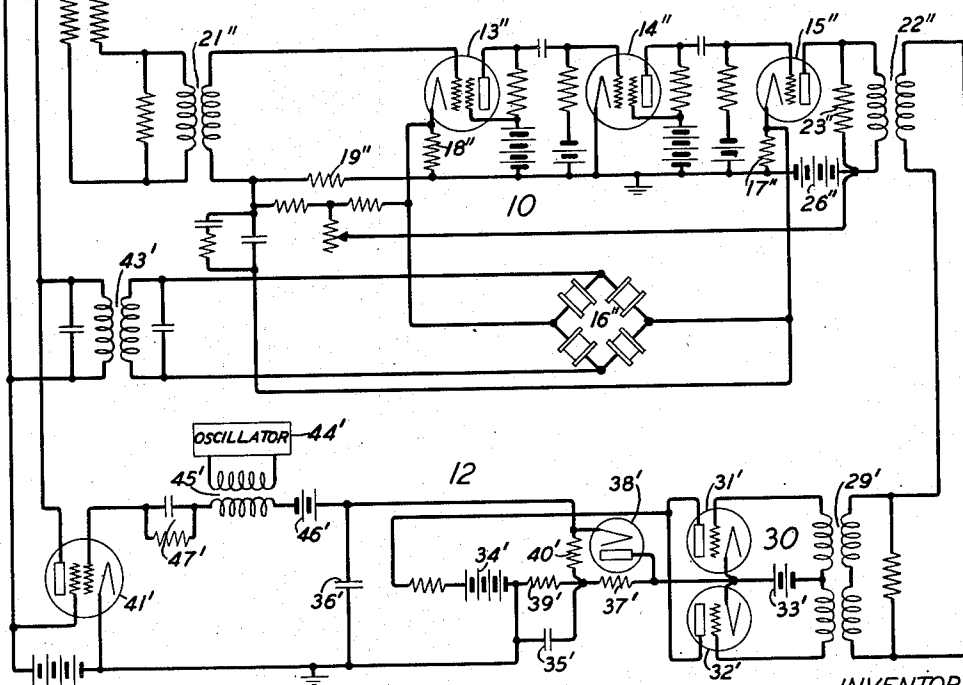
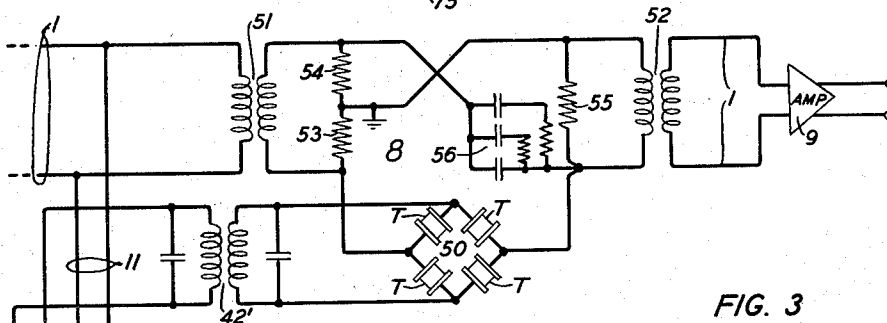
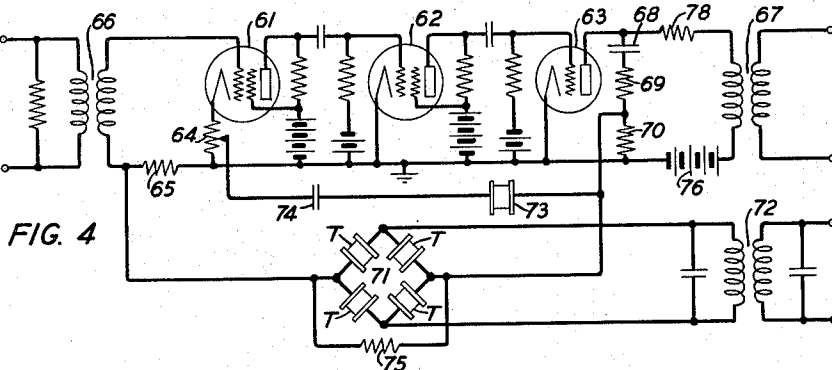
S. DOBA, JR

2,087,316

VOLUME CONTROL SYSTEM

Filed Dec. 11, 1935

2 Sheets-Sheet 2



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2,087,316

VOLUME CONTROL SYSTEM

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Application December 11, 1935, Serial No. 53,944

21 Claims. (Cl. 178-44)

The invention relates to signal transmission systems and particularly to circuits for controlling the volume range of signals in such systems.

An object of the invention is to control the amplitude level of signals in a desired manner at one or more points in a signal transmission system.

Another and a more specific object is to reduce the energy volume range of signals to be transmitted at one point in a signal transmission system and to restore the signals to the original volume range at another point therein.

In signal transmission systems, such as telephone systems, it is often desirable to transmit faithfully signals having an extremely wide range of volumes, such as music, over transmission circuits in which the volume range of currents which can be satisfactorily transmitted, is limited on the one hand by interference of line noises, and the other hand by the necessity of avoiding distortion due to overloading transmission apparatus such as repeaters. In the prior art this has been accomplished by employing amplifying circuits to introduce a variable loss in the path of signals at the transmitting end of a system, which is a function of the signal power level and such as to compress the signal energy volume range within the transmission limits of the signal line, and by employing at the receiving end of the system circuits to introduce a variable loss in the signal line which effectively expands the received signals to their original volume range at the transmitting end of the line.

The copending application of R. W. Cushman and H. E. Hill, Serial No. 672,964, which was issued March 24, 1936 as Patent No. 2,035,263, filed May 26, 1933, discloses circuits of the above-described type in which the impedance elements controlling the variable loss introduced by the amplifying circuits in the line comprise a material having a non-linear voltage current characteristic, such as a composition of silicon carbide crystals and an insulating binder (kaolin), commercially known as "Thyrityte", which is described in the patent to K. B. McEachron, No. 1,822,742, issued September 8, 1931, and are inserted in the input of the amplifiers. The impedances of these non-linear elements are controlled by direct current varying in accordance with the signal power level on the line.

The circuits of the invention are in the nature of improvements over the circuits of the above-mentioned application. They differ essentially from the latter circuits in that the amplifiers are of the feed-back type, and the variable impedance elements having a non-linear voltage-current characteristic, are located in the feed-back paths of the amplifiers and are controlled by high frequency alternating current instead of by direct current. These changes allow a great-

er reduction in noise and transients to be attained, increase the frequency range and volume range of the signals which may be accurately transmitted, and increase the speed of operation of the system.

The objects and advantages of the invention will be clear from the following detailed description thereof when read in connection with the accompanying drawings in which:

Fig. 1 is a diagrammatic view illustrating a signal transmission system employing at the transmitting end a volume range reducer and at the receiving end a volume range restorer embodying the invention;

Fig. 2 is a circuit diagram illustrating in more detail one embodiment of the volume range reducer of the invention which may be used in the system of Fig. 1;

Fig. 3 is a circuit diagram illustrating in more detail one embodiment of the volume range restorer of the invention which may be used in the system of Fig. 1; and

Fig. 4 is a circuit diagram illustrating a shunt type feed-back amplifier which may be substituted for the series type feed-back amplifier in the circuits of the invention shown in Figs. 2 and 3.

In the system of Fig. 1, a signal transmission line 1 of limited volume range capacity, such as a telephone line, has connected to it at a transmitting point a volume range reducer or compressor 2, and at a receiving point a volume range restorer or expander 3.

The volume range reducer 2 at the transmitting end of the line 1 includes a loss device 4, such as a vario-amplifier connected in the line 1 and a similar loss device 5 in a branch circuit 6 connected to the line 1 at a point in the output of the loss device 4. The loss devices 4 and 5 in line 1 and branch circuit 6, respectively, are governed by the control circuit 7 which in turn is controlled from the output of the loss device 5 in such manner as to make the volume input to the branch circuit 6 substantially constant and to reduce the volume range on the transmission line 1 in the output of the range reducer 2 to one-half the signal volume range in the input of the reducer 2.

The volume range restorer 3 at the receiving end of the line 1, comprises the loss device 8 and an amplifier 9 connected in the transmission line 1, a loss device 10, similar to the loss devices 4 and 5 in the reducer at the transmitting end of the system, in a branch circuit 11 connected to the transmission line 1 in front of and adjacent the loss device 8, and a control circuit 12 also connected to the line 1 through the loss device 10 and the branch circuit 11. The loss devices 8 and 10 are governed by the control circuit 12 in such manner as to maintain constant volume

in the branch circuit 11 in the output of the loss device 10, and to restore the signals in the transmission line 1 in the output of the restorer 3 to the original volume range they had at the input to the reducer 2 at the transmitting end of the line 1.

In Fig. 2 of the drawings is shown the circuit details of the range reducer 2 in the system of Fig. 1 in accordance with one embodiment of the invention.

As indicated in Fig. 2, the loss device 4 comprises a vario-amplifier consisting of three amplifying vacuum tubes 13, 14, and 15 coupled in tandem by resistance-capacity couplings, and a series feed-back circuit between tubes 15 and 13. A small (600-ohm) resistance 17 is common to the control grid-cathode circuit and cathode-anode circuit of tube 15, and a small (600-ohm) resistance 18 is common to the control grid-cathode circuit and cathode-anode circuit of tube 13. The control grid-cathode circuit of tube 13 also includes in series between resistance 18 and the secondary winding of the input transformer 21 another resistance 19 having the same value as resistance 18. The series feed-back path for the vario-amplifier is between the resistance 17 and the resistance 18. A bridge circuit 16 having in each of its four arms an element T of a material having a non-linear current-voltage characteristic, such as is disclosed in the aforementioned McEachron patent, is connected in the series feed-back path by connections from the respective cathodes of the tubes 15 and 13 to opposite vertices of the horizontal diagonal of the bridge circuit. The amplifying tubes 13 and 14 are screen grid tubes and the tube 15 is a triode.

The input of line 1 is connected to the first tube 13 of the feed-back vario-amplifier by transformer 21, and the output circuit of the last tube 15 in the feed-back amplifier is coupled to the outgoing portion of line 1 by output transformer 22. The shunt resistance 23 serves as a termination of the transformer 22 since the tube 15 does not do so because of the series type of feed-back employed.

A network 20 comprising a capacity shunted by a plurality of circuits each including a resistance and a capacity in series is connected between the cathode of tube 15 and the grid of tube 13 through the secondary winding of transformer 21. This is for the purpose of feeding back into the input of tube 13 a current which is 180 degrees out of phase with the current fed back through the bridge circuit 16, so as to balance or equalize for the effects of a similar network inherently a part of the elements T in the bridge circuit 16.

Two equal large (10,000-ohm) resistances 25 and 24 are connected in series across resistances 18 and 19 in series in the cathode-control grid circuit of tube 13. The junction point of the resistances 25 and 24 is connected to the positive terminal of plate battery 26 in the plate circuit of tube 15 by the conductor 27 including the variable resistance 28. This resistance arrangement is provided for the purpose of equalizing potential differences between the two resistances 17 and 18 so as to prevent the setting up of a direct current bias across the elements T in the bridge circuit 16. The variable resistance 28 is adjusted until the voltage drop across the vertices of the horizontal diagonal of bridge circuit 16 is zero.

The loss device 5 comprises a vario-amplifier

with a series feed-back circuit, substantially identical with the feed-back amplifier in the loss device 4, as indicated by the use of similar reference characteristics for identifying the various elements of the former, but followed by a prime (') mark. The loss device 5 is connected in tandem with the loss device 4 through the branch circuit 6 which is connected across the line 1 on the output side and adjacent the output transformer 22 in the feed-back amplifier in loss device 4.

The control circuit 7 includes the step-up transformer 29, the terminals of the primary winding of which are connected to the terminals of the secondary winding of the output transformer 22' of the feed-back amplifier in loss device 5. The secondary winding of the step-up transformer 29 is connected to the input of the full-wave detector circuit 30 comprising the two three-electrode detector tubes 31 and 32, the control grid-cathode circuits of which are connected in push-pull relation. The grids of tubes 31 and 32 are negatively biased by the common battery 33 so that the bias is much more than enough to reduce the plate current in the tube to zero. Hence, the detector will act as a marginal device, that is, the plate current thereof will not start flowing until a critical value of input has been exceeded, beyond which the plate current will increase rapidly.

When the input to the detector 30 exceeds the critical operating value, plate current flows from the common plate battery 34 over a circuit which may be traced from the positive terminal of the battery through resistance 60, anode-cathode circuits of tubes 31 and 32 in parallel, and through resistances 37 and 39 in series to the negative terminal of battery 34. The plate current also applies a positive charge to condensers 35 and 36 through resistance 37 and the two-element rectifier tube 38, respectively. The discharge path of condenser 35 is through resistance 39 and the discharge path of condenser 36 is through the resistance 40, and the resistance 39 and condenser 35 in parallel. The condenser 36 is made much smaller than condenser 35, and resistance 40 much larger than resistance 39 (in the same ratio).

Then the discharge of condenser 36 may be expressed approximately by the following equation:

$$E_t = E_{\max} e^{-t/RC} \left(1 + \frac{t}{RC} \right)$$

where

E_t = the instantaneous voltage across condenser 36 as the condensers 35 and 36 discharge.

$E_{\max}$ = the maximum voltage to which condensers 35 and 36 are charged.

e = base of natural logarithm system.

t = time.

RC = the product of the values of condenser 35 and resistance 39,

= the product of the values of condenser 36 and resistance 40.

The function of the two-element rectifier 38 is to enable the rapid charging of condenser 36. That is, when condenser 36 is being charged, the conduction is through the rectifier 38, and when condenser 36 is discharging, the resistance of the rectifier 38 is infinite and conduction is through resistance 40. The purpose of resistance 37 is to

insure the charging of condenser 35 at the same rate and to the same value as condenser 36. It (resistance 37) merely corresponds to the conducting resistance of rectifier 38.

Tube 41 is a high frequency modulator of any suitable type for supplying high frequency (say 700 kilocycles) voltage of controlled amplitude across the vertical diagonal of each of the bridge circuits 16, 16' through the high frequency transformers 42 and 43, respectively. The source of high frequency is the oscillator 44 of conventional type coupled to the input circuit of the modulator tube 41 by a transformer 45.

The condenser 36 in the control circuit 7 is connected across the control grid-cathode circuit of tube 41, so that the charge on condensers 35 and 36 controls the bias on the modulator tube 41. The control grid of the modulator tube 41 is negatively biased by the battery 46, this bias being made great enough so that with no charge on condenser 36, there is no transmission of high frequency to the circuits 16, 16'. The parallel resistance-capacity network 47 in the control grid-cathode circuit of the modulator tube 41 is provided to take care of the condition of a positive bias on condenser 36 greater than the value of the battery 46. This would make the grid of tube 41 conductive and a low impedance, and might stop oscillator 44 from oscillating. If this happens, the whole circuit would be disabled and would not restore itself to a normal working condition. However, the presence of the network 47 insures against this by effectively limiting the current that can flow through the control grid of tube 41. Incidentally, the modulator 41 may comprise two or more tubes in parallel.

The functions of the various elements of the volume range reducer or compressor shown in Fig. 2 will be brought out in more detail in the following complete description of operation.

Let it be supposed that it is desired to transmit over the transmission line 1 signals having a wider range of volumes than can be handled satisfactorily by the line 1, for example, signal waves corresponding to a musical program.

Referring to Fig. 2, the signal waves received in the input of line 1 are impressed by the input transformer 21 on the input of the loss device 4 and are amplified by the amplifying tubes 13, 14, and 15 therein. The amplified waves in the output of tube 15 are impressed by the output transformer 22 on the outgoing portion of the line 1.

Part of the amplified signal energy in the output of the loss device 4 is also picked off by the branch circuit 6, and is amplified by the vario-repeater tubes 13', 14', and 15' in loss device 5. The amplified signal energy in the output of loss device 5 is impressed by input transformer 29 on the input of the control circuit 7. If the impressed energy is sufficient to overcome the normal negative bias on the grids of the tubes 31, 32 in the full-wave detector 30, plate current will flow in the output circuit thereof and will cause a positive biasing charge to be applied to the condensers 35 and 36 through resistance 37 and rectifier 38, respectively. This charge will be proportional in value to the amplitude level of the signal energy applied to the control circuit 7. The condensers 35 and 36 so charged effectively decrease the negative bias on the control grid of the modulator tube 41, causing high frequency current energy of proportional amplitude to be supplied from its output to the non-linear elements T in bridge circuits 16 and 16' through

the high frequency transformers 42 and 43, respectively.

The impedance of the non-linear elements T in the bridge circuits 16, 16' is reduced in direct proportion to the amount of high frequency current flowing through them. As the amount of high frequency current increases with an increase in the positive charge on condenser 36, the amount of negative feed-back through the bridge circuits 16, 16' increases proportionately and therefore the gains of the vario-amplifiers in the loss devices 4 and 5 are simultaneously and equally reduced. This reduction in gain continues until the energy applied to the input of the detector 30 by transformer 29 is lower than the critical value necessary for the operation of the detector tubes 31 and 32. For a steady input, a point of equilibrium is soon reached.

If the level of the signal waves applied to the input of the reducer 2 and thus the level of the waves applied to detector 30 is again increased over the critical operating value of the detector, the positive charge stored in condenser 36 is increased proportionately, reducing the gain of the feed-back amplifiers in loss devices 4 and 5 until the energy level of the waves applied to the detector 30 is again reduced below a critical operating value. The increased input level of the waves in the line 1 applied to the volume range reducer 2, hence, results in an equal decrease in gain in the feed-back amplifiers of loss devices 4 and 5, half of which only is inserted in the line 1, so that the increase in signal level in the transmission line 1 in the output of reducer 2 will be one-half the increase in level of the original signals applied to the input of the reducer 2. If the volume level of the signals applied to the detector 30 is above the marginal operating value and then the signal input level decreases, the positive charge on condensers 35 and 36 will decrease and the amount of high frequency current supplied by tube 41 to the non-linear elements T in bridge circuits 16, 16' will decrease. The resultant increase in impedance of the non-linear elements in the bridge circuits will cause the negative feed-back in the vario-amplifiers in loss devices 4 and 5 to be proportionately decreased and the gain, therefore, of the vario-amplifiers to be increased. However, in this case the combination of resistance 37, resistance 39, condenser 35, resistance 40, the rectifier 38 and condenser 36 in control circuit 7 will introduce a desirable time lag between the decrease in signal input level of the reducer 2 and the resultant increase in gain of the vario-amplifiers in loss devices 4 and 5. A time lag of this sort is desirable since a too rapid variation in gain results in the generation of sum and difference frequencies that would not be part of the original signal. Another effect would be the rapid variation of noise amplitude at the expander at the other end of the line. In certain cases (with high noise) this also would be objectionable. In general it is desirable to make the reduction in gain as quick as possible to reduce overloading on peaks and the increase in gain as slow as possible for the above-mentioned reasons.

Fig. 3 shows in detail the preferred construction of the volume range reducer or expander 3 connected to the output of transmission line 1 in the system of Fig. 1. As indicated in Fig. 3, the loss device 8 and the amplifier 9 of the restorer circuit 3 are connected in tandem in the line 1. The loss device 8 includes a bridge circuit comprising in each arm thereof an element T

having a non-linear voltage current characteristic, as in the bridge circuits 16 and 16' in the range reducer circuit of Fig. 2, and the two tandem-connected transformers 51 and 52 in the line 1. The bridge circuit 50 is connected directly in series with the line 1 between the transformers 51 and 52 by connections from the lower terminal of the secondary winding of transformer 51 and the lower terminal of the primary winding of transformer 52, respectively, to opposite vertices of the horizontal diagonal of the bridge circuit.

Connected in series across the secondary winding of the transformer 51 are the two equal (small) resistances 53 and 54, which correspond respectively to the resistance 18 and the resistance 19 in loss device 4 in the circuit of Fig. 2. The primary winding of the transformer 52 is terminated by the shunting resistance 55, which resistance corresponds to the resistance 17 in the reducer circuit of Fig. 2. The junction point of the two resistances 53 and 54 is connected to ground, and to the upper terminal of the primary winding of transformer 52.

The capacitance-resistance network 56, which has a characteristic equivalent to a network inherent in the non-linear impedance elements T in bridge circuit 50, is connected in series between the upper terminal of the secondary winding of transformer 51 and the lower terminal of the primary winding of transformer 52, and thus across the bridge circuit 50, the resistance 53 and the resistance 54 in series. The network 56 as connected transmits over the line 1 between the transformers 51 and 52 signal waves which are 180 degrees out of phase with those transmitted therebetween through the bridge circuit 50, and thus balances or equalizes for the excess of high frequencies transmitted by network 50.

The input of the loss device 10 is connected across the line 1 in front of and adjacent to the loss device 8 by the branch circuit 11. The loss device 10 comprises a vario-amplifier of the series feed-back type identical with the feed-back vario-amplifiers in the loss devices 4 and 5 in the range reducer shown in Fig. 2, as indicated by the use of the same reference characters for identifying the component parts as used for the corresponding parts in Fig. 2, except that the reference characters in the case of loss device 10 are followed by a double prime (") mark.

The control circuit 12 connected to the output of the loss device 10 is identical with the control circuit 7 in the range reducer circuit 2 shown in Fig. 2, as indicated by the use of the same reference characters identifying the component parts as used in Fig. 2 except that in control circuit 12 the reference characters are followed by a prime (') mark. The control circuit 12 controls the impedances of the non-linear elements T in the bridge circuit 16'' in the feed-back path of the amplifier in loss device 10 and of the non-linear elements T in the bridge circuit 50 in series with the line 1, through the high frequency transformers 43' and 42', respectively, in accordance with changes in the signal volume range in line 1 in the input of the restorer circuit in the manner which will be described.

The operation of the range restorer circuit of Fig. 3 is as follows:

The signal waves received over the transmission line 1 are divided between the input of loss device 8 in line 1 and the input of branch circuit 11. The portion entering loss device 8 passes through transformer 51, the resistance network 53, 54,

bridge circuit 50 and resistance-capacity network 56 and are then impressed by transformer 52 on the input circuit of the amplifier 9 in which they are amplified to the desired degree.

The portion diverted into the branch circuit 11 is transmitted by transformer 21'' and are amplified by the amplifying tubes 13'', 14'', and 15'' in loss device 10. The amplified signals in the output of loss device 10 are impressed by the step-up transformer 29' on the input of the full-wave detector 30' of control circuit 12.

Whenever the volume range of the signals received over the line 1 is such that the energy level of the waves impressed on the detector 30' exceeds the critical operating value of tubes 31', 32' as in the same manner, previously explained in connection with the similar control circuit shown in Fig. 2, the positive bias on the condenser 36' is increased with a resultant increase in high frequency energy supplied through transformers 43' and 42' to the non-linear impedance elements T in the bridge circuits 16'' and 50 in the series feed-back path of the vario-amplifier of loss device 10 and in series with the line 1, respectively. The effective impedance of the bridge circuit 16'' and hence the gain of the vario-amplifier in series in the feed-back path of the vario-amplifier in loss device 10, is decreased. This decrease of gain continues until the level of the energy impressed on the detector 30' falls below the operating value of tubes 31', 32' when these tubes become inoperative and the supply of high frequency energy to the circuits 16'' and 50 is cut off.

The impedance of the non-linear elements T in the bridge circuit 50 is also decreased with the increase in high frequency energy applied thereto, but, because the circuit 50 is connected in series with the line 1, its decreased impedance results in a decrease in loss in the line 1, or an effective increase in gain. This increase in gain is equal to the decrease in gain of the vario-amplifier in loss device 10, and is equal in value to the increase in input to the range restorer 3. Hence, when the restorer 3 of Fig. 3 is used in combination with the range reducer of Fig. 2 in the system of Fig. 1, the volume range of the signals in the output of the restorer 3 at the receiving end of the line 1 will be substantially the same as the volume range of the signals in the input of the reducer 2 at the transmitting end of the line 1.

Also, when the level of the signals impressed on the input of the range restorer of Fig. 3 is above that value which will cause the waves applied to the control circuit 12 to exceed the operating value of detector tubes 31', 32', and then this input level decreases, the reduction in the positive charge on the condenser 36' will reduce the bias on the modulator tube 41' and result in a decrease in the amount of high frequency energy applied therefrom to the bridge circuits 16'' and 50 through the transformers 43' and 42', respectively. The reduction in the current then flowing through the non-linear elements T in these circuits will result in an increase in gain in the vario-amplifier of loss device 10 and an effective decrease in gain in line 1 provided by loss device 8. The decrease in gain produced by loss device 8 is equal to the increase in gain of the vario-amplifier in loss device 10, and equal in value to the decrease in the input level to the range restorer.

Fig. 4 shows a vario-repeater with a shunt feed-back circuit which may be substituted for the series type feed-back vario-amplifier in the loss devices 4 and 5 in the reducer circuit of Fig. 2

and in the loss device 10 in the restorer circuit of Fig. 3.

The vario-amplifier of Fig. 4 comprises the three resistance-capacity coupled amplifier tubes 61, 62, and 63. The input circuit of the first tube 61 in the vario-amplifier comprises between the cathode and the control grid a small resistance (potentiometer) 64, a resistance 65 of equivalent value and the secondary winding of input transformer 66 in series. The output circuit of tube 63 comprises in series between the anode and cathode the resistance 78, the primary winding of output transformer 67, and plate battery 76. Connected directly across the anode and cathode of the last tube 63 of the vario-amplifier is a circuit comprising condenser 68, resistance 69 and resistance 70 in series. Condenser 68 is a blocking condenser and resistances 69 and 70 comprise a potentiometer.

The feed-back path of the amplifier is between resistance 70 and resistance 65, and includes in series the bridge circuit 71 comprising in each of the four arms thereof an element T having a non-linear voltage current characteristic, similar to the bridge circuits 16, 16' in the circuit of Fig. 2 and the bridge circuits 50 and 16'' in the circuit of Fig. 3. The secondary winding of the high frequency transformer 72 is connected across the vertical diagonal of the bridge circuit 71, and the value of the impedance of the non-linear elements T in the bridge circuit 71 is controlled by the variable-amplitude alternating current supplied across the terminals of the primary winding of that transformer from an associated control circuit (not shown) similar to and operating in similar manner to the control circuits 7 and 12 in Fig. 2 and in Fig. 3, respectively.

To equalize for the non-linear frequency response of the impedance elements in bridge circuit 71, use is made of an element 73 having a non-linear frequency characteristic, similar to that of the elements T in the bridge circuit. The element 73 is connected in series with the condenser 74 in a connection from a point between resistances 69 and 70 in the output circuit of tube 63 and a variable tap on the resistance 64 in the input circuit of tube 61. The proper adjustment to equalize for the non-linear frequency response of the bridge circuit 71 is made by properly adjusting the potentiometer 64. To insure that the transmission between the resistances 70 and 65 through bridge circuit 71 is greater at all times than between resistance 70 and potentiometer resistance 64 through the element 73, the bridge circuit 71 is shunted by the resistance 75. The resistance 78 in the plate circuit of tube 63 is used to provide the terminating resistance for the output transformer 67, since the impedance of the amplifier tends to be a short circuit due to the shunt feed-back.

The vario-amplifier circuit of Fig. 4 is simpler than that of the vario-amplifier circuits in loss devices 4, 5, and 10 shown in Figs. 2 and 3, respectively, due to the elimination of the resistance network means for obtaining a direct current balance in the latter circuits.

The use of the feed-back amplifiers in the volume range reducer and restorer circuits of the invention as described above has an advantage over the similar circuits of the prior art employing ordinary amplifiers from the standpoint of reduction of noise and transients in that the gain of the amplifiers is not constant, but is decreased at the time the transients are introduced in the circuit by the variation in the im-

pedance of the controlling element. The use of the impedance elements having a non-linear voltage characteristic in the feed-back paths of the amplifier has the further advantage that the gain of the amplifier is reduced as the impedance of the non-linear elements is decreased and would be zero at the time the greatest transient is introduced.

A further advantage from the standpoint of the reduction in noise and transients is obtained by the use of a high frequency current instead of direct current as in the prior art circuits to control the impedance of the non-linear elements. If the non-linear elements used are substantially symmetrical in characteristic as would be the case where the material therein is such as disclosed by the McEachron patent referred to, little or no rectification would result from the application of a high frequency control current, and, if the high frequency itself were not passed by the amplifier, there would be no resulting transients.

The noise from the non-linear elements is reduced in much the same manner as are the transients. This noise is a function of current through the non-linear elements, being greatest when the current is at a maximum. However, the gain of the amplifier is at a minimum at this time, and hence the noise output actually decreases as the gain decreases.

Various modifications in the circuits illustrated and described which are within the spirit and scope of the invention will occur to persons skilled in the art. The invention is only to be limited in accordance with the appended claims.

What is claimed is:

1. In combination in a signal wave transmission system, a transmission line, a loss network connected effectively in said line, said network including an element having a non-linear voltage current characteristic, a source of alternating voltage, and means responsive to changes in the amplitude level of the signals in said line to apply to said element a proportional alternating voltage from said source to control the transmission loss to transmitted signals introduced by said network in said line.

2. The system of claim 1, in which said control voltage is a high frequency voltage.

3. In combination in a wave transmission system, a transmission line, a wave translating device having an input circuit and an output circuit, connected in said line, a feed-back path connecting said output circuit to said input circuit, an impedance element having a non-linear voltage current characteristic, in said feed-back path, the value of said impedance element determining the amount of feed-back, and means to apply to said impedance element a control voltage to vary its impedance and thus to control the gain of said translating device.

4. In combination in a wave transmission system, a transmission line, a wave amplifier connected therein, a feed-back circuit connecting the output of said amplifier to its input, said feed-back circuit including an impedance element having a non-linear voltage current characteristic, the value of said impedance element controlling the amount of feed-back and thus the gain of said amplifier in said line, and means to apply to said impedance element a control voltage to control the value of the impedance of said impedance element.

5. In combination in a wave transmission system, a wave amplifier having input and output

- circuits associated with said line, a feed-back circuit connecting said output and input circuits, a variable impedance device in series in said feed-back circuit, the value of the impedance of said device determining the amount of current feed-back and thus the gain of said amplifier, said variable impedance device consisting of impedance elements having a non-linear voltage current characteristic, and control means to apply across said elements an alternating voltage to control the gain of said amplifier.
6. In combination in a signal transmission system, a signal transmission line, an amplifier having a series feed-back circuit, connected in said line, a variable impedance network comprising a plurality of impedance elements in series with said feed-back circuit, each of said impedance elements having a non-linear voltage current characteristic, and means to apply across said impedance elements an alternating voltage the value of which varies in direct proportion to variations in the amplitude level of the signal waves, above a certain minimum level, in said line, to reduce the gain of said amplifier for increases in signal level and to increase the gain for decreases in signal level.
7. The system of claim 6, in which said impedance elements are connected in bridge formation, one diagonal of the bridge being connected in series in said feed-back circuit, and said alternating voltage being applied across the other diagonal of said bridge.
8. In combination in a signal wave transmission system, a transmission line, a wave amplifier having an input and an output circuit, connected in said line, a feed-back circuit of the series type connecting said output circuit and said input circuit, an impedance element connected in series in said feed-back circuit, said impedance element having a non-linear voltage current characteristic, a control circuit connected across said line in the output of said amplifier, and responsive to impressed signal waves above a certain minimum amplitude level to apply across said impedance element a control voltage which increases with increases in the amplitude level of the applied signals and decreases with decreases in their amplitude level, and means in said control circuit for producing a desired time lag in the change in value of the control voltage applied to said impedance element for decreases in signal level.
9. The system of claim 5, in which said feed-back circuit is of the shunt type, and said control means causes the alternating voltage applied across said impedance elements to increase with increase in the amplitude level of the waves in said line and to decrease with decrease in the amplitude level of said waves.
10. In combination in a wave transmission system, a transmission line, a loss network connected between two parts of said line, said network including a solid impedance element having a non-linear voltage current characteristic, in series with said line, means responsive to waves in said line above a certain minimum amplitude level, to apply to said element a control voltage which increases with increases in the amplitude level of the waves in said line and decreases with decreases in their amplitude level, to vary the loss introduced by said network in said line, and a circuit connecting said two parts of said line and including means having an impedance characteristic similar to that inherent in said impedance element, in such manner as to transmit between said two parts of said line waves 180 degrees out of phase with respect to the waves transmitted therebetween through said solid impedance element.
11. In combination in a wave transmission system, a transmission line, a wave amplifier having an input and an output circuit, connected in said line, a feed-back circuit connecting said output and said input circuit and including a series impedance element having a non-linear voltage current characteristic, means to apply a control voltage across said impedance element which, above a certain minimum level, varies in value in direct proportion to variations in the level of the waves in said line, a second feed-back circuit between the output and input circuit of said amplifier, 180 degrees out of phase with respect to the first feed-back circuit, and including impedance elements having a characteristic such as to compensate for the non-uniform frequency characteristic of the first element.
12. A system for compressing the volume range of signal waves transmitted over a signal transmission line, comprising a wave amplifier having a series feed-back circuit, connected at a transmitting point in said line, said feed-back circuit including in series at least one impedance element having a non-linear voltage current characteristic, a second wave amplifier substantially identical with the first amplifier, having its input connected across said line in the output of said first amplifier, a control circuit connected to the output of the second amplifier and responsive to variations in the amplitude level of the signal waves in the output thereof, if above a certain minimum level, to apply control voltages across the series non-linear impedance elements in the feed-back circuits of the two amplifiers which increase in direct proportion to the increases in signal level and decrease in direct proportion to decreases in the signal level, and means associated with said first amplifier for compensating for non-linear frequency effects introduced therein by the non-linear impedance elements in its feed-back circuit.
13. The system of claim 12 and in which the control voltages applied across the impedance elements in the feed-back paths of said amplifiers are alternating voltages.
14. The system of claim 12 and in which the last-mentioned means comprises a shunt feed-back circuit including a network simulating in impedance characteristics a network inherent in the non-linear impedance element in the feed-back circuit of said first amplifier.
15. A system for expanding the volume range of signal waves received over a signal transmission line, comprising a loss network connected in said line at a receiving point, said loss network including an impedance element having a non-linear voltage current characteristic, effectively in series with said line, a wave amplifier having a series feed-back circuit, with its input connected across said line in front of and adjacent said loss network, said feed-back circuit including in series a second impedance element having a non-linear voltage current characteristic, a control circuit connected to the output of said wave amplifier and responsive to variations in the volume level of the signal currents in the output thereof, above a certain minimum level, to apply control voltages across the non-linear impedance elements in series with said line and in the feed-back circuit of said amplifier, respectively, which increase proportionately with increases in the signal level and decrease proportionately with decreases in signal level, and means for compensating for the

non-uniform frequency response of the non-linear impedance element in series with said line.

16. The system of claim 15, in which said control voltages are alternating voltages.

5 17. The system of claim 15, in which said compensating means comprises a circuit for transmitting over said line signal currents which are 180 degrees out of phase with the signal currents transmitted thereover through the non-linear
10 impedance element in series with said line.

18. The system of claim 11, in which said control circuit comprises a marginally operated wave rectifier, a network connected across the output of said rectifier comprising a shunt resistance
15 followed by two shunt condensers, a two-element rectifier shunted by a second resistance connected between the two condensers, and in series with the output of the first rectifier, so that when the first rectifier operates, one of said condensers is
20 charged by its output current through said second resistance, and the other condenser is quickly charged through said two-element rectifier, and when the output current of the first rectifier ceases, said one condenser discharges through the
25 first resistance and said other condenser discharges through the two resistances and said one condenser, and means responsive to the charge on said second condenser for controlling the amount of control voltage which is applied across
30 the two non-linear impedance elements in the feed-back circuits of the two amplifiers.

19. In combination, a source of control waves of variable amplitude level, a wave rectifier supplied with said waves and operative when their
35 amplitude level exceeds a certain minimum value,

a network connected across the output of said rectifier, said network including a shunt resistance, two shunt condensers and a two-element rectifier shunted by a second resistance connected in series between said two condensers so that
5 when the first rectifier becomes operative one of said condensers is charged by the voltage drop in the first resistance and the other condenser is charged up quickly through said two-element rectifier, and when the first rectifier becomes inopera-
10 tive, said one condenser discharges through said first resistance, and said other condenser discharges through said second resistance as well as through said one condenser and said first resistance, and means for picking off and utilizing
15 the charge on said other condenser.

20. In combination, in a signal wave transmission system, a transmission line over which signal waves are transmitted, a loss network connected effectively in said line, said network including a
20 solid impedance element having a non-linear voltage current characteristic, an alternating current source connected across said element, and means responsive to changes in the amplitude level, above a given level, of the signal waves in
25 said line, to proportionately control the amount of alternating current from said source transmitted through said impedance element, and thus to vary the transmission loss introduced by said network
30 in said line.

21. The system of claim 20, in which said solid impedance element comprises a resistance material including a mass of silicon carbide crystals and a binder holding adjacent crystals in contact.

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