

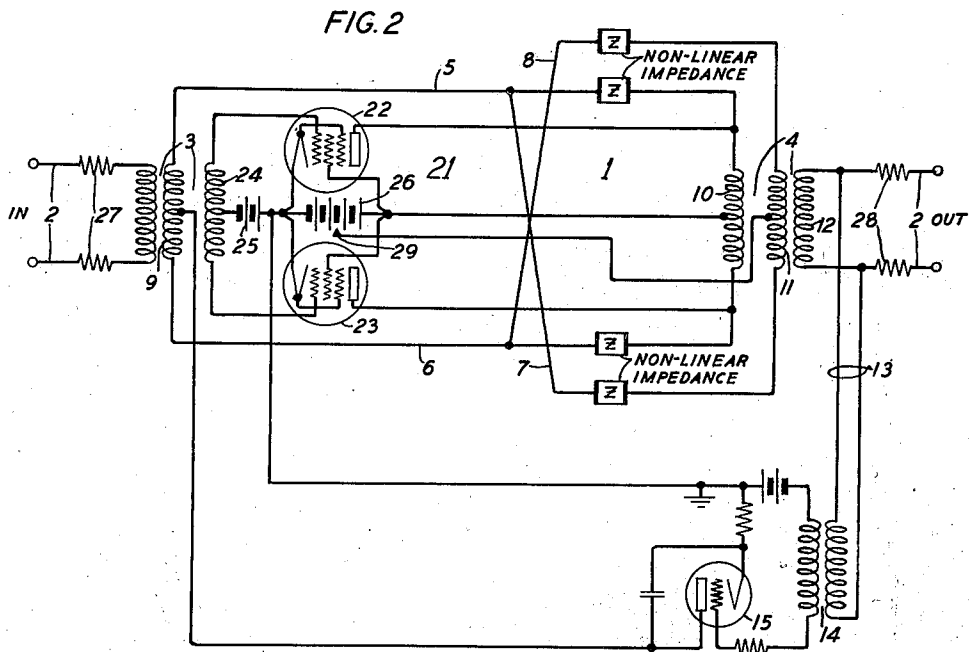
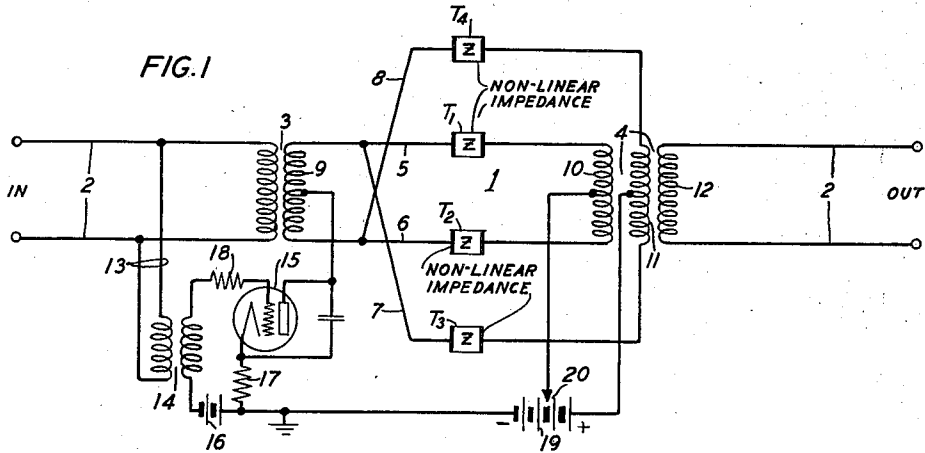
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TRANSMISSION CONTROL CIRCUITS IN WAVE TRANSMISSION SYSTEMS

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TRANSMISSION CONTROL CIRCUITS IN
WAVE TRANSMISSION SYSTEMS

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This invention relates to wave transmission systems and particularly to the control of attenuation in the wave transmission circuits of such systems.

An object of the invention is to vary the transmission loss introduced by an attenuation network in a wave transmission path without changing the characteristic impedance of the network.

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

A related but more specific object is to reduce the energy volume range of transmitted signals in a given ratio at one point in a signal wave transmission system and restore the signals to their original volume range at another point in the system.

These objects are attained in accordance with the invention by use of variable attenuation networks of the lattice type employing impedance elements having a non-linear voltage current characteristic, and by applying varying electromotive forces to these impedance elements in such manner as to produce a desired control of the loss value of the networks and their characteristic impedances.

The non-linear impedance elements preferably consist of a material, commercially known as "Thyrrite", which is a composition of silicon carbide crystals and an insulating binder (kaolin). This material was developed by Mr. K. B. McEachron and is disclosed in his U. S. Patent 1,822,742 issued September 8, 1931.

One embodiment of the invention is a circuit for automatically expanding the volume range of alternating current signals transmitted over a signal transmission line accurately to a given ratio of the signal volume range at the input of the circuit.

This expander circuit comprises a variable loss network or pad connected in the signal line, consisting of four "Thyrrite" elements arranged in lattice form with series and lattice arms respectively connected to separate but equal windings of an output transformer, and a control circuit therefor including a biased detector tube supplied with the signal waves from the line at a point in front of the loss pad.

The control circuit is so adjusted and connected to the elements of the loss pad that at low signal inputs the detector plate current is substantially zero and the plate battery of the detector sends equal currents through all of the thyrrite elements to control their impedance values in accordance with the amount of current

flowing through them. The loss value of the pad is then at maximum value. As the signal input increases, the detector tube becomes conductive and the voltage across and the current in one lattice arm of the pad is increased, while the voltage across and current in the other lattice arm is decreased in the same ratio, with a resultant reduction in the net loss value of the pad proportional to the increase in the amplitude level of the signals in the input of the pad. In effect, then, the circuit including the lattice loss pad and the detector for controlling its loss value provides an accurately controlled expansion of the signals in the line. Because of the reduction in impedance of one lattice arm of the pad and an equal increase in the impedance of the other lattice arm of the pad, while the net loss value of the pad is being varied, the input and output impedances of the pad will be maintained substantially constant.

Another embodiment is a circuit for automatically compressing the volume range of signals transmitted over a signal transmission line in a desired ratio. This compressor uses a "lattice" variable loss network, a pad similar to that used for the expander described above, but in the compressor the loss pad is located in the feedback path of a regenerative amplifier connected in the signal line, and uses a similar biased detector for controlling the impedance values of the non-linear impedance elements, but in the compressor the detector is controlled from the signal line in the output of the amplifier, so as to produce an operation which is the inverse of that of the expander.

The compressor and expander of the invention may be used at the input and output, respectively, of a signal transmission medium of limited transmission volume range, as a compander, for the purpose of transmitting effectively over the transmission medium signals having a wider range of volumes.

Among the advantages of the expander and compressor circuits of the invention are wide volume and frequency ranges, input and output impedances almost independent of gain, and their adaptability for operation as limited volume range devices, that is, as a compressor or expander in which the compression or expansion is obtained over a critical range of inputs outside which the device acts as a linear network or amplifier.

The objects and advantages of the invention will be better understood from the following detailed description thereof when read in con-

section with the accompanying drawing in which:

Fig. 1 shows schematically a volume range expander embodying the invention; and

Fig. 2 shows schematically a volume range compressor embodying the invention.

In the expander circuit of the invention of Fig. 1, the lattice type variable-loss network 1 is connected in the signal transmission line 2 by the input transformer 3 and the output transformer 4. The network 1 comprises two series arms 5, 6 and two lattice arms 7, 8. Each of the arms of the network 1 includes an impedance element having a non-linear voltage current characteristic, these elements being selected to have equal impedance values, the series arm 5 including the non-linear impedance element T_1 , the series arm 6 including the non-linear impedance element T_2 , the lattice arm 7 including the non-linear impedance element T_3 and the lattice arm 8 including the non-linear element T_4 . The elements T_1 , T_2 , T_3 , and T_4 preferably comprise equivalent blocks of the material "Thyrite".

The series arm 5 of the network 1 connects the upper terminal of the secondary winding 9 of input transformer 3 to the upper terminal of the primary winding 10 of output transformer 4, and the series arm 6 of the network connects the lower terminals of the same windings, so that the impedance elements T_1 and T_2 are connected effectively in series with the upper and lower conductors of transmission line 2, respectively. The lattice arm 7 of network 1 connects the upper terminal of secondary winding 9 of input transformer 3 and the lower terminal of a second winding 11 of output transformer 4, and the lattice arm 8 of network 1 connects the lower terminal of the secondary winding 9 of input transformer 3 and the upper terminal of the winding 11 of output transformer 4, so that the impedance elements T_3 and T_4 in lattice arms 7 and 8, respectively, of network 1 are connected effectively in shunt with the transmission line 2. The winding 11 of output transformer 4 is separate from but identical with the winding 10.

The terminals of a third winding 12 of the output transformer 4, inductively coupled to winding 10, are connected to the outgoing portion of the line 2, and the primary winding of input transformer 3 inductively couples the input of the network 1 to the incoming portion of line 2.

Connected across the line 2 at a point in front of the loss network 1 is the input of a control circuit 13 including the input transformer 14 and the three-electrode vacuum tube detector 15 which is normally biased by the biasing battery 16 and the series resistances 17 and 18 in the grid-cathode circuit of the tube so that for low inputs its plate current will be zero, or nearly zero, and plate current will flow for slight increases in the input level of the impressed voltages. The plate of the detector tube 15 is connected to a mid-point of the secondary winding 9 of input transformer 3. The positive terminal of the plate battery 19 is connected to a mid-point on the winding 11 of output transformer 4, and a mid-tap 20 on the plate battery 19 is connected to a mid-point on the winding 10 of the output transformer 4. A condenser is connected across the plate and cathode of the detector tube 15 so as to by-pass the alternating current component of its output current. An amplifier (not shown) may be connected in the

control circuit 13 in front of detector 15 to provide a more sensitive control circuit, if desired.

The circuits of Fig. 1 as just described form a balanced Wheatstone bridge circuit, each series branch 5, 6 of network 1 and each lattice branch 7, 8 thereof being included in one of the four arms of the bridge. The portion of plate battery 19, between the positive terminal thereof and the relatively negative tap 20, is connected across the mid-points of windings 10 and 11, forming one diagonal of the bridge so that current therefrom normally flows in one direction through impedance elements T_1 and T_3 in series and in the opposite direction through impedance elements T_2 and T_4 in series, the two series circuits being in parallel with respect to the polarizing source. The incoming portion of line 2 is coupled by the input transformer 3 across the circuit connecting the junction of lattice arm 7 and series arm 5 of network 1, and the junction of lattice arm 8 and series arm 6 thereof, this circuit forming the other diagonal of the bridge circuit. The outgoing portion of line 2 is connected by the inductively coupled windings 11 and 12 symmetrically to the two lattice arms 7 and 8 of the bridge circuit.

In an alternative arrangement, one of the windings 10 and 11 may be replaced by a retardation coil connected to the other winding through condensers. In either case the circuit connected to the two windings or winding and retardation coil are at the same alternating current potential but at different direct current potentials.

The method of operation of the expander circuit of Fig. 1 is as follows:

When the amplitude level of incoming speech currents in the line 2, a portion of which is diverted into the control circuit 13, is so low as to be insufficient to overcome the normal negative bias on the grid of the detector tube 15, the plate current of that tube will be zero, or nearly so, and equal amounts of direct current are sent through the series impedance elements T_1 , T_2 and the lattice impedance elements T_3 and T_4 of network 1 by the portion of plate battery 19 connected between the mid-points of windings 10 and 11, over two parallel circuits which may be traced as follows:

One circuit may be traced from the positive terminal of battery 19 to the mid-point of winding 11, and then in series through the upper half of winding 11, lattice arm 8 including impedance element T_4 , series arm 6 including impedance element T_2 , lower half of winding 10 to the mid-point thereof, and back to the relatively negative point 20 on battery 19. The other circuit may be traced from the positive terminal of the battery 19 to a mid-point of winding 11, and in series through the lower half of the winding 11, lattice arm 7 including impedance element T_3 , series arm 5 including impedance element T_1 , upper half of winding 10 to the mid-point thereof, and then back to the relatively negative point 20 of battery 19. The loss inserted in line 2 by network 1 for this low signal input condition, will depend upon the balance obtained between the non-linear impedance elements comprising the two arms of the lattice, that is, the arm comprising impedance elements T_1 and T_3 in series, and the arm connected in parallel therewith comprising elements T_2 and T_4 in series, and with ordinary care in selection of the individual impedance elements, losses of the order of 20 to 40 decibels may be readily obtained. For this

low input level condition, the loss inserted by network 1 into the line 2 is a maximum.

Now, let it be assumed that the amplitude level of the signal current incoming over the line 2 increases above the critical operating level of the rectifier tube 15. The tube 15 will then become conductive and plate current will start to flow in its output circuit, and the direct current component thereof will flow from battery 19 through the two lattice arms 7 and 8 of the bridge over a circuit which may be traced as follows: from the positive terminal of plate battery 19 to the mid-point of winding 11, and from that point in parallel through the upper half of winding 11, lattice arm 8 including impedance element T_4 and lower half of winding 9 of input transformer 3, and through the lower half of winding 11, lattice arm 7 including impedance element T_3 , and upper half of winding 9, respectively, to the mid-point of winding 9, plate-cathode impedance of detector tube 15 and resistance 17 back to the negative terminal of battery 19. This current will cause the voltage across and current in one of the lattice arms 7, 8 to be increased while the voltage across and current in the other lattice arm is decreased with a resultant reduction in loss inserted by the loss pad 1 in line 2 in proportion to the increase in detector plate current, which in turn is proportional to the increase in amplitude level of the incoming signals.

This reduction in loss will continue until either the detector tube 15 overloads or until the direct current voltage across one of the lattice arms 7, 8 becomes zero, in which case the loss will be at a minimum, say about 3 decibels. An increased amplitude level of the signals incoming in the line 2 beyond this point can result in no further increase in loss of network 1, and it will then operate merely as a constant loss pad.

The impedance looking into the network 1 from the incoming portion of line 2 or from the outgoing portion thereof, that is, the characteristic impedance of the network, will remain substantially constant as the loss value of the network 1 is varied in the above-described manner due to the opposite variations in the impedances of the two lattice arms effectively in shunt to the line.

The compressor circuit of Fig. 2 differs from the expander circuit of Fig. 1 in the following particulars only;

An amplifier 21 is connected between the incoming and outgoing portions of the line 2 in parallel with the lattice type network 1. The amplifier 21 comprises the two screen grid amplifying tubes 22 and 23 having their control grid-cathode circuits and their cathode-anode circuits, respectively connected in push-pull relation through a third winding 24 on the input transformer 3, inductively coupled to the other two windings thereof, and through the winding 10 of the output transformer 4. A normal negative bias is supplied to the control grids of amplifier tubes 22 and 23 by the common grid biasing battery 25, and plate potential is supplied to the plates of the two tubes by the common plate battery 26.

The input of control circuit 13, including input transformer 14 and the biased detector tube 15, is connected across the outgoing portion of the line 2 instead of across the incoming portion thereof as in the expander circuit of Fig. 1. A portion of the plate battery 26 of the amplifier 21 connected between the mid-points of the windings 10 and

11 of output transformer 4, serves as the polarizing direct current source of electromotive force normally transmitting equal amounts of direct currents through each of the series and lattice impedance arms of the network 1 to determine the loss condition of network 1 for signal input to detector 15 below a certain level, as in the system of Fig. 1, and the other portion of the plate battery 26 between the relatively positive tap 29 thereon and the negative terminal of the battery, serves for the plate current source of the biased detector tube 15.

The series resistances 27 are connected in the incoming portion of line 2 in front of the input transformer 3, and the series resistances 28 are connected in the outgoing portion of the line 2 beyond the point of connection of the input of control circuit 13 thereto, for a purpose which will be brought out later.

In effect, the combination of the amplifier 21 and lattice network 1 constitutes an amplifier of the shunt feedback type, with the variable loss network located in the shunt feedback circuit between the output and input of the amplifier. When the level of the signal wave in the outgoing portion of line 2 in the output of amplifier 21 increases above the critical operating level of the biased detector tube 15, that tube will become conductive and plate current will flow therein from battery 26 through the non-linear impedance elements T_3 and T_4 in lattice arms 7 and 8, respectively, of network 1 in such manner as to make the voltage across and the current in one lattice arm to be increased and the voltage across and the current in the other lattice arm to be decreased, thus reducing the effective loss of the network 1 in proportion to the increase in level of the signal currents in line 2. This action will continue until either the detector tube overloads or until the direct current potential across one of the lattice arms of network 1 becomes zero in which case the loss value of network 1 will be at a minimum, and further increases in input beyond this point can result in no further decrease in loss, the device acting then merely as a constant loss pad.

As the loss pad 1 is in the shunt feedback circuit of the amplifier 21, that is, in parallel thereto, the effect of this loss on the line 2 will be the inverse of that in the case of the expander circuit of Fig. 1, and the gain of the amplifier will be reduced in proportion to the decrease in loss of network 1. Thus, in effect, the signal currents in transmission from the incoming portion of line 2 to the outgoing portion thereof will be compressed in volume range to a range which, as will be shown in the following mathematical analysis, is exactly one-half of the volume range of the signals at the input to the amplifier.

As in the case of the expander circuit of Fig. 1, due to the increase in the impedance of one lattice impedance element of network 1 while the other lattice impedance element thereof is being reduced in impedance by the same amount, the input and output impedances of the compressor circuit of Fig. 2 will be maintained constant for all variations of loss therein. Since the input impedances of the shunt type feedback amplifiers tend to be short circuits, the terminating resistances 27 and 28 in the incoming and outgoing portions of line 1 are inserted for the purpose of preventing short-circuiting of the signal lines.

One advantage in using the lattice-type variable loss network in the circuits of the invention shown in Figs. 1 and 2, over the circuits of the prior art

employing variable loss networks of non-linear impedance elements in other configurations, is that no auxiliary networks are needed for compensating the non-uniform frequency response of the non-linear elements due to inherent shunt reactances. By a well known theorem, in a lattice network when all four arms are shunted by equal impedances, the effect of these impedances will be the same as that of two equal impedances of twice the value shunted, not across the bridge, but across the input and output circuits, respectively. Hence, the balance of the bridge, and also the loss value thereof is dependent on the direct current values of the non-linear elements and independent of their shunt reactances. The effect of the shunting impedances across the input and output circuits is much less serious than it would be across a variable loss controlling resistance used in the ordinary way.

The circuits of the invention employing lattice type variable loss networks, as described above, provide the following additional advantages over the circuits of the prior art used for similar purposes, employing non-linear impedance elements in other configurations: (1) The constant input and output impedance of the networks with variation in loss makes unnecessary the use of auxiliary resistance pads for screening the impedance variations of the loss networks from the input and output, and (2) the relation between the detector current and the ratio of output to input current in the variable loss device is linear providing an accurate 2 to 1 expansion rate or a 1 to 2 compression rate.

The invention is not limited to the particular type of non-linear impedance elements specifically described in connection with the lattice type loss networks, which were given by way of example only. Other types of non-linear impedance elements may be used, for example, copper-oxide rectifying units may be used in each arm of the lattice network to produce substantially the same result.

The factors controlling the constancy of input impedances, the relation between detector output and loss of the lattice networks in the circuits of the invention, as described above, are discussed in the following mathematical analysis.

The voltage-current characteristic of a typical piece of "Thyrite" may be represented by the following expression:

$$I = ae^{bE} \quad (1)$$

where I is the direct current, E the direct potential, and a , b are constants. The approximation to this relation is sufficiently close over the major portion of the characteristic to enable it to be used.

The following notations will be used.

Let

$$I_1 = ae^{bE_1}, \text{ and } I_2 = ae^{bE_2} \quad (2)$$

represent the relation between current and voltage of two "Thyrite" pieces in the two arms of a lattice network.

The reciprocal of the "Thyrite" impedance would be given by:

$$\frac{1}{R} = \frac{dI}{dE} = abe^{bE} \quad (3)$$

Then let

$$\frac{1}{R_1} = abe^{bE_1}, \text{ and } \frac{1}{R_2} = abe^{bE_2} \quad (4)$$

represent the relation between impedance and voltage of the two "Thyrite" pieces.

And let

$$E_1 + E_2 = E = \text{constant} \quad (5)$$

$$E_1 - E_2 = E_0 \quad (6)$$

$$I_1 - I_2 = I_0 \quad (7)$$

where E_0 and I_0 , the difference in voltage and current between the two lattice arms, is that supplied by the detector (detector 15 in the circuits of Figs. 1 and 2).

As is well known, in a lattice network,

$$R = \sqrt{R_1 R_2} \quad (8)$$

where R is the characteristic impedance, and

$$\beta = \frac{1 - \sqrt{\frac{R_1}{R_2}}}{1 + \sqrt{\frac{R_1}{R_2}}} \quad (9)$$

where β is the ratio of output to input current; Then from Equation (4)

$$E_1 = \frac{-\log ab - \log R_1}{b} \quad (10)$$

and

$$E_2 = \frac{-\log ab - \log R_2}{b} \quad (11)$$

and from Equation (5)

$$E = E_1 + E_2 = \frac{-2 \log ab - \log R_1 - \log R_2}{b} \quad (12)$$

$$= \frac{-2 \log ab - \log R_1 R_2}{b} \quad (13)$$

which may be reduced to

$$\log R_1 R_2 = -2 \log ab - bE = \text{constant} \quad (14)$$

Hence

$$R_1 R_2 = \text{constant} = R^2 \quad (15)$$

which is the required condition for a constant impedance lattice structure.

The two necessary conditions for this are:

(1) that the "Thyrite" characteristic be approximately $i = ae^{bE}$, and

(2) that $E_1 + E_2 = E = \text{constant}$.

To determine the relation between β and detector output, the following method may be used: Since, from Equations (4) and (6)

$$\frac{R_1}{R_2} = \frac{ab\epsilon^{bE_2}}{ab\epsilon^{bE_1}} = \epsilon^{b(E_2 - E_1)} = \epsilon^{-bE_0} \quad (16)$$

Then, from Equations (16) and (9) and definition of hyperbolic tangent,

$$\beta = \frac{1 - \epsilon^{-\frac{bE_0}{2}}}{1 + \epsilon^{-\frac{bE_0}{2}}} = \tanh \frac{bE_0}{2} \quad (17)$$

And from Equations (7) and (2)

$$I_0 = I_1 - I_2 = ae^{bE_1} - ae^{bE_2} \quad (18)$$

which from Equations (5) and (6)

$$= a \left[\epsilon^{\frac{b(E+E_0)}{2}} - \epsilon^{\frac{b(E-E_0)}{2}} \right] \quad (19)$$

which reduces to

$$I_0 = a\epsilon^{\frac{bE}{2}} \left[\epsilon^{\frac{bE_0}{2}} - \epsilon^{-\frac{bE_0}{2}} \right] \quad (20)$$

From Equation (20) by definition of hyperbolic

$$\sinh X = \frac{e^X - e^{-X}}{2}$$

$$\frac{I_0}{2a\epsilon^{\frac{bE}{2}}} = \sinh \frac{bE_0}{2} \quad (21)$$

Then using the identity

$$\sinh \mu = \frac{2 \tanh \frac{\mu}{2}}{1 - \tanh^2 \frac{\mu}{2}} \quad (22)$$

From Equations (21), (22), and (17)

$$\frac{I_0}{2ae^{\frac{bE}{2}}} = \frac{2\beta}{1 - \beta^2} \quad (23)$$

and for small values of β ,

$$\beta \doteq \frac{I_0}{4ae^{\frac{bE}{2}}} \quad (24)$$

Also, since $\tanh \mu \doteq \mu$ for small values of μ , from Equation (17)

$$\beta \doteq \frac{bE_0}{4} \quad (25)$$

Hence for a 2:1 compression ratio a linear detector is required, one that is readily obtained in practice.

In any compandor system it is essential that the over-all equivalent of the compressor and expander in tandem remain constant. That this is so in the system described above may readily be shown.

Let β = ratio of output in input current in the "Thyrite" variolossor.

Then the gain of the expander is:

$$G_e = 20 \log \beta$$

As is well known, in a feedback amplifier the effective amplification is:

$$\mu' = \frac{\mu}{1 + \mu\beta} \doteq \frac{1}{\beta} \text{ (if } \mu \text{ is sufficiently high)}$$

where μ is the gain of the amplifier, and β has the same meaning and value as in the expander, the "Thyrite" variolossor, however, being in the feed-back path of the amplifier. Hence, the effective gain of the amplifier is:

$$G_e \doteq -20 \log \beta$$

and

$$G_c + G_e = 0.$$

To obtain a 2:1 compandor, the output voltage of the compressor should be:

$$e_0 = K\sqrt{e_1} = \mu' e_1 \doteq \frac{e_1}{\beta}$$

where e_1 is the input voltage and μ' and β have the meanings given above.

To satisfy this identity, β must vary directly as the output voltage e_0 , which is the input voltage of the detector.

Similarly, in the expander, the output voltage is:

$$e_0 = K_1 e_1^2 = \beta e_1$$

and β should vary directly as e_1 , which is now the detector input voltage.

The relation between β and the detector output voltage and current is linear except for small values of loss. Hence, the linear relation between β and the detector input voltage can be met by a linear detector.

Various modifications of the circuits illustrated and described, which are within the spirit and scope of the invention, will be apparent to persons skilled in the art.

What is claimed is:

1. In combination, an attenuation network comprising series and shunt impedance elements having a non-linear voltage current character-

istic, and means to apply varying electromotive forces across said elements to vary the attenuation value of said network, without changing the characteristic impedance of said network.

2. In combination, an attenuation network of the lattice type employing an impedance element having a non-linear voltage current characteristic, in each of the line and lattice branches, means normally biasing said network in such manner that the alternating current impedances of the several non-linear impedance elements are equal, and means to vary the relative values of the electromotive forces across said impedance elements to vary the attenuation value of said network while maintaining the sum of the electromotive forces across said impedance elements constant.

3. In combination with a transmission line, an attenuation network of the lattice type comprising two arms effectively in series with opposite sides of said line and two lattice arms effectively in shunt therewith, an impedance element having a non-linear voltage current characteristic, in each of the arms of said network, a source of direct current voltage connected across two parallel circuits one comprising one series arm and one lattice arm of said network in series and the other circuit comprising the other series arm and the other lattice arm in series, and means to apply a varying direct current electromotive force across the two lattice arms of said network in parallel to vary the attenuation value of said network, so that as the direct current through one lattice arm increases the current through the other lattice arm decreases, thereby maintaining the input and output impedances of said network constant with change in the attenuation value of said network.

4. In combination in a signal wave transmission system, a transmission line, a loss network of the lattice type connected in said line, having two series arms connected effectively in series with opposite sides of said line and two lattice arms effectively in shunt with said line, each of the arms of said network comprising equivalent impedance elements having non-linear voltage current characteristics, a source of direct current connected across said network in such manner as to normally transmit equal amounts of current through each of said impedance elements, and means to vary the direct current through the impedance elements in the two lattice arms, to control the attenuation introduced by said network in said line, in such manner that as the current in one lattice element increases the current through the other lattice impedance element decreases in the same amount, thereby maintaining the input and output impedances of said network constant as the attenuation value of said network varies.

5. In combination, a line for transmitting alternating current waves, an attenuation network of the lattice type comprising two series arms connected effectively in series with said line and two lattice arms connected effectively in shunt therewith, each of the arms of said network comprising an impedance element having a non-linear voltage current characteristic, the impedance elements being of substantially equal values, a source of polarizing direct current voltage connected in parallel across one series arm and one lattice arm of said network in series, and across the other series arm and the other lattice arm of said network in series, to determine the normal values of the impedance elements in said

network, and means to apply a varying electromotive across the two lattice arms of said network in parallel to vary the loss value of said network in said line while maintaining the input and output impedances of said network substantially constant.

6. In combination, a line for transmitting alternating current waves, an attenuation network of the lattice type, an input transformer including a secondary winding, and an output transformer including two equal and separate primary windings, coupling said network between an incoming and an outgoing portion of said line, said network comprising two series arms connecting the terminals of said secondary winding and of one of said primary windings, and two lattice arms connecting the terminals of said secondary winding and the terminals of the other of said primary windings, each of the arms of said network comprising an equivalent impedance element having a non-linear voltage current characteristic, a source of direct current voltage connecting the mid-points of said two primary windings, to provide equal direct current bias on each of the non-linear impedance elements in said network, and means for applying a varying direct current voltage to said network to vary the attenuation introduced thereby in said line, while maintaining the characteristic impedance of said network constant as the attenuation is varied.

7. The combination of claim 6, in which the last-mentioned means is connected across the mid-point of said secondary winding and the mid-point of said other primary winding.

8. The combination of claim 6, in which the last-mentioned means comprises the output of a biased space discharge detector tube arranged to become conductive in response to increase in the amplitude level of the signal waves in the incoming portion of said line above a given value, to transmit proportional plate current through said lattice arms of said network in such manner that as the net current in one lattice arm increases the net current through the other decreases in equal amount.

9. The combination of claim 6, in which the last means comprises the plate circuit of a biased space discharge detector tube which is operatively responsive to an increase in the amplitude level of the signal waves in said incoming portion of said line above a given value, said plate current being connected across the mid-point of said primary winding and the mid-point of said other secondary winding.

10. A system for expanding the volume range of alternating current signal waves received over a wave transmission line comprising a loss network of the lattice type connected in said line at a receiving point, having two series arms connected effectively in series with said line and two lattice arms connected effectively in shunt therewith, each of said arms including an equivalent

impedance element having a non-linear voltage current characteristic, a source of electromotive force connected across one of said series arms and one of said lattice arms in series, and in parallel therewith across the other series arm and the other lattice arm in series, so as to normally transmit equal amounts of direct current through each of the impedance elements in said arms to set the loss of said network at a desired normal value, a control circuit connected to said line in front of said network and responsive to variations in amplitude level of the signals therein, above a given minimum level, to apply a varying direct current voltage across the two lattice arms in parallel, which increases proportionately with increases in signal level and decreases proportionately with decreases in signal level, to vary the net loss value of said network in said line, and thus effectively to expand the volume range of the signals in transmission therethrough.

11. The system of claim 10 in which said control circuit comprises a biased space discharge detector tube having its discharge path connected across said two lattice arms in parallel.

12. A system for compressing the volume range of signal waves transmitted over a signal transmission line comprising a wave amplifier having a shunt feedback circuit, connected in said line, said feedback circuit including a loss network of the lattice type having two series arms connected effectively in series in said feedback circuit and two lattice arms connected effectively in shunt therewith, each arm of said network including an equivalent impedance element having a non-linear voltage current characteristic, a source of direct current connected across one series arm and one lattice arm of said network in series, and in parallel across the other series arm and the other lattice arm in series, so as normally to transmit equal amounts of biasing direct current through each of said impedance elements, to set the loss of said network at a desired normal value, a control circuit connected to the output of said amplifier and responsive to variation in the amplitude level of the signal waves in the output thereof, if above a certain minimum level, to apply varying direct current control voltage across the two lattice arms of said network in parallel, which increases in direct proportion to the increases in signal level and decreases in direct proportion to decreases in signal level to vary the loss value of said network in said feedback circuit, and thus the gain of said amplifier accordingly, and means for preventing the input and output impedances of said amplifier from short-circuiting the transmitted signals.

13. The system of claim 12, in which the last-mentioned means comprises series terminating resistances of suitable value in said line on the input and output sides of said amplifier.

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