Aug. 12, 1941. R. J. HALSEY 2,252,002

TELEPHONE AND OTHER ELECTRIC WAVE TRANSMISSION SYSTEMS

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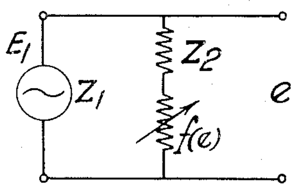

FIG. 1.

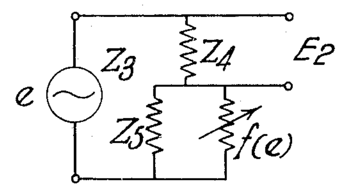

FIG. 2.

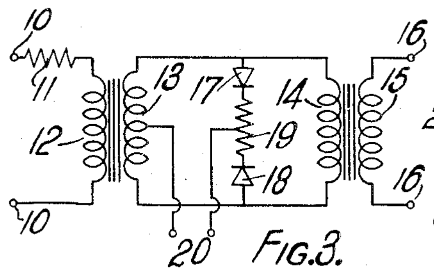

FIG. 3.

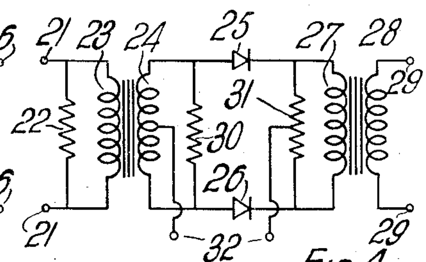

FIG. 4.

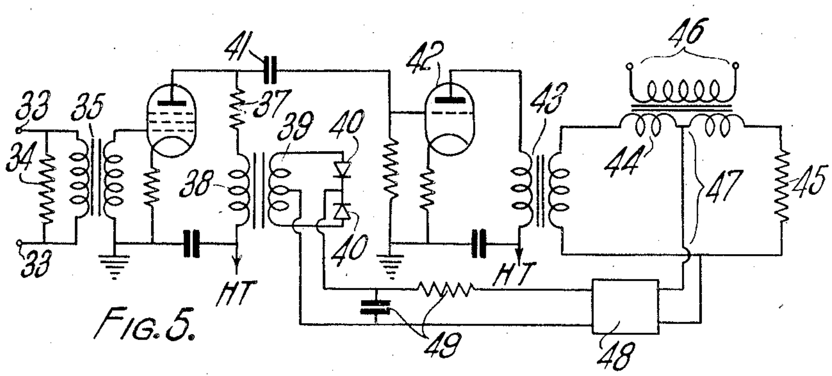

FIG. 5.

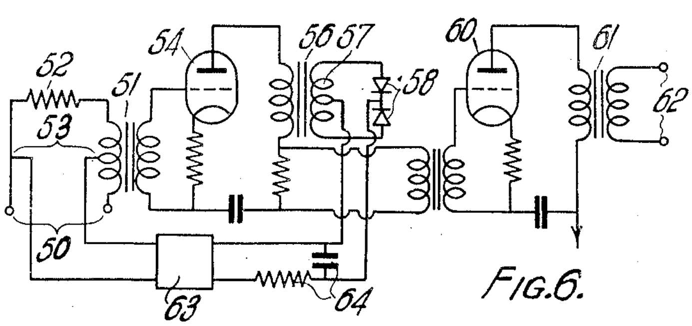

FIG. 6.

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TELEPHONE AND OTHER ELECTRIC WAVE TRANSMISSION SYSTEMS

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5 Claims. (Cl. 178—44)

This invention relates to electric wave systems of the type in which means are incorporated for the purpose of varying the amplification or attenuation at some point as a function of signal amplitude. More particularly the invention is concerned with electric communication systems in which devices of this type are incorporated at two points so that at one point the ratio of maximum to minimum amplitude signals is decreased, whilst at a second point the ratio of signal amplitudes is increased to the original value. The means by which such operation is obtained may be referred to as compressor and expander respectively and the complete equipment has sometimes been termed a "compander." The invention is not limited to electric communication systems, and may be used in any circumstances where it is desired to limit amplitude or amplitude range at some point, for example in gramophone and other sound recording.

In a complete system, in order to ensure faithful reproduction of the applied signal the expander must follow a law inverse to that of the compressor. On two-way communication circuits without singing suppressors this is also very desirable in order that stability shall be ensured at all signal levels.

The most direct method of effecting this operation is to provide a variable attenuation device at the compressor, and to make the corresponding attenuation device at the expander obey a law which is the inverse of the first. Such characteristics, however, are difficult to attain, particularly where non-linear characteristics are concerned.

It is much easier to make use of variable attenuation (or variable impedance) devices which are identical or similar in characteristic and to arrange that the amplification or attenuation at one point is made inversely proportional to the characteristic of the device there incorporated. By "similar characteristics" is to be understood that the characteristics obey similar laws of variation, corresponding impedances being related by a constant factor which need not be unity.

One such system of this type which has been proposed has involved connecting a replica of the compressor unit in the negative feed back path of an amplifier in the expander unit, but this system has certain disadvantages, notably in that in order that the attenuation may be controlled proportionally with change of characteristic of the feed back path the amplifier has to be of high forward gain with a considerable degree of degeneration.

Another, and much simpler, system involves the use of variable attenuation devices in series with and in shunt to the transmission path at the compressor and expander respectively and it is to this form of apparatus that the present invention relates. The principal object of the present invention is to provide a compander system and parts thereof which are improved in certain directions in order to provide apparatus which is suitable for use in the stringent conditions of telephone communication, though the apparatus improved by the present invention is improved in its operation in other apparatus.

According to the present invention there is provided an electric wave transmission device comprising an input circuit and an output circuit and a tranmission path extending between said circuits, a variable impedance device included in series in said transmission path, a finite and constant impedance in shunt to said transmission path, and means for controlling the impedance of said variable impedance as a function of a signal applied to said input circuit.

A further feature of the invention consists of an electric wave transmission device comprising an input circuit, an output circuit and a transmission path extending between said circuits, a variable impedance device having, in the absence of a signal in said input circuit, a high impedance, and a decreasing impedance with increasing signal in said circuit, and a finite constant impedance in shunt to said output circuit.

The invention also comprises an electric wave transmission device comprising an input circuit, and an output circuit and a transmission path extending between said circuits, a variable impedance device included in series in said transmission path, a finite and constant impedance in shunt to said transmission path, and means for controlling the impedance of said variable impedance as a function of a signal applied to said input circuit, said device presenting substantially constant and predetermined impedance when viewed from said input and from said output circuit throughout the range of amplitude of signals applied to said input circuit.

The invention still further comprises an electric wave transmission system including a device comprising an input circuit of impedance Z_1, a variable impedance device connected, in series with a constant impedance Z_2, in shunt to said circuit, a further device connected to said first device and having input circuit of impedance Z_3 an output circuit of impedance Z_4 and a variable impedance device of the same law of variation as said first variable impedance arranged, with an impedance Z_5 in parallel therewith, in series in the transmission path through said second device, and means for controlling said variable impedances in accordance with the amplitude of signals passing through the system, wherein the said impedances are substantially in accordance with the relations:

$$Z_5=Z_1+Z_2$$

$$Z_2=\frac{(Z_3+Z_4)Z_5}{Z_3+Z_4+Z_5}$$

In the accompanying drawing are shown by way of example embodiments of the invention.

Figures 1 and 2 are equivalent diagrams of a compressor and expander, respectively, according to the invention; Figs. 3 and 4 are circuit diagrams of the compressor and expander, respectively; and Figs. 5 and 6 are circuit diagrams of a modified compressor and expander, respectively.

Referring now particularly to Figure 1, a voltage generator having an electromotive force E_1 and an impedance Z_1 is shown as supplying a circuit comprising a constant impedance Z_2 in series with a variable impedance $f(e)$ which is a function of an applied control voltage. This control voltage is dependent upon the magnitude of the output voltage e which, for example, may be applied to a high impedance grid circuit of a valve amplifier, from the output of which is derived both the control voltage and the transmitted signal. In Figure 2, a voltage generator having an impedance Z_3 has an electromotive force e, which is proportional to, and derived from the output voltage of the system shown in Figure 1; for convenience it is assumed equal to this output voltage. The generator supplies a circuit comprising a variable impedance $f(e)$ shunted by a constant impedance Z_5, in series with a constant impedance Z_4, the output voltage E_2 being obtained from the terminals of the impedance Z_4.

Considering these circuits,

$$e=\frac{Z_2+f(e)}{Z_1+Z_2+f(e)}E_1$$

$$E_2=\frac{Z_4}{Z_3+Z_4+\dfrac{Z_5f(e)}{Z_5+f(e)}}e$$

$$\therefore E_2=\frac{[Z_2+f(e)]Z_4}{[Z_1+Z_2+f(e)]\left[Z_3+Z_4+\dfrac{Z_5f(e)}{Z_5+f(e)}\right]}E_1$$

$$=\frac{Z_4[Z_2+f(e)][Z_5+f(e)]}{[Z_1+Z_2+f(e)][(Z_3+Z_4)Z_5+(Z_3+Z_4+Z_5)f(e)]}E_1$$

If the expander is to correct exactly for the distortion produced by the compressor, E_2 must be independent of $f(e)$. There are two solutions to this expression but only one allows of any compressor action; this is when both the following expressions are independent of $f(e)$:

$$\frac{(Z_3+Z_4)Z_5+(Z_3+Z_4+Z_5)f(e)}{Z_2+f(e)} \quad (1)$$

and

$$\frac{Z_1+Z_2+f(e)}{Z_5+f(e)} \quad (2)$$

When this is the case,

$$Z_5=Z_1+Z_2 \quad (3)$$

and

$$Z_2=\frac{(Z_3+Z_4)Z_5}{Z_3+Z_4+Z_5} \quad (4)$$

i. e. (Z_3+Z_4) in parallel with Z_5.

In designing a circuit to comply with these conditions it may be that certain of the impedance values must be given certain values; for example, in designing a "compander" system of this type for use on telephone communication systems Z_1, Z_3 and Z_4 may be determined by line impedances.

In such a case, to ascertain the values of Z_2 and Z_5:

Substituting the value of Z_2 from (3), (4) becomes

$$Z_5-Z_1=\frac{(Z_3+Z_4)Z_5}{Z_3+Z_4+Z_5}$$

whence

$$Z_5^2-Z_1Z_5-Z_1(Z_3+Z_4)=0$$

$$\therefore Z_5=\frac{\sqrt{Z_1^2+4Z_1(Z_3+Z_4)}+Z_1}{2}$$

and

$$Z_2=\frac{\sqrt{Z_1^2+4Z_1(Z_3+Z_4)}-Z_1}{2}$$

If Z_1 is large compared with (Z_3+Z_4), i. e. referred to circuits involving the same value of $f(e)$, as will frequently be the case in the application of this invention

$$Z_2=Z_3+Z_4$$

and

$$Z_5=Z_1+Z_3+Z_4=Z_1+Z_2$$

Thus, for example, if Z_1 is large compared with Z_2 and $f(e)$, and if Z_3 is small compared with Z_4 and $f(e)$

$Z_2=Z_4$ and Z_5 can be omitted.

It will be observed that, although in the theory developed above, the variable impedances are determined by the voltage actually transmitted by the system, i. e. by the output from the compressor and the input to the expander, a similar result may be obtained if the two non-linear networks are controlled by any common or equal voltages. Thus, if the original signal and the final output signal are equal these may be used for derivation of the control voltages at the compressor and expander respectively.

In the foregoing it is assumed that $f(e)$ is reduced as e increases. If $f(e)$ is increased as e increases the so-called compressor becomes an expander and vice versa.

Figures 3 and 4 of the drawing are circuit diagrams of a compressor and expander respectively. In Figure 3, signals applied to input terminals **10** are fed, through a resistance **11**, to the input winding **12** of a transformer of which the secondary winding **13** feeds the winding **14** of a further transformer; the secondary winding **15** of this latter transformer supplies output terminals **16** which are closed by a high impedance such as the grid circuit of a valve amplifier. Shunted across the loop circuit between windings **13, 14**, is a variable impedance composed of two rectifiers **17, 18**, of the metal, dry contact type, in series with a resistance **19**. The impedance of the rectifiers may be controlled by a current supplied to terminals **20** and if this current is made proportional to the output signal, for example by being derived therefrom by rectification, the attenuation produced will vary with the signal amplitude and "volume" compression will result.

Figure 4 indicates the corresponding volume expander. Input terminals **21**, shunted by resistance **22**, are connected to winding **23** of a transformer whose secondary winding **24** is connected through rectifiers **25, 26** to a transformer winding **27**, and this transformer in turn has a secondary winding **28** feeding output terminals **29** which are closed by a high impedance such as the grid circuit of a valve amplifier. The loop circuit between transformer windings **24, 27** includes shunt resistances **30**, **31** and control current is applied to terminals **32**.

In designing the circuits of Figures 3 and 4 to operate on a telephone transmission line where the input in each case is to be a 600 ohm line and the output is to be fed to the input of a valve amplifier the following values may be adopted:

	Ohms
Resistance **11**	600
Resistance **19**	32
Resistance **22**	600
Resistance **30**	200,000
Resistance **31**	20

Turns ratio of windings **12**, **13**	1:13
Turns ratio of windings **14**, **15**	1:6
Turns ratio of windings **23**, **24**	5:1
Turns ratio of windings **27**, **28**	1:130

The rectifiers **17**, **18**, **25**, **26** are of a type giving a total alternating current impedance of approximately 400 ohms when the control current is about 1 mÅ., and rising to about 12,000 ohms at the lowest signal level to be subjected to compression and expansion.

The values given for resistances **19** and **30** are the calculated values: in practice their effect is usually small. It will be understood that these figures are given solely by way of illustration, and may be varied in accordance with circuit requirements.

In general the effect of the series resistance **19** associated with the compressor is to limit the volume range over which the compressor is effective. Thus this resistance will in general be small by comparison with all working values of $f(e)$. In practice, therefore, it may be desirable to omit the resistance from the compressor circuit where this may be done without substantial change of the compression law. Further it may be required to limit the volume range over which compression or expansion occurs and this may be done by suitably increasing the value of the appropriate resistances **19** and **31**.

The compression law commonly required from this type of equipment is a 2:1 law, i. e. for each 2 db. reduction of the input voltage, the output voltage is reduced by 1 db. The circuits shown can be adapted to give approximately such a law over a wide range of input voltages but it will be understood that impedances may be added to the compression and expansion networks shown in order to match this or any other desired law. In particular, in order to obtain a 2:1 law it is frequently necessary to shunt the rectifier networks by resistors and to include non-linear, as well as linear, impedances in series with the control path.

Another possible method of operating a system according to the present invention is to arrange for the impedance of the source at the compressor to be very high with respect to the variable impedance, whilst at the expander the impedance of the generator is very low with respect to the variable impedance; that is, in the equations above $f(e)$ is large with respect to Z_1 and Z_3 is large with respect to Z_5 and $f(e)$. In this arrangement Z_2 becomes equal to Z_4 and Z_5 is omitted.

An example of a system of this type is shown in Figures 5 and 6, which indicate the compressor and expander respectively. The necessity for the generator impedances to be made very high and very low respectively involves the use of valve amplifiers, and this arrangement therefore is not so economical as that described above.

The compressor has input terminals **33** shunted by a suitable impedance **34** when it is desired to operate from a constant impedance supply and feeding through transformer **35**, the grid circuit of a high impedance valve **36**, suitably of the pentode type. This valve may thus be treated as a generator of high internal impedance. The valve, which is supplied with suitable operating potentials in known manner, has an output circuit including a constant impedance **37** and a variable impedance formed by a transformer having windings **38**, **39** and of which the secondary winding **39** is shunted by variable impedances **40**. The voltage developed across the output impedances **37** and **38** of the valve **36** is coupled, through condenser **41** to the input of any suitable amplifying valve such as **42**. The output from valve **42** is fed through transformer **43** to a balanced differential transformer **44** having a suitable balancing impedance **45**. Signals appearing in the windings of transformer **43** from valve **42** are divided, by the differential transformer **44**, with balance **45**, between the load, which is connected across terminals **46** and the control impedance which is connected across terminals **47**, in such a way that circuits **46** and **47** are mutually unaffected, according to known principles. The signals entering terminals **47** are used after rectification in the rectifier **48** to control the impedance of the rectifiers **40**, a smoothing circuit **49** of suitable time constant being included in the circuit. The rectifier **48** may sometimes be preceded by a control amplifier which is not shown.

The corresponding expander circuit is shown in Figure 6, in which input terminals **50** are connected through a balanced differential transformer **51** to the grid circuit of a low impedance valve **54**, suitably a triode. By means of the differential transformer **51** and the balance **52**, the control signal is derived across terminals **53**, without sensibly affecting the main transmission path. The output circuit of the triode includes a fixed resistance **55** and a variable impedance constituted by the primary winding **56** of a transformer of which the secondary winding **57** has rectifier elements **58** connected across it. The output voltage from the valve **54** is obtained from that developed across resistance **55**, and is fed, for example by transformer **59**, to an amplifying valve **60** feeding, by output transformer **61**, output terminals **62**. In order to control the value of the impedances of the rectifiers **58** as a function of the amplitude of the received signal a D. C. control current is obtained by rectifying that part of the input signal which appears across terminals **53** by means of rectifier **63**, and applying the rectified current, after smoothing by filter **64** of suitable time constant, to the rectifiers **58**. As in the case of the compressor, the rectifier **63** may sometimes be preceded by an amplifier which is not shown.

With this embodiment of the invention, in order to approximate as closely as possible to the ideal generator conditions it may be desirable to apply negative feed back to the valves associated with the non-linear networks. It is well known that when negative feed back voltage is derived from a resistance in series with the load and applied to the input, the effective generator impedance rises, thus tending towards the condition of constant load current. Similarly, when the negative feed back voltage is derived from a potentiometer across the load resistance, the effective generator impedance is reduced, thus tending towards the condition of constant load voltage.

It is therefore clear that a suitable generator for the compressor shown in Figure 5 would be a high impedance valve such as the pentode shown with series negative feed back, and for the expander shown in Figure 6 a low impedance valve, such as the triode, with parallel negative feed back.

It will be understood that the circuit arrangements of Figures 3, 4, 5 and 6 are given only as examples of the application of the invention and that compressor networks other than that shown may be employed. Moreover, although in the examples given the control current is obtained by rectification and smoothing of the signal current, it will be understood that the use of an alternating current for control purposes is not excluded.

Furthermore, it may be more suitable with certain types of non-linear networks to take the output voltage from across a resistance in the case of the compressor and across the non-linear network in the case of the expander.

The use of a balanced differential transformer at the output of the compressor and/or at the input of the expander, in order that the control currents may be derived by means of rectifiers without feeding back rectified signals into the main transmission path, is an important feature of the invention.

What I claim and desire to secure by Letters Patents is:

1. An electric wave transmission system including a device comprising an input circuit of impedance Z_1, a variable impedance device included, in series with a constant impedance Z_2, in shunt to said circuit, a further device connected to said first device and having input circuit of impedance Z_3 an output circuit of impedance Z_4 and a variable impedance device of the same law of variation as said first variable impedance arranged, with an impedance Z_5 in parallel therewith, in series in the transmission path through said second device, and means for controlling said variable impedances in accordance with the amplitude of signals passing through the system wherein the said impedances are substantially in accordance with the relations:

$$Z_5 = Z_1 + Z_2$$

$$Z_2 = \frac{(Z_3 + Z_4)Z_5}{Z_3 + Z_4 + Z_5}$$

2. A system according to claim 1, wherein the impedance Z_3 is high compared with the value of the variable impedance associated therewith.

3. A system according to claim 1, wherein said input circuit includes a valve of high internal impedance.

4. A system according to claim 1, wherein the impedance Z_1 of the input circuit is low in comparison with the value of the variable impedance associated therewith.

5. An arrangement according to claim 1, wherein the means for controlling the impedance of the variable attenuation device or devices includes a connection to the transmission path, said connection being made by a balancing transformer or the like whereby the effect of the control current so obtained on the transmission path is reduced.

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