Sept. 12, 1944. H. L. BARNEY 2,358,045

NOISE REDUCTION IN SIGNAL TRANSMISSION SYSTEM

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FIG. 1

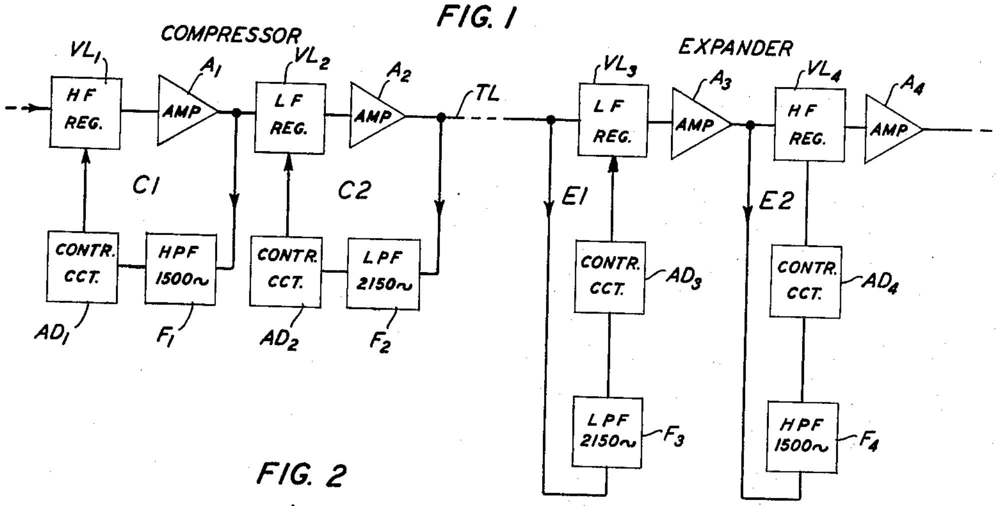
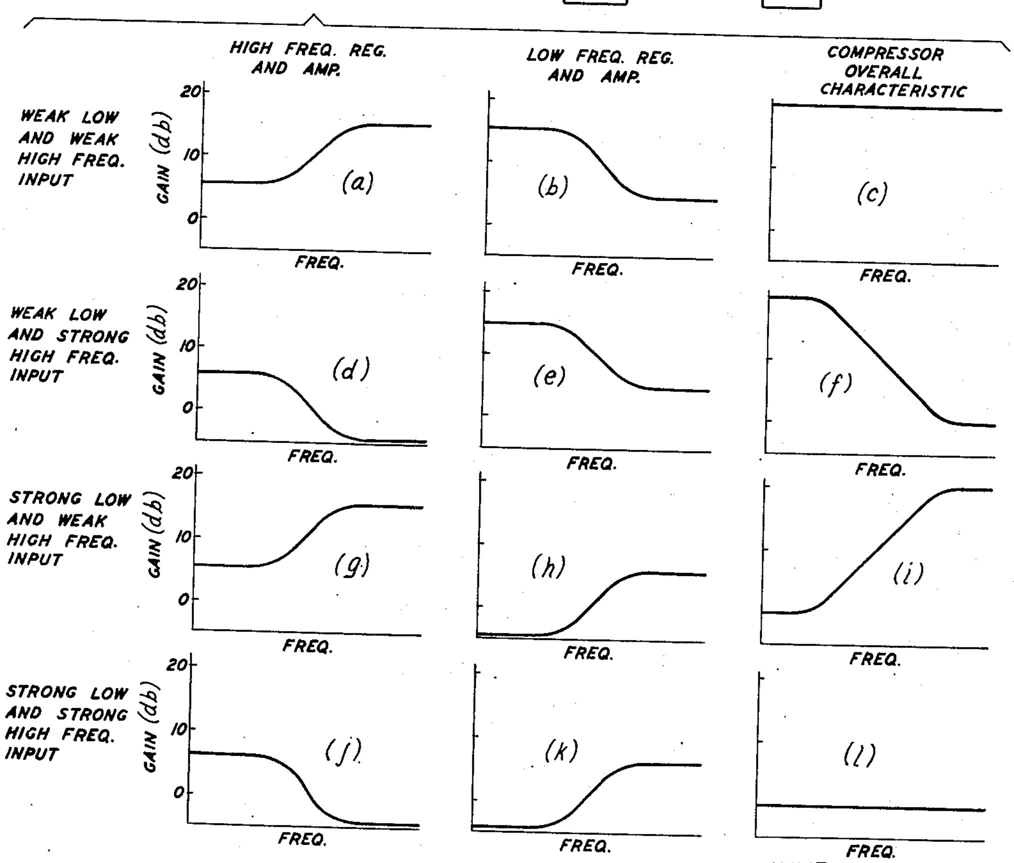


FIG. 2



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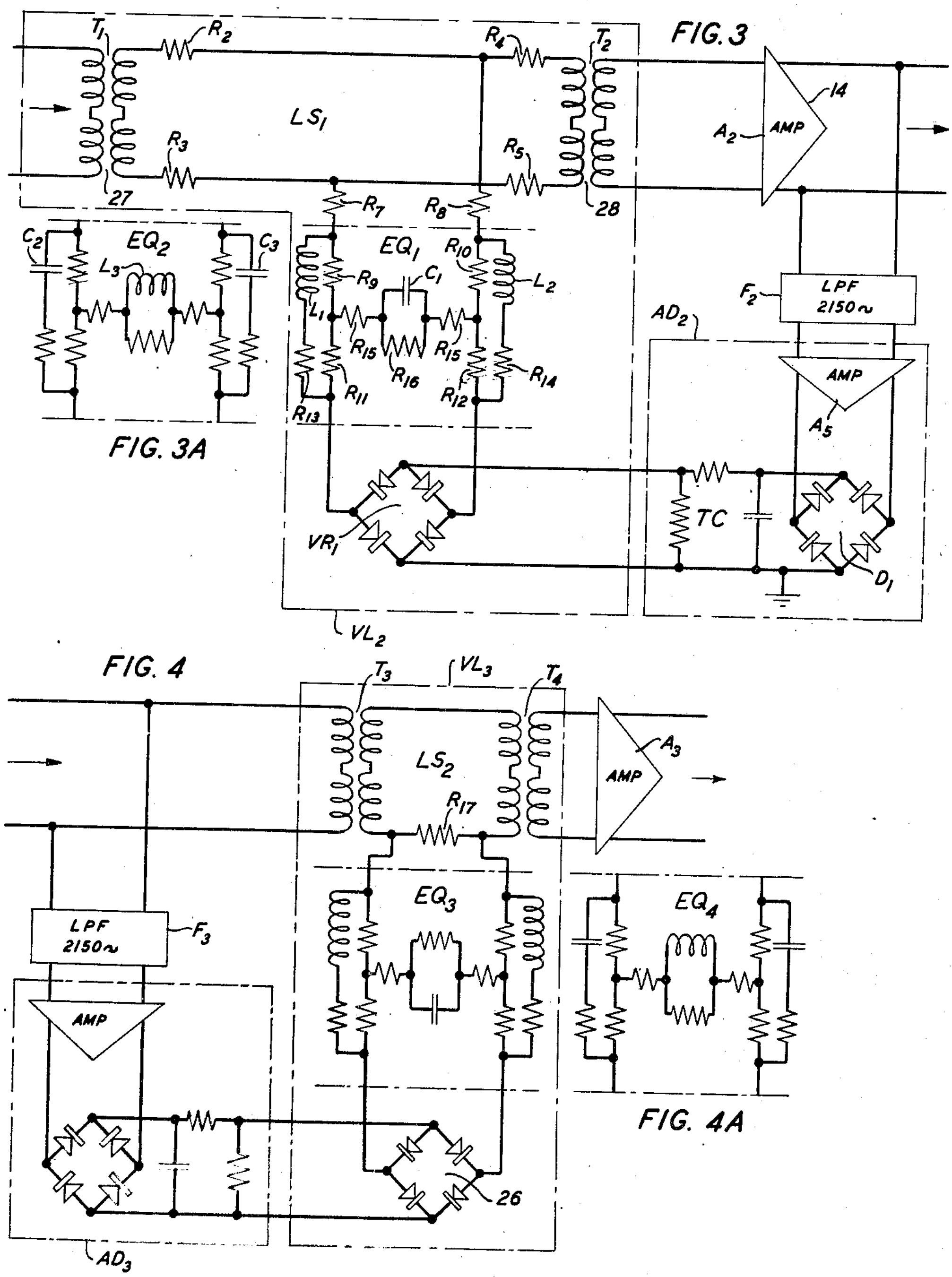

FIG. 3

FIG. 3A

FIG. 4

FIG. 4A

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FIG. 5

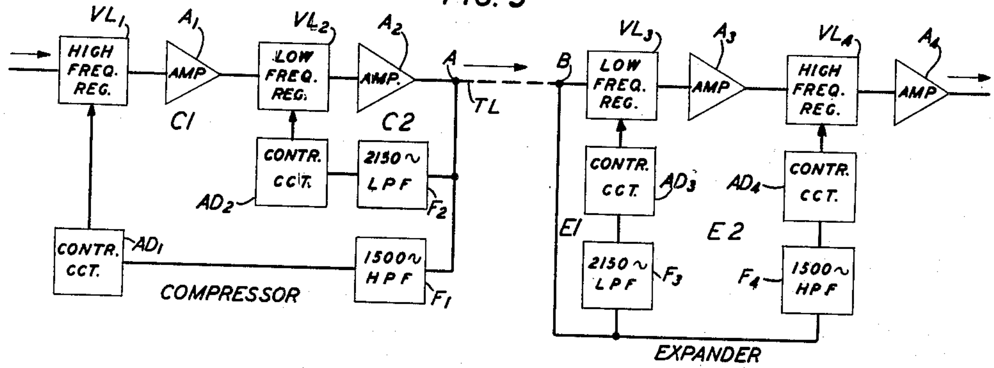
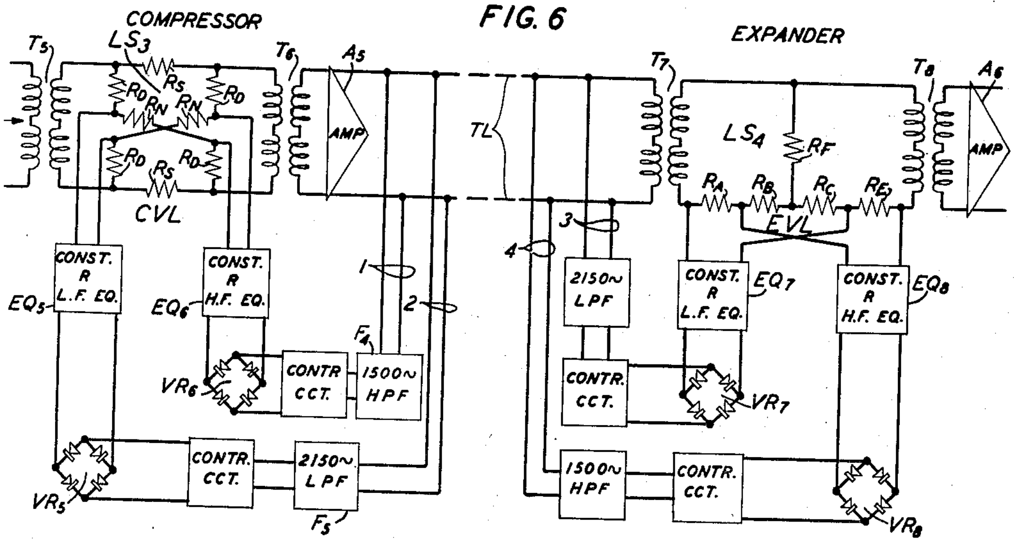


FIG. 6



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Patented Sept. 12, 1944

2,358,045

UNITED STATES PATENT OFFICE

2,358,045

NOISE REDUCTION IN SIGNAL TRANSMISSION SYSTEMS

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Application August 6, 1942, Serial No. 453,831

9 Claims. (Cl. 178—44)

The invention relates to signal transmission systems and particularly to circuits for reducing the effects of noise in such systems.

In telephone or other sound current transmission systems, it is often desirable to transmit faithfully signals having an extremely wide range of volumes, such as music, by means of a telephone line, sound recording and reproducing system, or other transmission medium. The range of signal volumes which can be satisfactorily transmitted is limited by the characteristics of the line or other medium used and those of the transmission apparatus which may be employed. In order to prevent signal distortion, it is necessary that the minimum transmitted signal volumes be maintained above that of the noise or other interference introduced by the transmission medium or apparatus, and that the maximum transmitted signal volumes be maintained below that value which would cause transmission apparatus, such as repeaters, in the system to overload.

Various devices, known in the art as compressors and expanders (compandors), range reducers and restorers, or rooters and squarers, have been proposed for accomplishing this. Certain of these devices employ signal-controlled variable gain amplifiers, or vario-lossers in combination with fixed gain amplifiers, at the transmitting end of the system to relatively over-amplify the smaller amplitudes of the signals until they are large with respect to the undesired noise wave amplitudes and to under-amplify the larger amplitudes of the signals so that they do not overload the transmission medium or the apparatus therein, thus effectively compressing the volume range of the signals to bring them within the volume transmission range of the transmission medium before transmitting them thereover; and by employing similar apparatus operating in reverse manner at the receiving or reproducing end of the system to effectively expand the volume range of the received signals to restore their original amplitude relations.

Experimental tests of the effects of conventional devices of this type on program transmission have shown that their ability to improve the effective signal-to-noise ratio of a transmission line was much less than the measurements of idle circuit noise reduction would indicate. When the amount of loss in the expander at the receiving end of the circuit is decreased by the action of incoming signals, the changes of loss cause the line noise to increase and to vary in amplitude with the signal, thus making the noise more likely to be noticed by the listener. If the signal is composed chiefly of low frequencies and the noise has strong high frequency components, the frequent changes in the magnitude of the noise may be audible as a swishing sound, which has been termed "hush-hush." In addition to being a function of the amount of masking produced by the signal, "hush-hush" is affected by the choice of time constants in the compressor and expander control circuits. The compressor and expander control circuits are usually designed to provide very fast attack time but relatively slow recovery time. For reasons of circuit stability, it was not possible to make the recovery time much less than one-half of a second which made the hush-hush very noticeable since the amplified noise heard at the expander output persisted for a fraction of a second after the signals had ceased. By reducing the recovery times, it is possible to decrease the effect of hush-hush to some extent, but even with instantaneous recovery times, such as are obtained in rooter and squarer circuits, it is still noticeable with certain types of signal transmission, due to the fact that low frequency signals do not effectively mask high frequency noises.

The United States patent to Doba, No. 2,173,-472, issued September 19, 1939, discloses a variable equalizer type of compandor for overcoming this objection, which operates by varying compressor and expander gains and losses at high frequencies, and only when high frequency signal energy is present. One disclosed modification employs, in addition to the usual compressor and expander operating on the whole band of signal frequencies, another compressor and expander operating separately on the high frequencies in the signals.

An object of the invention is to improve the operation of devices of the general type described above.

A more specific object is to improve the effective signal-to-noise ratio of signal broadcast transmission lines or other broad-signal band transmission media.

These objects are attained in accordance with the invention by a double variable equalizer type of compandor using separate specially designed tandem-connected compressors and expanders for the high and low frequency components of the signal to give improved suppression of circuit noise in the over-all system. A feature of the invention is the use of control circuits for the high and low frequency compressors and expanders such as to minimize the effect of changes of line attenuation on the shape of the transmission frequency characteristic of the overall system.

The various objects and features of the invention will be better understood from the following complete description when read in conjunction with the accompanying drawings in which:

Fig. 1 shows diagrammatically a signal transmission system equipped with a compandor embodying one form of the invention;

Fig. 2 shows curves illustrating the action of the double compressor in the system of Fig. 1 with applied signals of various amplitudes and energy distributions;

Figs. 3, 3A, 4 and 4A show schematically circuit arrangements which may be employed in the low and high frequency compressors and expanders in the system of Fig. 1;

Fig. 5 shows diagrammatically a signal transmission system employing a modified form of compandor in accordance with the invention in which the control circuits for the high and low frequency compressors and expanders are operated from the same point at the transmitting and receiving end of the systems, respectively; and

Fig. 6 shows schematically a signal transmission system employing a compandor of a modified form in accordance with the invention in which a single regulator network of a special type is substituted for the two regulator networks in each high and low frequency compressor and expander, thereby reducing the circuit complexity and the amount of apparatus required.

Fig. 1 shows a block diagram of a compandor embodying one form of the invention. The compressor at the sending end of the transmission medium TL, which may be a telephone line, radio link or sound recording and reproducing system, comprises two variable equalizer compressor portions C1 and C2 connected in tandem. The expander at the receiving end of the medium TL comprises two variable equalizer expander portions E1 and E2, connected in tandem.

The first compressor portion C1 comprises the high frequency regulator (vario-losser) VL_1 followed by the amplifier A_1 in the main signal transmission path, and the backward-acting control circuit (amplifier-detector) AD_1 for that regulator, having a 1500-cycle high-pass filter F_1 in its input. The following compressor portion C2 comprises the low frequency regulator (vario-losser) VL_2 followed by the amplifier A_2 in the main signal transmission path, and the backward-acting control circuit (amplifier-detector) AD_2 for the latter regulator, having a 2150-cycle low-pass filter F_2 in its input.

The first expander portion E1 comprises the low frequency regulator VL_3 followed by the amplifier A_3 in the main signal transmission path, and the forward-acting control circuit (amplifier-detector) AD_3 for that regulator, having a 2150-cycle low-pass filter F_3 in its input. The following expander portion E2 comprises the high frequency regulator VL_4 followed by the amplifier A_4 in the main signal transmission path, and the forward-acting control circuit (amplifier-detector) AD_4 for the latter regulator, having a 1500-cycle high-pass filter F_4 in its input.

The signals applied to the input of the system of Fig. 1 first pass through the regulator VL_1 in which they undergo a loss and then through the amplifier A_1 in which they are amplified. A portion of the higher frequency signal components above 1500 cycles in the output of the amplifier A_1 is selected by the high-pass filter F_1 and causes the operation of the control circuit AD_1 to adjust the regulator VL_1 so as to increase its loss value and thus reduce the effective gain of the regulator-amplifier combination VL_1, A_1 for the transmitted signals, if they are in a frequency range above about 1000 cycles, in accordance with their amplitude level. If the transmitted signals are in the frequency range below about 1000 cycles, they pass through the regulator-amplifier combination VL_1, A_1 with a constant amplification. The high-pass filter F_1 in the input of the control circuit AD_1 prevents the low frequency signals from changing the gain of the regulator-amplifier stage VL_1, A_1 at low frequencies.

The signals in the output of the amplifier A_1 are impressed on the second portion C2 of the compressor and pass through the regulator VL_2 and amplifier A_2, and if they are within the frequency range below 2150 cycles passed by the low-pass filter F_2 in its output, cause operation of the control circuit AD_2 to reduce the loss of the regulator VL_2 so as to effectively reduce the gain of the regulator-amplifier combination VL_2, A_2 at frequencies below about 3000 cycles in accordance with their amplitude level. The 2150-cycle low-pass filter F_2 in the input of the control circuit AD_2 will prevent the high frequency signals from changing the gain of the rectifier-amplifier combination VL_2, A_2 at low frequencies. In the compressor portion C2, the high frequency signals are transmitted with constant amplification at all times.

Due to the fact that the characteristics of the regulator stages cannot be made to cut off sharply at a given frequency, there will be an overlapping region from about 1500 to 2150 cycles in which a signal may control the gain of both high and low frequency compressor portions C1 and C2. This overlap and the characteristics of the filters in the inputs of the control circuits for the high and low frequency compressors are so selected, however, that substantially constant gain versus frequency is obtained through the combination of compressors when a test tone sent into the compressors is maintained at a given amplitude.

At the receiving end of the system, the signals of compressed volume range received over the transmission medium TL, first pass through the low frequency portion E1 and then through the high frequency portion E2 of the expander, which is the reverse of the order for the two compressor portions at the sending end. As the high frequency signal components of the signals impressed on the expander portion E1 are excluded from the forward-acting control circuit AD_3 by the 2150-cycle low-pass filter F_3, the low frequency signal components in the frequency range below 2150 cycles only will cause operation of the control circuit AD_3 to adjust the regulator VL_3 to decrease its loss value. This will increase the effective gain of the regulator-amplifier stage VL_3, A_3 at the low frequencies below about 1000 cycles in accordance with their amplitude level and no change in gain will be made at the high frequencies for any signal. In the following high frequency expander portion E_2, the low signal frequencies below 1500 cycles are excluded by the 1500-cycle high-pass filter F_4 from the forward-acting control circuit AD_4 which will respond only to the high frequency signals in the range above about 1500 cycles to reduce the loss of the regulator VL_4 and thus effectively increase the gain of the regulator-amplifier stage VL_4, A_4 for the high frequency signals in the frequency range above about 3000 cycles in accordance with their amplitude level. The low frequency signals below about 1000 cycles will be transmitted with constant amplification through expander E_2.

The separate compressors and expanders for the high and low frequency signal energy in the system of Fig. 1 insure that if all the signal energy is concentrated at one end of the frequency spectrum, there will be no expander action to increase the gain at the other end of the frequency spectrum. Also the high frequency components of the line noise heard at the output of the system will be increased in amplitude by expander action only when there is high frequency signal energy present on the line. This provides improved masking of the noise by the signals which results in greater effective noise reductions with this type of compandor circuit than have previously been obtainable.

By proper selection of circuit constants, the low frequency compressor C2 and the low frequency expander E1, and likewise the high frequency compressor C1 and the high frequency expander E2, may be made to have exactly complementary characteristics with respect to time actions, frequency characteristics and output-input characteristics. Thus, assuming that the line TL introduces no distortion, the output of the low frequency expander E1 or the input of the high frequency expander E2 will be identical in all respects with the output of the high frequency compressor C1 or the input of the low frequency compressor C2, so that the over-all system will be linear and distortionless. If there are distortions or non-linear characteristics in the line TL, the effects on the over-all system will be similar to that which would obtain if the conventional 2 to 1 ratio compandor were in the circuit.

When transmission through a double compressor such as described is measured by noting the effect on a transmitted test tone of a single frequency, the compressor action is found to be similar to that of the conventional type of 2 to 1 compressor in which the output amplitude increases at about half the rate of increase of input amplitude at any frequency tested. A transmission frequency characteristic measured with a given amplitude of input tone would be approximately flat though the over-all characteristic is the sum of the two compressor-regulator characteristics, neither one of which is flat. The curves of Fig. 2 illustrate the action of the double compressor with signals of various amplitudes and energy distributions.

In Fig. 2, the upper set of curves (*a*), (*b*) and (*c*), respectively represent the frequency characteristics of the high and low frequency portions C1 and C2 of the compressor in Fig. 1 and their addition to give a flat over-all characteristic, when the input signals are weak. The second set of curves (*d*), (*e*) and (*f*) and the third set of curves (*g*), (*h*) and (*i*), respectively represent characteristics which may be obtained if all the signal energy is concentrated at the high or low frequencies. As the expander characteristics are complementary to these in all cases, it may be seen that there may be considerable noise suppression in the high frequency band when the signal energy is all low frequency or vice versa. The fourth set of curves (*j*), (*k*) and (*l*) show the characteristics when the signal energy is strong and evenly divided between high and low frequencies.

Circuit arrangements which may be used to obtain the type of high and low frequency compandor action described above, are shown in Figs. 3, 3A and 4, 4A for compressor and expander, respectively. The regulator circuits shown in those figures are of the general constant resistance variable equalizer type described in an article "Variable Equalizers" by H. W. Bode, Bell System Technical Journal, volume XII, No. 2, April 1938, page 229; and broadly claimed in Bode Patent 2,096,027, issued October 19, 1937. Modifications of the design of the constant resistance equalizer in each regulator stage have been made which result in practically constant over-all loss versus frequency for a high and a low frequency regulator in tandem, when the impedances of the copper-oxide resistors employed for terminating the equalizers in the two regulators are equal.

A circuit arrangement which may be used for the low frequency portion C2 of the compressor in the system of the invention shown diagrammatically in Fig. 1, is illustrated in Fig. 3, corresponding elements in the two figures bearing the same identification characters. As indicated, in the compressor C2, the low frequency regulator VL_2 shown within the dot-dash box so labeled, comprises a short section of line LS_1 connected in the main signal transmission path by input transformer T_1 and output transformer T_2, having the equal resistances R_2, R_4 and R_3, R_5 respectively connected in series with each side of the line section; and a network comprising the constant resistance equalizer section EQ_1 having a variable impedance termination VR_1 shown as a copper-oxide varistor (rectifier bridge), connected in series with the resistances R_7 and R_8 in shunt with the line section LS_1 from a point between the series resistances R_2, R_3 to a point between the series resistances R_4, R_5.

The constant resistance equalizer section EQ_1 is a low-pass filter network including shunt capacitance C_1 and the series inductances L_1 and L_2. The constant resistance equalizer section EQ_1 includes also the resistances R_{13} and R_{14} respectively connected in series with the windings L_1 and L_2 and the inverse shunt resistance R_{16} in parallel with capacitance C_1, provided to limit the range of loss (or gain) change with variation of the variable impedance termination VR_1 for the highest frequencies. Also incorporated in the network EQ_1 are the resistances R_9 and R_{11} connected in series across the series impedance comprising the inductance L_1 and the resistance R_{13}, the series resistances R_{10} and R_{12} in series connected across the series impedance comprising inductance L_2 and resistance R_{14}; and the inverse resistance R_{15} in series with the shunt impedance comprising capacitance C_1 and parallel resistance R_{16}. The latter modification improves the frequency characteristics by taking out a variation in gain at the low frequencies which is in the opposite direction to the variation at high frequencies. One diagonal (horizontal) of the copper-oxide rectifier bridge forming the variable impedance portion VR_1 of the low frequency regulator VL_2 is connected across the equalizer network EQ_1 at the points shown.

The control circuit AD_2 for the low frequency compressor C2 includes the amplifier A_5 and the detector D_1 which may be a copper-oxide rectifier bridge as illustrated. The output of the detector D_1 is connected through a resistance-condenser network TC across the other (vertical) diagonal of the rectifier bridge VR_1 forming the variable impedance part of the regulator VL_2. The values of the elements of network TC determine the time constant of the control circuit. The variation of the shunt impedances of the rectifiers in the bridge VR_1 with the amplitude of the applied detected signal current of frequencies below 2150 cycles (cut-off frequency of the low-pass filter F_2 in the input of the control circuit), produces the required variation in loss of the regulator VL_2, or gain of the regulator-amplifier combination VL_2, A_2 giving the desired compression of the low signal frequencies in the main signal transmission path.

The high frequency compressor C1 in the system of Fig. 1 may have the same arrangement of elements as the low frequency compressor C2 as shown in Fig. 3, except for the substitution of a 1500-cycle high-pass filter F_1 for the 2150-cycle low-pass filter F_2 in the input of the regulator control circuit, and the substitution of the high frequency constant resistance equalizer section EQ_2 shown in Fig. 3A for the low frequency constant resistance equalizer section EQ_1 used in the low frequency regulator of Fig. 3. The configuration of the high frequency network of Fig. 3A differs from that of the low frequency network EQ_1 of Fig. 3 in that a shunt inductance L_3 is substituted for the shunt capacitance C_1 of Fig. 3 and the series capacitances C_2 and C_3 are substituted for the series inductances L_1 and L_2 of network 20, thus providing a high-pass filter network.

Different values are selected for the condenser and resistances in the network TC in the control circuit AD_2 for the low frequency compressor C1 than for the similar elements in the corresponding network in the control circuit AD_1 for the high frequency compressor C1, to provide a greater time constant for the low frequency compressor than for the high frequency compressor. The time constants of the low frequency control circuit are made large in order that the filtering action in the control circuit may be sufficient to avoid excessive distortion of the very low frequency wave shapes. In the control circuit for the high frequency compressor, on the other hand, the high-pass filter in its input prevents low frequencies from reaching the control circuit rectifier, so that a large time constant is not necessary to filter the control current. Also by making the time constant small for the latter case, the high frequency control circuit is made to operate very quickly and thus to minimize overshooting of the output amplitudes of the compressor which might otherwise overload the line.

The component elements which may be used in the low frequency expander E1 in the system of Fig. 1 are illustrated in Fig. 4, the corresponding elements in the two figures bearing the same identification characters.

The control elements in the control circuit AD_3 for the low frequency expander of Fig. 4 are the same as used in the control circuit AD_2 for the low frequency compressor of Fig. 3, as described above. The low frequency regulator VL_3 in the expander of Fig. 4 differs from the low frequency regulator VL_2 in the low frequency compressor of Fig. 3 essentially only in that the low frequency constant resistance equalizer section EQ_3 corresponding to the low frequency equalizer section EQ_1 in the system of Fig. 3, is connected across a resistance R_{17} in series with one side of the short line section LS_2, corresponding to the line section LS_1 in Fig. 3, instead of in shunt with the line section through series resistances R_7 and R_8 as in Fig. 3.

The component elements of the high frequency expander E2 in the system of Fig. 1 may be identical with those of the low frequency expander E1 shown in Fig. 4, except that the high frequency constant resistance equalizer section EQ_4 of Fig. 4A, having the same arrangement of elements as the high frequency equalizer section EQ_2 shown in Fig. 3A, would be substituted for the low frequency equalizer section EQ_3 of Fig. 4.

A compandor circuit such as illustrated diagrammatically in Fig. 1 in which the low and high frequency compressor and expander circuits are as illustrated in Figs. 3, 3A and 4, 4A, and described above, was built and tested. It was found that hush-hush was substantially decreased, being practically unnoticeable with any amounts and types of line noise which may be expected in practice. Listening tests on that compandor used with distortionless artificial lines have shown that the compandor introduces negligible distortion, and that it affords effective noise reductions in the order of 15 to 20 decibels.

In the compandor arrangement of the invention diagrammatically illustrated in Fig. 1, the inputs of the backward-acting control circuits for the high and low frequency compressors C1 and C2, and the inputs of the forward-acting control circuits for the low and high frequency expanders E1, E2 are each separated by a low frequency regulator VL_2 and VL_3, respectively. In a modified compandor in accordance with the invention shown in Fig. 5, the inputs of the corresponding backward-acting high frequency and low frequency control circuits for the compressor are both connected at the point A in the output of the amplifier A_2 in the low frequency compressor C2, and the inputs of the corresponding forward-acting low frequency and high frequency control circuits for the expanders E1 and E2 are both connected at a point B in front of the low frequency expander regulator VL_3. It is obvious that if the high and low frequency regulators and their control circuits had infinitely sharp cut-off at their frequency of cross-over (1800 cycles) so that the low frequency regulator had no effect at all on frequencies in the range of the high frequency regulators, and vice versa, such a connection would be satisfactory. However, in the practical case the cut-off at the cross-over frequency is not sharp, and there might be some question as to the compandor action in the region of the cross-over frequency with the control circuits connected together at the output of the low frequency compressor regulator as shown in Fig. 5. However, experiments have shown that satisfactory operation will be obtained for the latter condition also.

Though the performance of the compandor arrangement of Fig. 5 is similar in its effects on over-all transmission to the compandor arrangement of Fig. 1, there is a difference in the way losses are inserted by the two regulators for frequencies in the middle of the band. At 1800-cycle inputs the two compressor regulators in the arrangement of Fig. 5 insert equal losses for all input amplitudes whereas in the compressor of Fig. 1, the losses inserted are equal only at the maximum input amplitude. At input amplitudes less than maximum, with the circuit of Fig. 1 the low frequency regulator inserts more loss than the high frequency regulator. This is because of the fact that for the lower inputs there is gain in the low frequency compressor regulator. With the control circuits receiving input from a common point as in the arrangement of Fig. 5, their sensitivities remain unchanged in relation to each other.

Since it is unnecessary to take the input for the high frequency control circuits between high and low frequency regulators, the functions of the two regulators in the compressor circuit, and the functions of two regulators in the expander circuit of Fig. 5, may each be combined in single regulators of the double equalizer type, such as disclosed in the copending application of S. Darlington, Serial No. 461,171, filed October 7, 1942, as shown in the modified compandor circuit of Fig. 6.

In Fig. 6, the compressor at the transmitting end of the system comprises the single regulator CVL followed by the single amplifier A_5 in the main signal transmission path, and the backward-acting high frequency and low frequency control circuits 1 and 2 both controlled from the output of the amplifier A_5, which respectively include the same elements as described for the corresponding high frequency and low frequency compressor control circuits described above in connection with Figs. 3 and 3A.

The regulator CVL includes a short section of line LS_3 connected by the input transformer T_5 and the output transformer T_6 between the source of signals to be transmitted and the input of amplifier A. A loss network inserted in the line section comprises two series arms each including a series resistance R_S; two shunt arms respectively connected across the line section on either side of the series resistances R_S, one comprising in series the two equal resistances R_D and the intermediate low frequency constant resistance equalizer section EQ_5 with the associated variable impedance termination (rectifier bridge) VR_5, and the other comprising in series the two equal resistances R_D and the intermediate high frequency constant resistance equalizer EQ_6 with its associated variable impedance termination (rectifier bridge) VR_6; and two lattice arms each including an equivalent resistance R_N cross-connecting the two shunt arms as indicated.

The low frequency, constant resistance equalizer EQ_5 may be identical with the low frequency equalizer EQ_1 shown in Fig. 3, and the high frequency, constant resistance equalizer EQ_6 may be identical with the high frequency equalizer shown in Fig. 3A. The output of the high frequency control circuit 1 is connected through a suitable network (not shown), similar to the network TC in Fig. 3, for providing the required time constant, across the variable impedance termination VR_6 of the high frequency equalizer EQ_6, and the output of the low frequency control circuit 2 is connected across the variable impedance termination VR_5 of the low frequency equalizer EQ_5.

The expander at the receiving end of the medium TL in Fig. 6 comprises the single regulator EVL followed by the single amplifier A_6 in the main signal transmission path, and the forward-acting low frequency and high frequency regulator control circuits 3 and 4, respectively, identical with the corresponding low frequency and high frequency expander control circuit used in the system of Fig. 1, described in connection with Figs. 4 and 4A, the inputs of both of the control circuits 3 and 4 being connected across the main signal transmission path in front of the single regulator EVL.

The regulator EVL includes a short section of line LS_4 connected in the main signal transmission path between the line TL and the input of amplifier A_6 by input transformer T_7 and output transformer T_8. A loss network inserted in the line section is of the T-type comprising a series arm including the four resistances R_A, R_B, R_C and R_E in series with each other in one side of the line section, a shunt arm including the resistance R_F connected from a point between the series resistances R_A, R_B and the series resistances R_C, R_E and the other side of the line section; a low frequency, constant resistance equalizer EQ_7 having a variable impedance termination (rectifier bridge) VR_7, connected in parallel with resistances R_A, R_B and R_C in series in the series arm; and the high frequency, constant resistance equalizer EQ_8 having the variable impedance (rectifier bridge) termination VR_8, connected in parallel with the resistances R_B, R_C and R_E in series in the series arm.

The low frequency, constant resistance equalizer EQ_7 may be identical with the low frequency equalizer EQ_3 in the expander control circuit of Fig. 4, and the high frequency constant resistance equalizer EQ_8 may be identical with the high frequency, constant resistance equalizer EQ_4 shown in Fig. 4A. The output of the low frequency control circuit 3 is connected across one diagonal (vertical) of the rectifier bridge VR_7 forming the variable impedance termination of the low frequency equalizer EQ_7, and the output of the high frequency control circuit 4 is connected across one diagonal (vertical) of the rectifier bridge VR_8 forming the variable impedance termination of the high frequency equalizer EQ_8.

The signals applied to the input of the system of Fig. 6 pass through the compressor-regulator CLV in which they undergo a loss and are amplified by the amplifier A_5. The low frequency components below 2150 cycles in the signals in the output of amplifier A_5 passing through the low-pass filter F_1, operate low frequency control circuit 2 to increase the loss of the regulator CVL, and thus reduce the gain of the regulator-amplifier combination CVL, A_5, for the transmitted signals in the frequency range below about 3000 cycles, and the high frequency signal components above about 1500 cycles, in the output of amplifier A_5, passing through the high-pass filter F_2, control the high frequency control circuit 1 to increase the loss of the regulator CVL, and thus reduce the gain of the regulator-amplifier combination CVL, A_5 for transmitted frequencies above about 1000 cycles. The low-pass filter F_1 in the input of the control circuit 2, and the high-pass filter F_2 in the input of control circuit 1, respectively prevent the high frequency signals above 2150 cycles from varying the gain of the compressor at low frequencies, and the low frequency signals below 1500 cycles from varying the gain of the compressor at high frequencies.

The signals of compressed volume range received over the line TL are impressed on the regulator EVL and on the forward-acting control circuits 3 and 4 of the expander. The high frequency components above 1500 cycles in the impressed signals cause operation of the control circuit 4 to reduce the loss of the regulator EVL and thus to increase the gain of the regulator-amplifier combination EVL, A_6 for the high frequency signals above about 3000 cycles. The low frequency components below 2150 cycles in the impressed signals cause operation of the control circuit 3 to reduce the loss of the regulator EVL and thus increase the gain of the regulator-amplifier combination EVL. As for the low frequency signals below about 1000 cycles.

If the low and high frequency expander control circuits and their input filters are selected to have the same frequency characteristics, input-output characteristics and time actions within close limits as the corresponding low frequency and high frequency compressor circuits at the sending end of the system, and the regulators CVL and EVL are properly designed, so that the expander characteristics are substantially complementary to the compressor characteristics, the over-all system will be linear and without distortion of frequency characteristics, and the effects of line noise will be greatly reduced.

In the compandor arrangement of Fig. 6 because each of the double regulators disclosed may be readily arranged to have only a few more decibels loss than each of the single regulators of the system of Figs. 1 and 5, one of the two amplifiers required in the compressor and expander of the latter systems may be eliminated, as indicated. This reduces the number of transformers required in tandem in the system from fourteen to seven, and, if a single transformer is employed for both the output of the compressor double regulator network and the input to the compressor amplifier, the number of transformers in the transmission path may be reduced to six, which would materially ease the requirements on individual transformers for a given over-all transmission requirement.

The manner in which each of the double regulator networks in the system of Fig. 6 accomplishes the functions of the two regulators in the compressor and expander of the systems described in the previous figures, without undue interaction between the high frequency and low frequency control circuits, may be understood from the more detailed description of the similar networks in the aforementioned Darlington patent application.

A further advantage of placing both compressor control circuits following the compressor regulators, and both expander control circuits preceding the expander regulators, as in the systems of Figs. 5 and 6, is that the high frequency control circuits are then separated only by the transmission line or other medium, so that small variations in transmission through the low frequency regulator section will not influence the synchronization of high frequency compressor and expander control circuits. This should assist in making it easier to meet requirements of over-all transmission of the compandor with respect to frequency, load and time actions.

Various modifications of the compandor circuit illustrated in the drawings and described above which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. In combination in a signal wave transmission system, a source of signal waves of a wide band of frequencies, two compressors in tandem at the transmitting end of said system, one for compressing the volume range of the higher frequency components only and the other for compressing the lower frequency components only in said signal waves, a wave transmission medium for transmitting the signal waves of compressed volume range, and two expanders in tandem at the receiving end of the system, respectively having characteristics which are the inverse of those of a different one of the compressors at the transmitting end, for separately expanding the volume range of the higher and lower frequency components in the received signal waves to reproduce the original signal waves.

2. The system of claim 1, in which the order of connection of the low frequency and high frequency expanders at the receiving end of said system is the reverse of that of the low and high frequency compressors at the transmitting end of the system.

3. The system of claim 1, in which each of the compressors at the transmitting end of the system comprises an adjustable attenuation equalizer followed by an amplifier in the main signal wave transmission path, and a backward-acting control circuit responsive to the signal energy in the output of said amplifier to adjust said attenuation equalizer so as to increase its loss value, and thus reduce the effective gain of the equalizer-amplifier combination, in proportion to the level of the transmitted signal energy, the attenuation equalizer in the high frequency compressor having a high-pass filter characteristic and the attenuation equalizer in the low frequency compressor having a low-pass filter characteristic with respective cut-offs at intermediate frequencies in the signal frequency band, said high frequency and low frequency compressors respectively including means to prevent operation of the control circuit for the high frequency compressor by said lower frequency components in said signals and to prevent operation of the control circuit for the low frequency compressor by said higher frequency components in said signals, and said low frequency and high frequency expanders at the receiving end of said system being connected in tandem in the transmission path in an order which is in the reverse of that of the low frequency and high frequency compressors at the transmitting end of the system, and having such characteristics as to act on the received signals in a manner which is respectively complementary to that in which said low and high frequency compressors, respectively, act on the transmitted signals.

4. The system of claim 1, in which each expander at the receiving end of the system comprises an adjustable attenuation equalizer followed by an amplifier in the main signal wave transmission path, and a forward-acting control circuit responsive to the signal energy in the input of the attenuation equalizer to reduce the loss value of the attenuation equalizer, and thus increase the effective gain of the equalizer-amplifier combination, in proportion to the level of the signal energy controlling the control circuit, the attenuation equalizer in the high frequency expander having a high-pass filter characteristic and the attenuation equalizer in the low frequency expander having a low-pass filter characteristic with respective cut-offs at intermediate frequencies in the signal frequency band, said high frequency and said low frequency expanders respectively including means to prevent operation of the control circuit for the high frequency expander by said lower frequency components in the signal waves and to prevent operation of the control circuit for the low frequency expander by said higher frequency components in the signal waves, and said low and high frequencies compressors at the transmitting end of the system being connected in tandem in the signal transmission path in an order which is the reverse of that of the low and high frequency expanders at the receiving end of the system.

5. The system of claim 1, in which each of said compressors comprises a variable loss network followed by an amplifier in the main signal transmission path and a signal controlled backward-acting control circuit for increasing the loss value of said network in proportion to the amplitude level of the transmitted signals, each of the variable loss networks including in shunt with the main transmission path, a constant resistance equalizer section with a variable impedance termination the value of which is varied by operation of the control circuit for that network to control its loss value, the component elements of the equalizer section in each network being such that one acts as a high-pass filter and the other as a low-pass filter with pass ranges respectively embracing said higher frequency signal components and said lower frequency signal components, the control circuit for the network including the equalizer section of high-pass filter characteristic, having a high-pass filter in its input for preventing operation of the control circuit by said lower frequency signal components, the control circuit for the network having a low-pass filter characteristic, having a low-pass filter in its input for preventing operation of the control circuit by said higher frequency components in the signals, and the control circuits for both networks being fed from a point in the output of the second amplifier in the tandem-connected compressors.

6. The system of claim 1, in which each of said expanders comprises a variable loss network followed by an amplifier in the main signal transmission path and a signal controlled forward-acting control circuit for reducing the loss value of said network in proportion to the amplitude level of the received signals, each variable loss network including in series with the main signal transmission path a constant resistance equalizer section with a variable impedance termination the value of which is varied by operation of the control circuit for that network to control the loss value of the network, the component elements of the equalizer sections in the two variable loss networks being such that one acts as a high-pass filter and the other as a low-pass filter with pass ranges respectively embracing said higher frequency components and said lower frequency components in said signals, the control circuit for the network including the equalizer section of high-pass filter characteristics having a high-pass filter in its input to prevent operation in response to the low frequency components in said signals, the control circuit for the network including the equalizer of low-pass filter characteristics having a low-pass filter in its input to prevent operation by the high frequency signal components, and the control circuits for both networks being fed from a point in front of the loss network of the first expander in the tandem connection.

7. In combination in a signal transmission system, a source of alternating signals having a wide range of volumes, a signal transmitting path at the transmitting end of said system supplied from said source, a compressor effective in said transmitting path to separately compress the volume range of the high frequency components only and the low frequency components only in the signals supplied from said source without changing the signal frequency relation, a transmission medium for transmitting the resulting waves, a signal receiving path at the receiving end of said system fed from said medium, and an expander having characteristics which are substantially complementary to those of said compressor, effective in said receiving path to separately expand the volume range of the low and high frequency components in the received waves so as to reproduce the original signals.

8. The system of claim 7 in which said compressor comprises a single variable attenuation network followed by an amplifier in said signal transmitting path and two control circuits respectively responsive to the higher and lower frequency components in the signals in the output of said amplifier to respectively increase the loss of said network for the lower and higher frequency components in the transmitted signals in proportion to the amplitude level thereof, said attenuation network including two shunt arms respectively including in series therewith constant resistance equalizer sections having a high-pass filter characteristic and a low-pass filter characteristic respectively, with respective cut-offs at intermediate points in the signal frequency band, the equalizer sections having variable impedance terminations the values of which respectively determine the shunt impedance of a different shunt arm for said higher and lower frequency signal components, respectively, the control circuit responsive to said higher frequency signal components controlling the value of the variable impedance termination of the high-pass equalizer section in accordance with the amplitude level of said higher frequency signal components and the control circuit responsive to said lower frequency signal components controlling the value of the variable impedance termination of the low-pass equalizer section in accordance with the level of said lower frequency signal components, and cross connections including equal resistances between said constant resistance equalizers for preventing reaction between the low and high frequency control circuits for said network.

9. The system of claim 7, in which said expander comprises a single variable attenuation network followed by an amplifier in said signal receiving path, and two control circuits respectively responsive to the higher and lower frequency components of the received signals at a point in front of said network, to reduce the loss of said network for the low and high frequency signal components transmitted therethrough in proportion to the level of the energy therein, said variable attenuation network including two constant resistance equalizer sections in series with each other in series with the said signal receiving path, respectively having a high-pass filter characteristic and a low-pass filter characteristic with respective cut-offs at intermediate points in the signal frequency band, each of said equalizer sections having a variable impedance termination the values of which determine the series loss in said main signal transmission path for said higher and lower frequency signal components, respectively, and which are respectively controlled by said control circuits responsive to the higher and lower frequency components of the received signals, and cross connections including equal resistances between said high-pass and low-pass equalizers for preventing reaction between the two control circuits.

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