May 6, 1930. R. C. MATHES 1,757,729

WAVE TRANSMISSION SYSTEM

Original Filed March 13, 1925 2 Sheets-Sheet 1

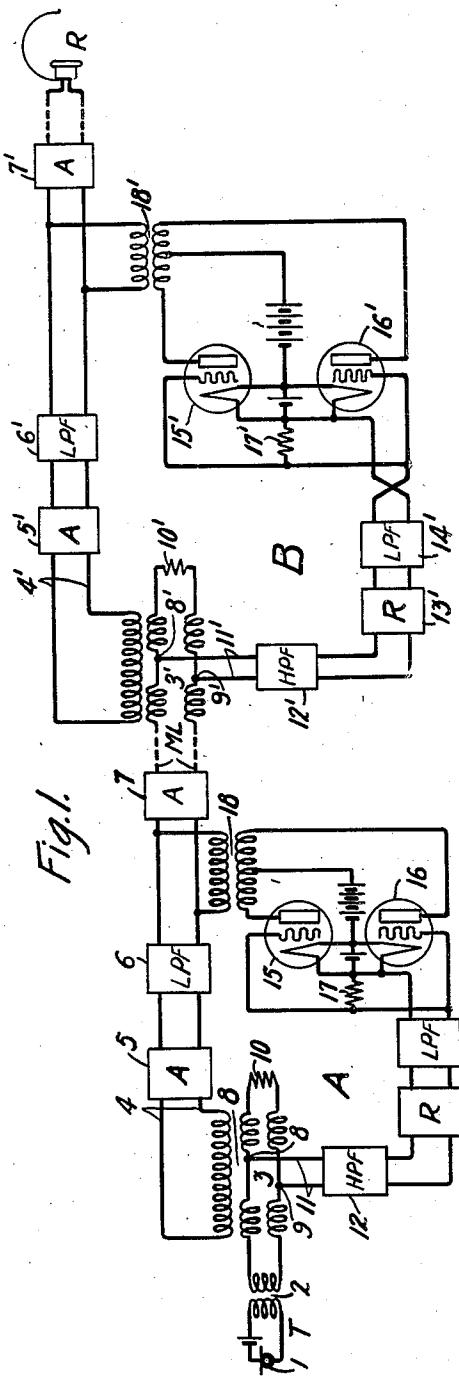


Fig. 1.

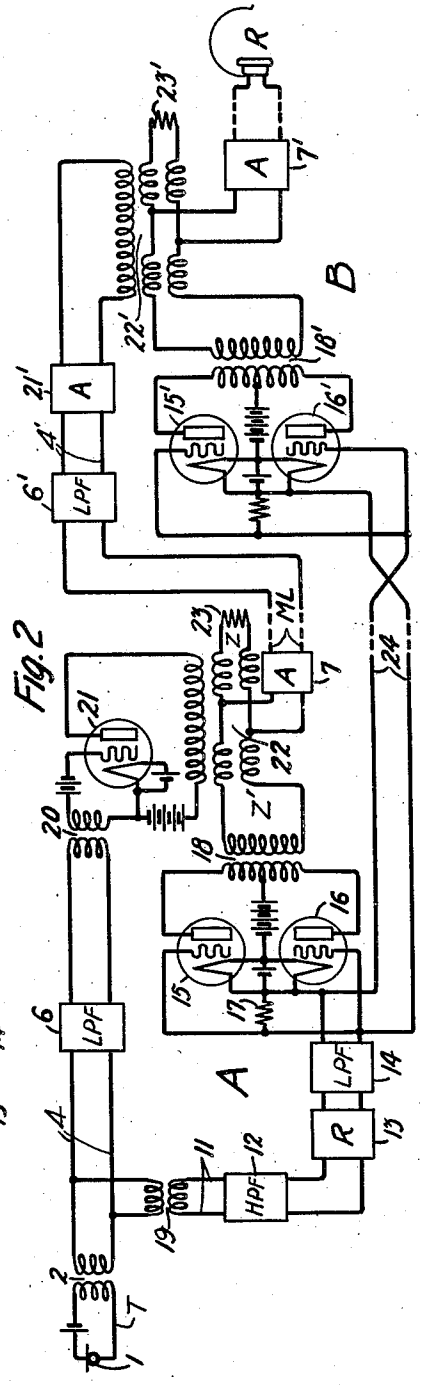


Fig. 2.

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Fig.3

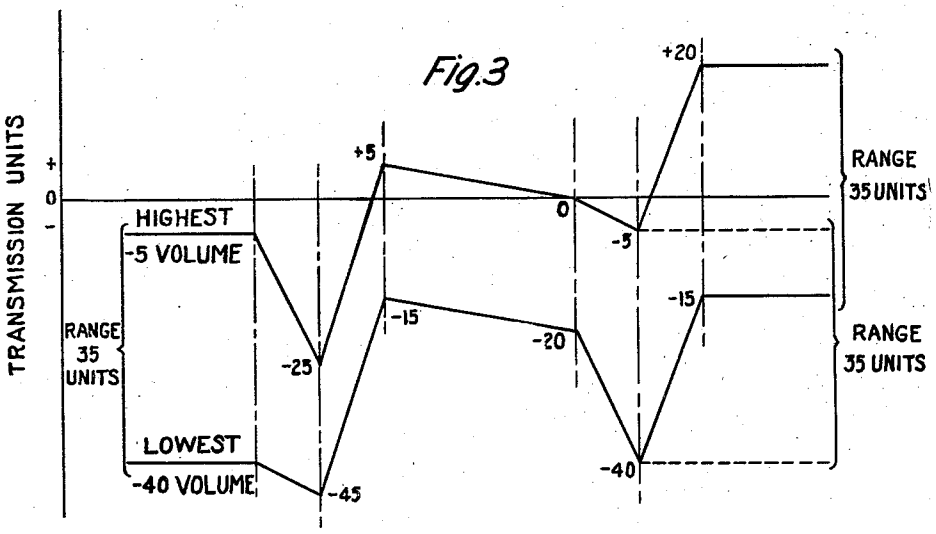
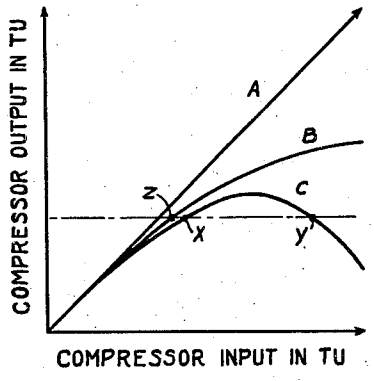


Fig.4



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Patented May 6, 1930 1,757,729

UNITED STATES PATENT OFFICE

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WAVE-TRANSMISSION SYSTEM

Application filed March 13, 1925, Serial No. 15,227. Renewed October 17, 1929.

This invention relates to wave transmission systems and particularly to the control of the energy level of transmission in such systems.

An object of the invention is to provide methods of and means for effectively transmitting energy having a wide range of volumes over systems inherently capable of transmitting only a narrow range of volumes.

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

To illustrate, it has been determined that the upper power limit for two-wire repeated transmission lines is about +5 transmission units, and the lower about −25 transmission units. A transmission unit is defined so that the number of transmission units corresponding to a power ratio of $\frac{P_1}{P_2}$ is equal to $10 \log_{10} \frac{P_1}{P_2}$. In the case of four-wire circuits, the upper limit may be about +10 transmission units. The range, therefore, through which the power may vary is 30 to 35 transmission units. For high quality transmission, this range must be still further reduced, since the noise that can be permitted is less than that in commercial voice channels. The range given is sufficient for speech, whose variation with time is ordinarily not greater than about 25 transmission units. Orchestral music, however, generally has a volume range of 50 to 60 transmission units or more. Under such conditions it is necessary to provide some means for maintaining the power within the limits of a transmission system, when programs having such a wide range of volumes are to be transmitted over it.

In accordance with the present invention, control of the volume of transmission is obtained by introducing at each end of the transmission line a variable loss which is a function of power level and not of frequency. Compression at the input end is obtained by causing the loss to increase as the input level increases, and expansion at the output end is produced by a converse operation.

Specifically the control of the volume is accomplished by sending the transmission through circuits having variable impedance elements, the impedance of these elements being made a function of power level. The variable impedance element at each end of the line comprises three-electrode vacuum tubes, the impedance of these tubes being varied by the application of a control potential to their grid circuits. The control potential is obtained by rectifying some of the received energy before being varied. By one method the compression or expansion is obtained by the shunting action of the variable impedances on the line. By another method the compression or expansion action is obtained by incorporating the variable impedance elements in bridge circuits at each end of the line, and by utilizing their variation in impedance with power level to change the balance of the bridge circuits.

The various features and objects of the invention will be understood from the following detailed description when read in connection with the accompanying drawings.

In the drawings: Fig. 1 is a diagrammatic view illustrating a transmission system embodying the shunt control modification of the invention; Fig. 2 is a diagrammatic view illustrating a transmission system embodying the bridge control modification of the invention; Fig. 3 is a transmission level diagram illustrating the operation of the system shown in Figs. 1 and 2; and Fig. 4 shows curves illustrating the principles of the invention. Like parts throughout the several figures of the drawings bear similar reference characters.

The shunt control modification of the invention will now be described. Referring to Fig. 1, a transmission system comprising a

sending station A and a receiving station B connected by a transmission line ML is shown. The circuit of the sending station A comprises a transmitter circuit T including a microphone transmitter 1, which is associated through transformer 2 and hybrid coil arrangement 3 with a main channel 4, which through the amplifier 5 low pass filter 6 and the amplifier 7, is associated with the line ML. The usual balancing impedance 10 is associated with the hybrid coil arrangement 3 for balancing the incoming line. The transmitter circuit T through transformer 2 and hybrid coil 3 is also associated with a volume control channel 11, which comprises a high pass filter 12, a suitable rectifier 13, a low pass filter 14 and a variable impedance element comprising the three-electrode space discharge devices 15 and 16, which are connected in push-pull relation at their outputs. The output circuits of the space discharge devices 15 and 16 by means of transformer 18 are connected effectively in shunt of the main channel 4 between the filter 6 and the amplifier 7.

At the receiving station B of Fig. 1, the transmission line ML is associated through hybrid coil arrangement 3′ with a main channel 4′, which through amplifier 5′ and low pass filter 6′ is connected to the input circuit of an amplifier 7′. The usual balancing impedance 10′ is associated with the hybrid coil 3′ to balance the incoming line ML. The output circuit of amplifier 7′ may be connected to a suitable receiving apparatus R or to outgoing transmission lines. The transmission line ML at the receiving station through the hybrid coil arrangement 3′ is also connected to a volume control channel 11′, similar to the channel 11 at the sending station, which comprises the high pass filter 12′, the rectifier 13′, the low pass filter 14′, and the variable impedance element comprising the three-electrode vacuum tubes 15′ and 16′, which are connected in push-pull relation at their outputs. The output circuits of the vacuum tubes 15′ and 16′ through transformer 18′ are connected effectively in shunt of the main channel 4′ between the filter 6′ and the amplifier 7′.

The purpose of the filter combination used at the sending and receiving stations in the system of Fig. 1, and also in the system of Fig. 2, and the particular features of the individual filters of the combination are described in detail later. These filters may be designed in accordance with the principles set forth in the patents to Campbell, Nos. 1,227,113 and 1,227,114, dated May 22, 1917.

The operation of the system of Fig. 1 will now be described. Sound variations, corresponding to the music or voice program to be transmitted to station B, are received by the microphone transmitter 1, and the corresponding electrical variations produced in transmitter circuit T are transmitted through transformer 2 and hybrid coil arrangement 3 to main channel 4, and after amplification in the amplifier 5 pass through the low pass filter 6. A portion of the energy received by the hybrid coil 3, however, is tapped off at the points 8 and 9 of the coil and supplied to the high pass filter 12 in the volume control channel 11. The energy in the output circuit of filter 12 is rectified by the rectifier 13, and after passing through the low pass filter 14 is supplied to the input circuit of the variable impedance device comprising the three-electrode vacuum tubes 15 and 16. The rectified variations in the output circuit of filter 14 are applied to the common branch of the grid circuits of tubes 15 and 16 across resistance 17, so that a rectified control potential is applied to the two tubes symmetrically. The rectified control potential causes like variations in the grid voltage of each tube and consequently equal variations in the plate impedances of the two tubes. As the output circuit of the variable impedance device comprising push-pull tubes 15 and 16 is coupled by means of transformer 18 across main channel 4, a loss corresponding to the plate impedances of tubes 15 and 16 in series is thus effectively inserted in shunt to that channel between the filter 6 and the amplifier 7. The push-pull arrangement of the tubes making up the variable impedance element provides that, while their impedances are responsive to changes in the control potential applied to their grids, their combined impedance as viewed from the main transmission line is substantially independent of the magnitude of energy passing over that line. The hybrid coil arrangement 3 provides a means whereby the variable impedance element will not react on the amount of input supplied to the rectifier 13, even if amplifier 5 were omitted.

As the impedances of the tubes 15 and 16 in the manner described above are controlled by the power level of the energy input to the system, it is readily seen that the loss in shunt to the channel 4 will also vary in accordance with that input level. Also, it is readily seen that, if the poling of the grids of the tubes 15 and 16 with respect to the rectifier 13 is properly selected, the impedances of these tubes will decrease, and therefore the loss inserted in channel 4 will increase with increase in the input level and decrease with decrease in the input level. If the volume control apparatus is properly designed, the loss varying with input level in channel 4 will be such as to compress the volume range of the variations passed by filter 6 within the range capable of being transmitted satisfactorily by the transmission system. The volume range of the variations to be transmitted over the line ML being controlled in this manner, it may be necessary for sat-

isfactory transmission to raise or lower the average amplitude level, and this is accomplished by sending the compressed volume through the amplifier 7 before transmitting it over the transmission line ML.

At station B, the variations received from the line ML are transmitted through the hybrid coil 3′ to the main channel 4′, and after amplification in the amplifier 5′ pass through low pass filter 6′. A portion of the energy received by the hybrid coil 3′, however, is tapped off at the points 8′ and 9′ of hybrid coil 3′ and is supplied to high pass filter 12′ in the volume control channel 11′. The variations in the output of filter 12′ are rectified by the rectifier 13′ and after passing through the low pass filter 14′ are supplied to the input circuit of push-pull tubes 15′ and 16′ across the resistance 17′ in the common branch of their grid circuits, to vary the impedance of the two tubes 15 and 16 in accordance with the input power level in the manner described in connection with the volume control channel 11 at the sending station. As the output circuits of the tubes 15′ and 16′ by means of transformer 18′ are connected in shunt of the main channel 4′, a loss corresponding to the impedance of the tubes is thus inserted in shunt to channel 4′. The poling of the grids of the tubes 15′ and 16′ with respect to the rectifier 13′ is made the reverse from that of the similarly designated elements at the sending station, so that in this case, the impedance of the tubes 15′ and 16′ will increase, and therefore the loss in shunt to the main channel 4′ between filter 6′ and the input circuit of amplifier 7′, will decrease with increase in the input level of the transmitted variations and increase with decrease in the input level. This loss will have the effect of expanding the volume range of the variations received from the output circuit of filter 6′ in channel 4′. By suitable design of the apparatus at each station, the net equivalent of the circuit is made independent of amplitude (or power level), and the volume range of the variations supplied to the amplifier 7′ will be an exact copy of the input to the compression apparatus at the sending station. As at station A, the hybrid coil arrangement 3′ is provided to prevent the variable impedances of the tubes 15′ and 16′ from reacting on the amount of input supplied to the rectifier 13′. The average amplitude level of the received variations are changed in the amplifier 7′ to any desired level, and the variations supplied to the receiver R, or if desired sent out over another transmission line to another station.

The push-pull arrangement of the vacuum tubes 15, 16 and 15′, 16′ in the volume control channels at the sending and receiving stations respectively, also has two other advantages: in the first place, the effect of harmonics caused by the insertion of a variable impedance in the main channel is negligible in such an arrangement; secondly, thorough rectification of the control current is unnecessary as troublesome A. C. components of the control current will be balanced out in the push-pull arrangement.

The purpose of the filter combinations used at the transmitting and receiving stations will now be explained. In order that the control current in the volume control channels at the sending and receiving stations will represent an envelope of the received volume (or the average received volume over any desired range of time), it is necessary to filter out the speech frequency components in the rectified current. In so doing, however, a time lag will be introduced into the control current so that the control of volume will no longer be simultaneous with volume changes in the received energy. Hence, it may be necessary to introduce delay circuits, such as filters, in the main transmission path to compensate for these differences in time.

The filters 14, 14′ in volume control channels 11, 11′ respectively are low pass filters designed to remove the audio frequency components from the rectified currents which control the impedances of the push-pull circuits. The filters 6, 6′ in the main channels 4, 4′, respectively, are provided to put the necessary time delay in the transmission. These filters are designed to pass all of the audio frequency components essential to the proper transmission of speech or music. The cut-off frequencies of 6, 6′ will have to be relatively high for circuits used as part of broadcasting systems. The number of filter sections in the filters 6, 6′ will have to be greater than the number of sections in the filters 14, 14′ by a factor equal to the ratio of their respective cut-off frequencies.

As the cut-off frequencies of filters 14, 14′ should ordinarily be quite low, this would mean that filters having a rather large number of sections would be needed to put the necessary compensating time lags into the varied transmission. It is, therefore, desirable to put the cut-off frequencies of filters 14, 14′ as high as possible. This can be done since the envelope of the frequency components above some specified value can fairly represent the volume changes of the total energy. High pass filters 12, 12′ can then be inserted in front of the rectifiers 13, 13′ in volume control channels 11, 11′ respectively. The cut-off frequencies of the low pass filters 14, 14′ can then be placed a little below the cut-off frequencies of the filters 12, 12′ instead of below the total range of frequencies involved. As stated above, the filters used may be designed in accordance with the principles set forth in the patents to Campbell Nos. 1,227,113 and 1,227,114, dated May 22, 1917.

In Fig. 2 is illustrated the bridge control modification of the invention. The system shown in Fig. 2 differs from the system of Fig. 1 in the following particulars: The volume control channel 11 at station A instead of being associated with the incoming line through hybrid coil 3 as in the previous figure, is coupled thereto by means of the transformer 19. The output circuit of the transformer 2 at station A instead of being associated with main channel 4 through a hybrid coil 3 as in the previous figure, is connected directly to the main channel 4. The main channel 4, instead of being connected through amplifier 5 and filter 6 to the input circuit of amplifier 7 as in the previous figure, is connected to filter 6, the output of which is coupled by means of transformer 20 to the input circuit of amplifier 21, the output circuit of which is associated with the input circuit of amplifier 7 through the hybrid coil arrangement 22. The terminals of the secondary of the output transformer 18, instead of being connected directly across the main channel 4 as in the previous figure, are connected through the line coils of the hybrid coil arrangement 22 to the terminals of a balancing impedance 23. The input circuit of the variable impedance device comprising the vacuum tubes 15′ and 16′ at station B, instead of being connected through filter 14′, rectifier 13′, filter 12′ and hybrid coil 3′ across the line ML as in the system of Fig. 1, is connected directly through a pilot channel 24 to the output of filter 14 in the volume control channel 11 at station A. The transmission line ML instead of being connected at station B through hybrid coil arrangement 3′ and through amplifier 5′ and filter 6′ directly to the input circuit of amplifier 7′ as in the system of Fig. 1 is connected directly to the input of filter 6′ in the main channel 4′, and the output of filter 6′ is associated with the input circuit of amplifier 7′ through amplifier 21′ and the hybrid coil arrangement 22′. The terminals of the secondary winding of output transformer 18′, instead of being connected across channel 4′ as in Fig. 1, are connected through the line coils of the hybrid coil arrangement 22′ to the terminals of a balancing impedance 23′. The other elements of the system of Fig. 2 correspond to the similarly designated elements in Fig. 1.

The operation of the system of Fig. 2 will now be described. At station A, sound variations corresponding to the music or speech program to be transmitted to station B, are received by the microphone transmitter 1, and the corresponding electrical variations in the transmitter circuit T are transmitted through transformer 2 to the input of filter 6 in main channel 4. The filter 6 passes all the audio frequency components of the received variations which are essential to the proper transmission of music or speech, the transmitted variations being supplied through transformer 20 to the input circuit of amplifier 21. The corresponding amplified variations in the output circuit of amplifier 21 are impressed on the hybrid coil arrangement 22. A part of the received energy in the output circuit of transformer 2 through transformer 19 is supplied to the input of high pass filter 12 in the volume control channel 11. The transmitted energy in the output of filter 12 is rectified by the rectifier 13 and passed to the filter 14, which removes the audio frequency components from the rectified current. The rectified variations in the output of filter 14 are applied to the resistance 17 in the common branch of the grid circuits of the push-pull tubes 15 and 16, and in the manner described in connection with the corresponding circuit in Fig. 1, control the plate impedances of the two tubes 15 and 16 in accordance with the changes in the power level of the energy generated by transmitter 1. As in the case of the corresponding elements of Fig. 1, the polarity of the grids of the tubes 15 and 16 with respect to the amplifier 13 is made such that the impedance of these tubes will increase with increase in the power level at the input and decrease with decrease in the power level at the input.

It is readily seen, that the arrangement of the circuits as shown is such as to form a Wheatstone bridge circuit comprising the coils of the hybrid coil 22, the constant balancing impedance 23, and the variable impedance looking towards the transformer 18, which connects the output of the tubes 15 and 16 to the hybrid coil arrangement 22. Designating the impedance looking towards transformer 18 as Z′ and the constant impedance of 23 as Z, it is readily seen that the loss through the hybrid coil 22 depends upon the relation of Z′ to Z. If Z′ is less than Z, then it should be nearly equal to Z with high level input and decrease in impedance as the input level becomes lower, so that the unbalance will be greater and the loss through the bridge circuit less. Because of the poling of the input to the push-pull set of tubes 15 and 16, this loss will be low for low level inputs to the system and high for high level inputs. Therefore, the speech or music variations from the output circuit of amplifier 21 when transmitted through hybrid coil 22 will be compressed in volume. The amount of compression can be fixed at a desired value by selecting the apparatus constants to obtain the required ratio of Z′ to Z. This may be done either by changing the magnitude of the impedance 23 or by changing the impedance ratio of the primary and secondary coils of transformer 18.

To obtain the desired type of compression in the bridge type of compressor described it may be necessary to add a constant

resistance to the plate impedances of the tubes 15 and 16. This may be done by adding resistance in series with the secondary winding of transformer 18.

The compressed volume transmitted through the hybrid coil 22 is supplied to the input circuit of amplifier 7. The amplifier 7 may be utilized to change the average amplitude level of the compressed variations to any desired value before transmitting them over the line ML.

In the hybrid coil type of compressor just described, it is possible of course to replace the constant balancing impedance 23 with another push-pull set of tubes so poled that as the impedance of one set increases the impedance of the other decreases. However, satisfactory operation for most purposes may be obtained by using a constant balancing impedance instead of the double variation arrangement.

At station B, the transmitted variations after passing through the low pass filter 6' are amplified by the amplifier 21' and impressed on the hybrid coil 22'. To control the volume of the transmitted variations at station B, a pilot channel 24 connected across the output of the filter 14 in the channel 11 at station A, is utilized to convey rectified control current, which will be proportional to the original input at the transmitter 1, to the input circuit of the variable impedance device comprising the tubes 15' and 16' at station B. This control current is applied to the resistance 17' in the common branch of the grid circuits of tubes 15' and 16', and in the manner described in connection with the corresponding elements at the sending station, will cause the plate impedances of the tubes to vary in accordance with changes in the power level of the energy generated by transmitter 1 at the sending station. However, in this case, the poling of the grids of the tubes 15' and 16' with respect to the poling of the rectifier 13 is reversed from that used at the sending station, so that the plate impedances of the tubes 15' and 16' will decrease with increase in the input power level and increase with decrease in the input level.

As the terminals of the secondary winding of the transformer 18', associated with the output circuits of the tubes 15' and 16' are connected through the line coils of hybrid coil 22' across the balancing impedance 23', a Wheatstone bridge circuit is formed comprising the line coils of hybrid coil arrangement 22, the constant balancing impedance 23', and the impedance looking towards the transformer 18'. As in the case of the similar arrangement at station A the loss through the hybrid coil 22' will be determined by the relation of the impedance looking toward transformer 18' to the balancing impedance 23'. In this case, because of the reverse poling between the rectifier 13' and the tubes 15' and 16', the loss through hybrid coil 22' will be low for high level inputs and high for low level inputs. Therefore, the speech variations from the output circuit of amplifier 21' transmitted through hybrid coil 22' will be expanded in volume range. If as at the sending station, the constants of the circuit are properly selected the volume range of the transmitted variations may be made a copy of the input to the compression apparatus at the sending station. As at the sending station, it may be necessary in some cases to add a constant resistance in series with the secondary winding of the output transformer 18' to get the desired amount of expansion. The expanded variations are transmitted through the amplifier 7' to adjust the average amplitude to any desired value and are received in suitable receiving apparatus R, or are retransmitted over other lines to other stations.

It is to be noted that, while variations in the pilot power correspond to those in the input to the compression apparatus at station A, the volume range that can be transmitted by the pilot channel 24 is not as limited as that which can be transmitted by the main line ML because of the different circuit characteristics, provided this pilot power is the output of the rectifier 13. The pilot wave being pulsing direct current with a frequency spectrum smaller than that of the wave in the main transmission line, the frequency band required for its transmission may be much less than that required for the transmission of music. By the use of a pilot channel, therefore, the effect of line noise on the volume control at the receiving station can be substantially eliminated.

The operation of the circuits of Fig. 1 or 2 may be more clearly understood from a consideration of the transmission level diagram of Fig. 3. It will be assumed for the purpose of explanation that the volume of the variations, corresponding to the speech or music to be transmitted, in the output of filter 6 in the system of Fig. 1, or in the output circuit of the amplifier 21 in the system of Fig. 2, varies from a maximum value of -5 transmission units to a minimum value of -45 transmission units. It will be also assumed that the maximum range of volume that can be efficiently transmitted by the transmission line of Fig. 1, or of Fig. 2, is 20 transmission units. In Fig. 3, changes in the maximum volume or power of the energy in transmission from station A to station B are shown in the upper curve, and changes in the minimum volume or power of the energy in transmission from station A to station B are shown in the lower curve. The maximum volume of the energy is first reduced by the volume controlling apparatus

at station A to a transmission level of −25 transmission units, as indicated and is then amplified by amplifier 7 to a transmission level of +5 transmission units. The maximum volume is then attenuated in passing over the transmission line ML due to the line loss so that it drops down to 0 transmission units. At station B, the volume controlling apparatus reduces the maximum volume level to −5 transmission units, which corresponds to the original maximum volume in the output of filter 6 of Fig. 1, or in the output circuit of amplifier 21 of Fig. 2. The maximum volume is then amplified by amplifier 7′ to a transmission level of +20 transmission units.

Similarly, the minimum volume of −40 transmission units in the output of filter 6 of Fig. 1, or in the output circuit of amplifier 21 of Fig. 2, at station A is first reduced by the volume control apparatus at that station to a level of −45 transmission units. The minimum volume is then amplified by the amplifier 7 to a volume level of −15 transmission units. In transmission over the transmission line ML, the minimum volume is attenuated due to the line loss so that it falls to a level of −20 transmission units. The minimum volume is further reduced by the volume control apparatus at station B so that it drops to a level of −40 transmission units which corresponds to the original minimum volume at station A. The minimum volume is then amplified by the amplifier 7′ to raise the level to 15 tranmsission units.

It will be noted by reference to the curves that, at all corresponding points in the system between the output terminals of the volume control apparatus at station A and the input terminals of the volume control apparatus at station B, the maximum and minimum values for volume level will be separated by a range of 20 transmission units, which is the range which can be carried satisfactorily by the transmission line, and that at all corresponding points beyond the output terminals of the volume control apparatus at station B, the maximum and minimum values for volume level are separated by a range of 35 transmission units, which is equal to the range between the maximum volume and the minimum volume at the input to the volume control apparatus at station A. The transmitted music or voice programs when reproduced at the output of the system therefore, will have the same range of volumes as at the input of the system.

The curves of Fig. 4 show qualitatively two types of compressed outputs that may be obtained by suitable adjustments of the volume control apparatus in the systems of Figs. 1 and 2. The curves show variations in the output of the volume control apparatus with variations in input indicated in transmission units (TU). Referring to Fig. 4, the straight line A represents the case where the TU output is directly proportional to the TU input, that is, the case when there is no compression in volume. Curve B represents the case where the adjustment of the volume control apparatus is such that the output is less than the input, but increases with increase in input at a gradually diminishing rate. The curve C represents the case where the adjustment is such that the output increases with increase in input at a gradual diminishing rate up to a maximum point, and falls off greatly with further increase in input giving a drooping characteristic. The important difference between the curves B and C to be noted, is that for compression of the type shown in curve C, the same amount of output will be obtained for two different values of input, as indicated by the points X and Y on the curve C, and that for the type of compression shown in curve B, each value of output corresponds to only one input as indicated by the point Z on curve B. In the type of compression shown in curve B, then, it is evident that the compressed output received over the line from the sending station may be used to control apparatus to cause its own expansion, as in the system shown in Fig. 1. For the type of compression shown in curve C, however, it is evident that some means, such as a pilot channel, must be used to convey to the receiving station power proportional to the original input, which power may be used to control the apparatus to cause the expansion of the compressed power received over the line. A system of that type has been illustrated in Fig. 2.

Only one stage of compression and one stage of expansion have been shown in the system of Fig. 1 and in the system of Fig. 2. However, it is to be understood that, in accordance with the invention these systems are not limited to one stage of compression and one of expansion each, but by adding additional apparatus, similar to that shown, several stages of compression and expansion may be obtained. However, in the case where compression of the type shown in curve C of Fig. 4 is obtained in one compressor, additional compression is limited to that which just brings the output down to 0 TU when the input TU is maximum; and it has been found that such total compression can easily be done in one operation. With the type of compression shown in curve B of Fig. 2, however, as many stages of compression may be used as desired, the only limit being a final output independent of input when the number of stages is infinite.

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

What is claimed is:

1. The method of controlling the volume of energy passing over a system, which comprises rectifying a portion of the energy input to the system, and continuously changing the volume in response to changes in the rectified energy below a preassigned frequency, while preventing more rapid changes in the rectified energy from affecting the volume.

2. In a transmission system, a source of energy of varying volume, a transmission medium supplied with said energy, means to rectify a portion of the energy input to the system, and means responsive only to changes in the rectified energy below a preassigned frequency to continuously control the volume of energy transmitted over the system.

3. In a signaling system, means to generate signaling energy having variations in volume, a transmission medium upon which said energy is impressed, a transmission element in said medium, and means operating to make the transmission efficiency of said transmission element a function of the average volume over a limited period of time of the energy impressed on said medium to control the volume of energy passing over the system, said last mentioned means operating with all of its constituent parts in a fixed relation to one another.

4. In a signaling system, means to generate energy having variations in volume, a transmission medium, means to control the volume of energy passing over the system and means for impressing said energy on said medium independent of said control means, said control means comprising a transmission element whose impedance is a function of the average volume of the energy impressed on said medium, over a limited period of time.

5. In a signaling system, means to generate waves of electrical energy in the speech or music frequency range having variations in volume, a transmission medium upon which said energy is impressed, and means to control the volume of energy transmitted over said medium, said controlling means comprising a variable impedance element including a space discharge device effectively connected to said medium, and means for controlling the impedance of said space discharge device in accordance with the average volume of the energy impressed on said medium over a limited period of time.

6. In a signaling system, means to generate waves of electrical energy in the speech or music frequency range having variations in volume, a transmission medium, a space discharge device connected to said medium, and means for impressing the speech or music waves on said medium independent of said device, the impedance of said device determining the volume of energy transmitted over said medium, and means to control the impedance of said device in accordance with the volume level of the speech or music frequency waves impressed on said medium.

7. In a signaling system, means to generate signaling currents having variations in amplitude, a transmission circuit, a Wheatstone bridge circuit including a variable impedance element, means to impress said signaling currents on said transmission circuit through said Wheatstone bridge circuit, the amount of unbalance current passing through said Wheatstone bridge circuit to said transmission circuit being determined by the impedance of said variable impedance element, and means to control the impedance of said variable impedance element in accordance with the amplitude level of said signaling currents impressed on said circuit.

8. In a transmission system a source of waves of electrical energy comprising a range of frequencies such as speech or music frequency range, a transmission medium supplied with said energy, and means to control the volume of energy transmitted over said medium comprising a three-electrode space discharge device having a grid circuit and an output circuit, said grid and output circuits being associated in energy transfer relation with said medium, means to produce a control current varying in accordance with the volume level of the energy from said source, and means to apply said control current to said grid circuit to control the impedance of said device.

9. In a transmission system, a source of signaling currents, a transmission medium, a Wheatstone bridge circuit comprising a variable impedance element, means to impress said signaling currents on said transmission medium through said bridge circuit, and means to control the amount of unbalance current transmitted through said bridge circuit to said medium, the controlling means comprising means for varying the impedance of said variable impedance device in accordance with the power level of the signaling currents from said source.

10. In a transmission system, means to generate waves of electrical energy in the speech or music frequency range, a transmission line supplied with said energy, a three-electrode space discharge device having a grid circuit and an output circuit, said output circuit being connected to said line, means also connected to said line to rectify a portion of the generated signaling energy, means to filter out variations in the rectified energy above a pre-assigned frequency, and means to impress the filtered rectified energy upon said grid circuit to control the impedance of said space discharge device, thereby controlling the volume of energy transmitted over said transmission line.

11. In a signaling system, a source of electrical energy representing speech or music

having variations in volume, a transmission medium, a circuit for impressing the energy on said medium, a transmission element connected to said medium in such manner that its impedance determines the volume of energy transmitted over said medium, another circuit for rectifying a portion of the energy from said source, means to utilize the rectified energy to control the impedance of said transmission element in accordance with changes in the power level of the energy from said source, and means for associating said circuits in energy transfer relation with said medium to prevent the variable impedance of said transmission element from reacting on the amount of input supplied to said rectifying means.

12. In a transmission system, a source of energy, a transmission medium, a hybrid coil arrangement for impressing said energy upon said medium, a constant impedance element, a variable impedance element, said hybrid coil arrangement, said constant impedance element and said variable impedance element being arranged with respect to each other to form a Wheatstone bridge circuit, means to vary the impedance of said variable impedance element directly in accordance with changes in the power level of the energy from said source, thereby varying the balance of said bridge circuit, a receiving circuit at the output end of said transmission medium, a second hybrid coil arrangement for impressing the energy received over said medium upon said receiving circuit, a second constant impedance element, a second variable impedance element, said second hybrid coil arrangement, said second constant impedance element and said variable impedance element being so arranged with respect to each other as to form a second Wheatstone bridge circuit, and means to vary the impedance of said second variable impedance element inversely in accordance with changes in the power level of the energy from said source.

13. In a transmission system, a source of energy of varying levels, a transmission line, a hybrid coil arrangement at the input end of said line, means to impress energy from said source on said line through said hybrid coil arrangement, a constant impedance element, a space discharge device having an input circuit and an output circuit, said hybrid coil arrangement, said constant impedance element and the output circuit of said space discharge device being arranged to form a Wheatstone bridge circuit, means to rectify a portion of the energy from said source, means to apply the rectified energy to the input circuit of said space discharge device so as to vary the impedance of said device directly in accordance with changes in the power level of the energy from said source, thereby varying the balance of said bridge circuit, a receiving circuit at the receiving end of said line, a second hybrid coil arrangement for impressing the energy received over said line on said receiving circuit, a second constant impedance element, a second space discharge device having input and output circuits, said second hybrid coil arrangement, said second constant impedance element and the output circuit of said second space discharge device being arranged to form a second Wheatstone bridge circuit, means to convey a portion of said rectified energy produced at the input end of said line to the output end of said line, and means to apply the conveyed rectified energy to the input circuit of said second space discharge device so as to vary the impedance of said second device inversely in accordance with changes in the power level of the energy from said source.

14. In a signaling system, a source of signaling energy, a transmission medium, an amplifier having an input circuit and an output circuit at the transmitting end of said medium, a hybrid coil arrangement, a variable impedance element, a constant impedance element, said hybrid coil arrangement, said variable impedance element, and said constant impedance element being arranged to form a Wheatstone bridge circuit, means to impress signaling energy from said source upon the input circuit of said amplifier through said hybrid coil arrangement, and to vary the impedance of said variable impedance element in said Wheatstone bridge circuit in accordance with changes in the power level of the energy from said source to change the balance of said Wheatstone bridge circuit, thereby controlling the loss through said hybrid coil arrangement, and means to impress the energy in the output circuit of said amplifier upon said medium.

15. In a transmission system, a source of energy, a transmission medium, an amplifier having input and output circuits at the transmitting end of said medium, said output circuit being connected to said medium, a Wheatstone bridge circuit comprising a hybrid coil arrangement, a variable impedance element and a constant impedance element, means to impress energy from said source on the input circuit of said amplifier through said hybrid coil arrangement, means to vary the impedance of said variable impedance element in said Wheatstone bridge circuit in accordance with changes in the power level of the energy from said source so as to compress the amplitude range of the energy impressed on said medium through said hybrid coil arrangement and said amplifier, a second amplifier comprising input and output circuits at the receiving end of said medium, a receiving circuit connected to the output circuit of said second amplifier, a second Wheatstone bridge arrangement comprising a second hybrid coil arrangement, a second constant impedance element and a

second variable impedance element, means to impress the energy received over said medium on the input circuit of said second amplifier through said second hybrid coil arrangement, means to transmit energy from said source to the receiving end of said medium, means to apply the transmitted energy to said second variable impedance element to vary its impedance inversely in accordance with changes in power level of the energy from said source, thereby expanding the amplitude range of the energy received by said receiving circuit through said second hybrid coil and said second amplifier.

16. In a signaling system, a source of signaling energy of varying volume, a transmission circuit comprising a main channel and an auxiliary channel, a high pass filter in said auxiliary channel, means to impress a portion of said signaling energy upon said auxiliary channel through said high pass filter, means to rectify the energy transmitted by said high pass filter, a low pass filter associated with the rectifying means and adapted to transmit the rectified energy below a preassigned frequency, a volume control device in said main channel responsive to the energy transmitted by said low pass filter means to impress signaling energy from said source upon said volume control device through said main channel, and means to load said main channel with inductance to synchronize the operation of said volume control device with volume changes in the energy impressed on said device through said main channel.

17. In a signaling system, a source of electrical energy representing speech or music having variations in volume, a transmission medium supplied with said energy, a space discharge device connected to said medium, means also connected to said medium for rectifying a portion of the energy from said source, means to produce a voltage from the rectified energy and apply the voltage to the device to control the impedance of said device in accordance with changes in the power level of the energy from said source, means to associate said device with said medium to introduce the impedance of said device into said medium, and means to prevent the variable impedance of said device from reacting on the amount of input supplied to said rectifying means.

18. In a transmission system, a source of signal impulses to be transmitted, means to impress said impulses on the system, a branch circuit including a space discharge device, means in said branch circuit for controlling the impedance of said device in accordance with the average volume of the signal impulses over limited time periods, and means for effectively introducing the impedance of said device into said transmission system to control the volume of the transmitted impulses.

19. In a transmission system, a source of speech energy of varying volume, a transmission medium supplied with said energy, means to rectify a portion of the energy input to the system, means responsive only to changes in the rectified energy below a preassigned frequency to continuously control the volume of energy transmitted over the system, and delay means in said transmission medium between the point therein where the volume of the transmitted energy is controlled and said source for compensating for the lag in operation of said control means.

20. In a transmission system, means to generate waves of electrical energy in the speech or music frequency range, a transmission line supplied with said energy, a three-electrode space discharge device having a grid circuit and an output circuit, said output circuit being connected to said line and offering an impedance to the energy transmitted thereover, means also connected to said line for rectifying a portion of the generated signaling energy, means for filtering out variations in the rectified energy above a preassigned frequency, means to impress the filtered rectified energy upon said grid circuit to control the impedance of said space discharge device, and delay means in the transmission line between the connection of said output circuit thereto and the wave generating means to compensate for the lag in the control of said impedance introduced by said filtering means.

In witness whereof, I hereunto subscribe my name this 12th day of March, A. D. 1925.

ROBERT C. MATHES.