

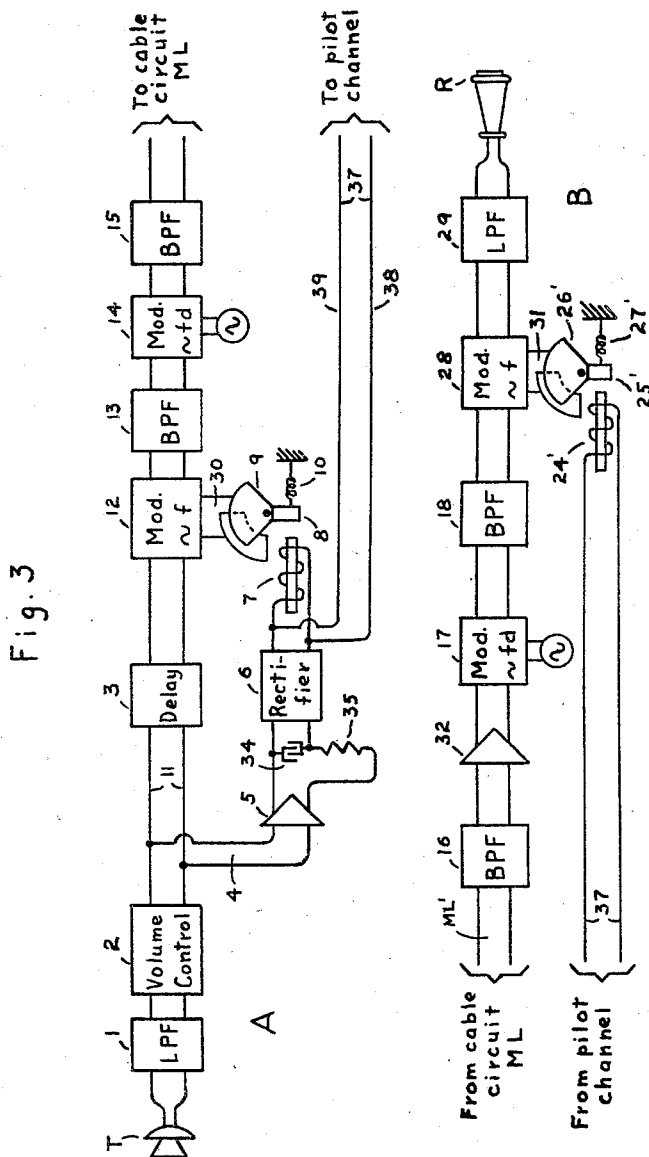
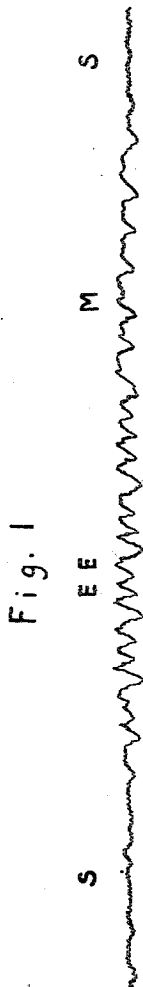
Sept. 10, 1935.

J. A. CSEPELY

2,014,081

WAVE TRANSMISSION SYSTEM

Original Filed Jan. 5, 1933 4 Sheets-Sheet 1



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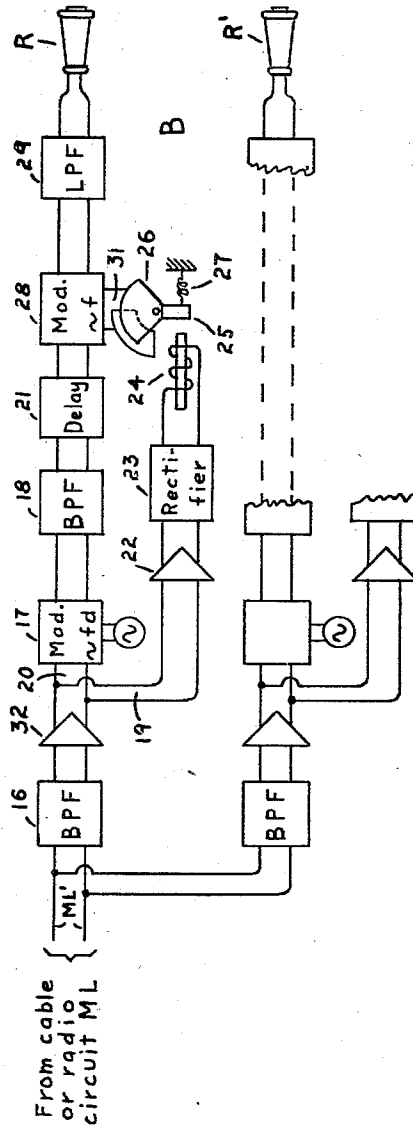
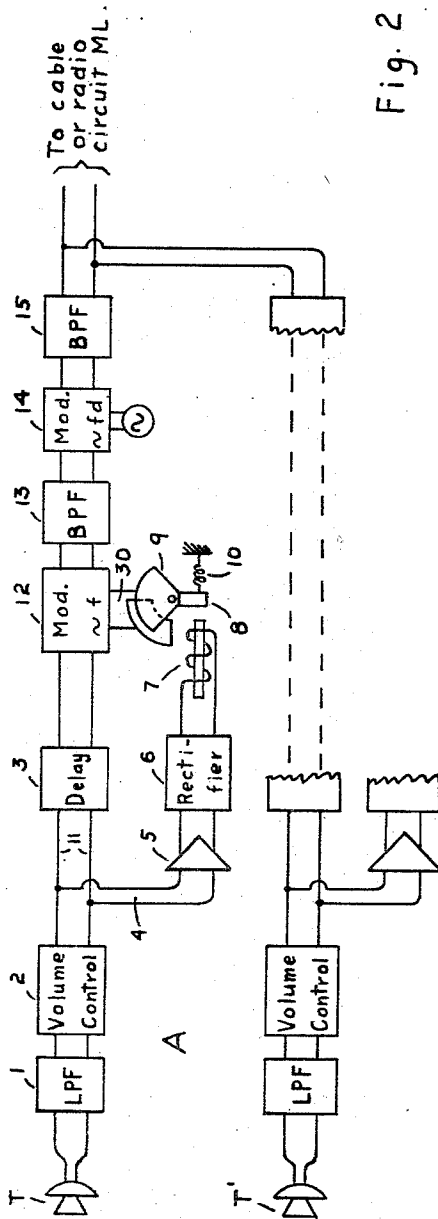
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WAVE TRANSMISSION SYSTEM

Original Filed Jan. 5, 1933 4 Sheets-Sheet 2



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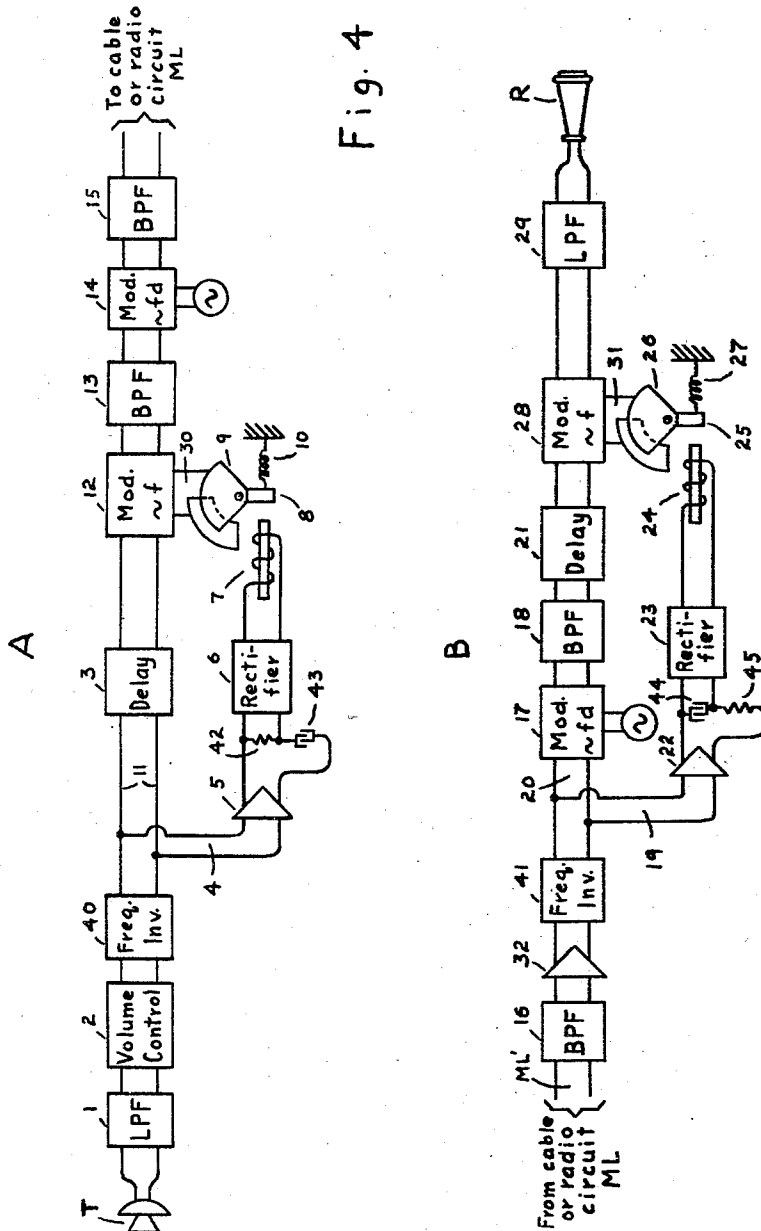
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2,014,081

WAVE TRANSMISSION SYSTEM

Original Filed Jan. 5, 1933 4 Sheets-Sheet 3



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2,014,081

WAVE TRANSMISSION SYSTEM

Original Filed Jan. 5, 1933 4 Sheets-Sheet 4

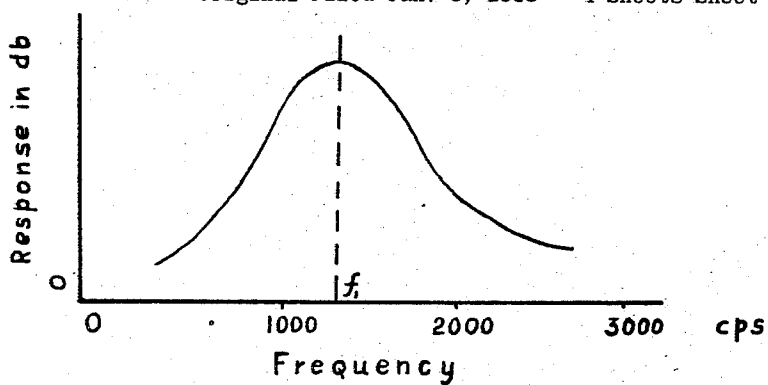


Fig. 5

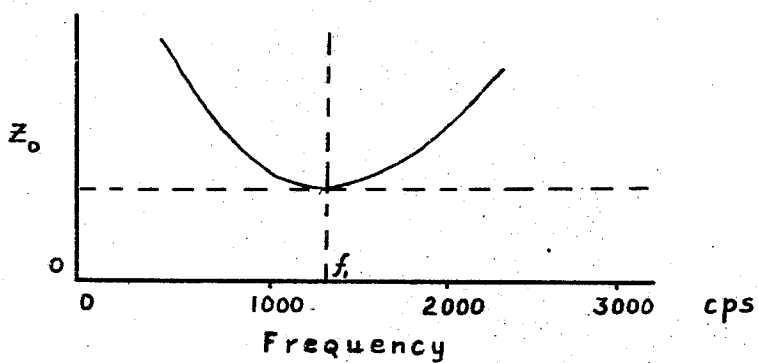


Fig. 6

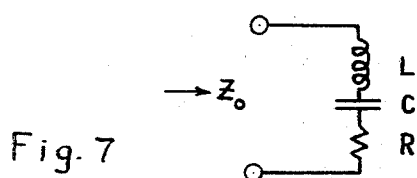


Fig. 7

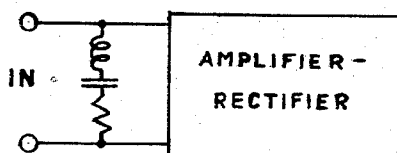


Fig. 8

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## UNITED STATES PATENT OFFICE

2,014,081

## WAVE TRANSMISSION SYSTEM

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Application January 5, 1933, Serial No. 650,253  
Renewed January 29, 1935

31 Claims. (Cl. 178—44)

This invention relates to wave transmission systems, either wire or radio, and particularly to the control of the frequency range of transmission in such systems.

An object of the invention is to provide methods of and means for effectively transmitting wave components having a wide range of frequencies over transmission systems inherently or purposely incapable of transmitting more than a narrow range of frequencies.

Certain embodiments of the invention also provide means for attaining greater secrecy in transmission. In such embodiments the input wave components are inverted either before, after or during frequency compression by means of a frequency inverter or modulator so that low frequencies are raised and high frequencies lowered. The relative energy contents of the converted frequencies, however, may remain substantially as they were before the frequency inversion. The inverted wave components are then transmitted to a distant station, preferably in a compressed frequency range and there reversed again either before, after or during frequency expansion, thereby reproducing the original amplitude and frequency relations of the wave components. By this means, also, the effect of static can be reduced.

A further object is to make possible an increase in the number of transmission channels over any wave transmission system. It is well recognized that if a plurality of messages are to be transmitted simultaneously over any transmission medium, the frequency bands of the several messages should not overlap. It is therefore desirable that the frequency band width for each carrier channel should be as narrow as possible in order to obtain as large a number of channels as possible over a given transmission medium.

In accordance with the preferred embodiment of the present invention, control of the frequency band width of transmission is obtained by introducing at each end of the transmission channel a frequency shifting circuit such as a modulator, the amount of frequency shift at any instant being a function of the power level of the wave components of the message. Compression of the frequency range at the transmitting end is obtained by shifting the frequency band downward or upward as the input level increases, and expansion at the receiving end is produced by a converse operation.

The invention will be described with particular reference to speech waves, altho the invention is equally applicable to other kinds of waves, such

as music, or those utilized in television, in which the characteristics hereinafter described are evidenced.

The invention depends upon the existence of certain characteristics in the waves which enable their sub-division into components of different amplitudes and frequencies, varying from instant to instant. The components of frequency occurring at any one instant do not fill the entire frequency range occupied by the waves occurring over a considerable period of time. In the case of speech the lower portion of the total frequency range is predominately occupied by the vowel and semi-vowel sounds. The upper portion is occupied principally by the stop and fricative consonant sounds. Also, both classes of sounds do not exist in speech in the same instant of time but they do sometimes occur in rapid succession. Moreover, the amplitudes of the vowel and semi-vowel sounds are larger than those of the stop and fricative consonants. The two classes can, therefore, be distinguished from each other in time, in frequency range and in amplitude or energy.

There is thus a fairly definite relationship, for example, in ordinary speech, between the frequency and energy content or amplitude of the constituent waves and I propose to take advantage of this relationship to shift the frequencies in any desired manner by means of a device which is responsive to the energy content. For example, if the speech at a given instant required the transmission of a vowel or semi-vowel sound embracing frequencies from 150 to 1,500 cycles, each frequency might be converted to a lower frequency by means of a frequency shifting circuit such as a modulator, the conversion being made, if desired, in such a manner that the converted frequencies will all bear the same ratio to the original frequencies. In this case the frequency shifting circuit used is arranged in such a manner as to vary the amount of frequency shift in proportion to the amplitude or energy content of the waves acted upon at any given instant. Accordingly, the amount of the frequency shift in the case of a vowel or semi-vowel sound might be relatively small.

If, on the other hand, the transmitted speech required a particular consonant reproduction, having a predominance of high frequencies and a relatively low energy content, the amount of the frequency shift might be relatively large.

For example, the frequency shift of a vowel sound such as the sound A, might be from a range of say 150 to 1500 cycles to a range of say 100 to 55

1000 cycles, whereas the frequency shift of a consonant sound such as the sound S, might be from a range of say 2000 to 3000 cycles to a range of say 1000 to 1500 cycles.

5 At the receiving end a second device responsive to the amplitude or energy content of the wave components controls a frequency shifting circuit which effects a change opposite to that produced in these components at the transmitting end.

10 It should be noted that the amount of frequency shifting need not be a linear function of the amplitude or energy content of the wave components acted upon, nor need the amplitude controlled frequency shifters at the transmitting and receiving ends perform exactly complementary operations. For example, in the case of a very long transmission line the high frequency components are attenuated more severely than the low frequency components. Accordingly, since the frequency shifter at the receiving end is amplitude controlled, it may be desirable to shift the frequency range of the low intensity high frequency components upward at the receiving end to a greater extent than the range was shifted downward at the transmitting end in order to restore the components to their proper or desired relation in the received speech.

As the shift and countershift of frequencies at opposite ends of the line occurs in response to changes in energy content of successive sounds transmitted and received, it is apparent that such shifts will occur automatically without the necessity of employing additional means to secure synchronism or proper timing of the shift controlling devices. However, in certain cases there may be advantages in employing additional synchronizing means which preferably operates through a synchronizing or pilot channel separate from the signal transmission channel. The pilot channel might be utilized to send control currents to the receiving end which will control the frequency shifter located there. The variations in the pilot power correspond to the envelope of the volume (or the average volume over any desired range of time) applied to the input of the transmitting frequency shifter control circuit. The pilot wave may be made a pulsating or varying direct current with a frequency spectrum smaller than that of the waves in the main transmission line, and hence the frequency band required for its transmission may be much less than that required for the transmission of speech. By the use of a pilot channel, therefore, the effect of line noise on the frequency shifter at the receiving station can be substantially eliminated.

The invention will be more fully set forth in the following detailed description of certain illustrative embodiments showing the preferred manner of practicing it, and the claims will define the invention not only as embodied in these illustrative examples, but also in a scope to embrace various other forms which it is capable of assuming in practice.

In the accompanying drawings, Figure 1 shows a graph that will be referred to in describing the action of the invention, Figures 2, 3 and 4 show terminal circuit diagrams in schematic form, of systems for carrying out the inventive idea and Figures 5 and 6 are diagrams illustrating a non-linear frequency response of a telephone transmitter, and the manner in which it may be corrected. Figure 7 is a diagrammatic view of one form of correcting circuit, and Figure 8 shows the manner of connecting the correcting circuit to the amplifier-rectifier circuits.

The three characteristics of speech upon which the practice of the present invention depends, namely frequency, amplitude and time of occurrence, are graphically illustrated in Figure 1 which shows approximately an actual oscillogram of the word "seems". For convenience, this oscillogram has been condensed so that relatively few undulations corresponding to each sound are given. This oscillogram shows, however, that the "e" and "m" sounds are of much greater amplitude than the sibilant sound "s". Also, the frequency of the sound "s" is shown by this oscillogram to be composed entirely of higher frequencies. It is not possible to determine exactly from this oscillogram whether the "s" and "m" sounds might possess higher harmonics, but at least the fundamental waves are seen to be of much lower frequency. It is also evident that the sounds occur in different instants of time.

With regard to the difference in amplitude between the vowel and semi-vowel sounds on the one hand and the consonant sounds on the other, it has been determined that, referred to a common reference level, the vowel and semi-vowel sounds are of the order of 10 db. or more greater in intensity than the consonant sounds.

The application of the invention to a particular system will first be described in connection with the apparatus shown schematically in Figure 2, comprising a sending station A and a receiving station B connected by a transmission line ML. It may be assumed for purposes of illustration that this is part of a carrier's telephone system and that it is desired to transmit a plurality of messages simultaneously, each having a band width of say 1500 cycles, one message occupying the frequency band say 7000 to 8500 cycles and another occupying the frequency band say 9000 to 10,500 cycles, other message bands being similarly displaced 500 cycles away with relation to each other. It will be understood by those skilled in the art that by means of suitable modulators and band filters the different messages may be separated from each other at the transmitting and receiving ends of the line and transmitted simultaneously without interfering with each other. Of course, speech could be transmitted by utilizing a frequency band width of 1500 cycles without the method of the present invention, but the quality of the received speech would be much impaired. However, in case it is desired to obtain a higher quality of received speech, the method of the present invention may be employed so as to in effect transmit a band width of say 3000 cycles for each message, as will be described in detail hereinafter.

In Figure 2 the transmitter T and the receiver R may be associated with the message occupying, when transmitted over the line ML, the frequency range 7000 to 8500 cycles, while the transmitter T' and the receiver R' may be associated with the message occupying the frequency range 9000 to 10,500 cycles when transmitted over the line. Equipment similar to that to be described in detail hereinafter may be utilized to compress the frequency range of transmitter T', and the compressed frequency range may then be shifted by modulation so as to occupy the proper place in the frequency spectrum. Other apparatus similarly disposed may be utilized for the remaining messages to be transmitted. The following description, however, will be confined to the message band assigned to transmitter T and receiver R, it being understood that similar circuit

operations may be performed in connection with the remaining message bands.

In Figure 2 the input band of frequencies originating in transmitter T and extending from 0 to 3000 cycles, is transmitted through a low pass filter 1 to eliminate any extraneous frequencies present. It is then passed through a volume control circuit 2 for making the volume level of the speech waves approximately the same for all users of the same transmission channel ML. This volume control may be of any suitable type, either automatic or manual, or both, but preferably automatic. The purpose of this volume control in this system, and also in the systems of Figures 3 and 4, will be described in detail later.

The output of volume control 2 is connected to two branch circuits 4 and 11. The former of these circuits includes an amplifier 5 and a rectifier 6 and is for the control circuit. The latter circuit includes delay device 3 and is for the message channel. The control circuit includes the electromagnet 7 which controls the armature 8 of the variable condenser 9, and by its pull will determine the exact capacity introduced in circuit 30.

The output side of delay device 3 leads to variable frequency modulator 12, and the frequencies applied to it are there modulated on a carrier frequency  $f$  which varies say from 18,500 to 20,000 cycles, depending upon the energy content of the impressed wave components. The manner in which this is accomplished in the present system is as follows:—For example, let it be assumed that at a given instant the predominant frequencies in the message band lie between 150 and 1500 cycles and that the amplitude or energy content of the wave components is a maximum. This high energy content actuates electromagnet 7 powerfully and thus decreases the capacity in circuit 30. This will tend to increase modulator frequency  $f$  to, for example, 20,000 cycles. The message band of 150 to 1500 cycles which passes along the message path 11, through the delay circuit 3, will finally be impressed upon modulator 12, where it will be modulated by 20,000 cycles.

The purpose of the delay device 3 will now be explained. In order that the variations in modulator frequency  $f$  will follow an envelope of the volume (or the average volume over any desired range of time) applied to it, it may be necessary to introduce a time lag in the variations of modulator frequency  $f$ , in which case the change in modulator frequency  $f$  will no longer be simultaneous with volume changes in the applied energy. In the present system, the required time lag is obtained by the use of variable condenser 9, whose inertia, in combination with the restoring spring 10, is such that the motion of the movable plates of the condenser will substantially follow the envelope of the volume. Any other desirable means for control might be utilized. It may therefore be necessary to introduce delay devices, such as acoustic delays, in the main transmission path to compensate for these differences in time. These acoustic delays may consist of suitable pipes terminating in audible responsive devices, such as transmitters and receivers, and equalizing networks to equalize the frequency response characteristics of the interconnecting pipe. By making the pipes of suitable length, the delay introduced by the transmission of sound through the air in the pipes may be made as large as desirable. Other delay circuits

such as electrical delay networks may be utilized, if desired.

The purpose of volume control 2 will now be explained. In a signal transmission system, signals which have very different average volume levels are in many cases received at the transmitting station. The significant momentary volume range in most cases is substantially the same, but may vary. The difference in the average volume level of the received signals may be caused by toll lines in telephone systems of different electrical lengths and by speakers who talk loudly and softly. The average volume level of any given speaker may also vary during a conversation. Since the practice of the present invention is based on the relative amplitudes or energy contents of high and low frequency wave components, it is evident that the message volume levels of these two classes of components should remain substantially constant for uniform performances. It may therefore be necessary to introduce volume controls in the main transmission paths to compensate for the possible variation of average volume with time, and to maintain a substantially constant maximum peak level. The volume controls when used in the present system would have a relatively large time lag so that their adjustment will not be changed for instantaneous variations in speech level but so that they will regulate only the average speech level over a considerable period of time.

The filter 13 passes one of the side bands, say the upper side band, of the wave components delivered by modulator 12. In the example previously given this upper side band will be 20,150 to 21,500 cycles. This upper side band passes through the filter 13, which cuts off the lower side band and the other unwanted products of modulation, and the upper side band is applied to modulator 14. This modulator will have a fixed frequency  $fd$  say 28,650 cycles, and operate to step down the frequencies of the transmitted side band to the band say 7150 to 8500 cycles, which is applied to the transmission line ML after passing through band pass filter 15, the other components of modulation being outside the transmission range of the filter and therefore suppressed. Instead of shifting the frequencies of the transmitted side band to the band 7150 to 8500 cycles the modulator 14 may be arranged to shift the band of frequencies into any other band of 1500 cycle width such as the band say 9150 to 10,500 cycles, and this band of frequencies may be applied to the line through a suitable band pass filter. If desired, separate modulators may be used to accomplish this result. It will be seen that by this means, separation may be obtained between separate messages simultaneously transmitted over the line ML.

Let it be assumed that at another given instant the predominant frequencies in the message band supplied by transmitter T lie between say 2,000 and 3,000 cycles and that the energy content of the wave components is low. This low energy content will cause electromagnet 7 to be actuated less powerfully than before, and the restoring spring 10 will therefore operate to increase the capacity in circuit 30. This will tend to decrease the modulator frequency  $f$  to, for example, 18,500 cycles. The message band of 2000 to 3000 cycles will then be modulated by 18,500 cycles and the upper side band will be 20,500 to 21,500 cycles. When this is demodulated by  $fd$ , or 28,650 cycles, the result will be a band occupying a range in

the frequency spectrum of 7,150 to 8,150 cycles, which passes through band pass filter 15 to the transmission line ML. Obviously, these values assumed for  $f$  and  $fd$  are only for purposes of illustration, and other values may be used.

At the receiving station B of Figure 2 is shown receiving apparatus suitable for use with the arrangements of the invention. The 1500 cycle message bands are impressed on receiver circuit ML', and the band say 7000 to 8500 cycles may be transmitted by band pass filter 16, the other bands being outside of the transmission range of the filter and therefore suppressed. Other band pass filters may be utilized, each one passing one of the remaining frequency bands and rejecting the others, and these filters may be associated with receiving apparatus similar to that described in detail hereinafter. In this manner the separate message bands may each be selected by the proper receiving equipment, there to be reconverted to the original transmitter frequency range for transmission to the associated receiver.

The circuit for the band say 7000 to 8500 cycles includes band pass filter 16 and amplifier 32, and is part of the message receiving circuit for this band. The message receiving circuit includes a double modulator arrangement comprising modulator 17 having the fixed frequency  $fd$  similar to the fixed frequency  $fd$  of modulator 14 at the sending station, a band filter 18, a delay device 21 providing a delay similar to that provided by delay circuit 3 at the sending station, a modulator 28 having the variable frequency  $f$  similar to variable frequency  $f$  of modulator 12 at the sending station, a low pass filter 29 and a receiver R.

To the output of amplifier 32 are connected two branch circuits 19 and 20. The former circuit includes modulator 17. The latter circuit includes amplifier 22 and rectifier 23 and is for the control circuit. The electromagnet 24 in the control circuit controls the armature 25 of a variable condenser 26 equipped with a restoring spring 27, and consequently the position and hence the capacity of condenser 26 are determined by the energy content of the incoming wave components of the message band. The movable plates of condenser 26 should accordingly follow successively the changes in energy content so as to produce a countershift corresponding to the shift produced by modulator 13. The oscillator circuit 31 of modulator 28 will have its frequency varied by the condenser 26. The control circuit is therefore arranged to perform functions similar to those performed by the control circuit at the sending station.

By this double modulator arrangement at the receiving station, the frequency band will be returned to its normal position in the frequency scale for transmittal to the receiver R. For example, let it be assumed that at a given instant the predominant frequencies in the voice band originating in the transmitter T were from 2000 to 3000 cycles and that the energy content of the wave components were relatively small. It has been pointed out that this band would be shifted so as to occupy during transmission a range of say 7,150 to 8,150 cycles. At the receiving station, this band would be modulated in modulator 17 by the frequency  $fd$ , or 28,650 cycles, and the lower side band would be 20,500 to 21,500 cycles. The control circuit 19 would cause condenser 26 to make the frequency  $f$  the same as the frequency  $f$  at the sending station at the same relative point of the envelope of the received volume (or the average received volume over any desired range

of time). Hence the frequency  $f$  would equal 18,500 cycles. The result of the modulation in modulator 28 would be to transmit a band of frequencies through low pass filter 29 ranging from 2000 to 3000 cycles, the other components of modulation being outside the transmission range of the filter and therefore suppressed. In other words, the voice band would be reshifted to its original position in the frequency scale for transmission to the receiver R.

It should be pointed out that, in the embodiment of the invention disclosed, the modulator frequency  $f$  at the transmitting and receiving station varies in a substantially gradual or continuous manner in accordance with the variations in the envelope of the transmitted volume (or the average transmitted volume over any desired range of time), thus avoiding the occurrence of disturbing transient phenomena, and the undesirable modulation products which would result if rapidly varying modulator frequencies unrelated to the envelope of the transmitted volume were utilized.

It will be seen that a saving in frequency range of 1500 cycles per second has been effected since the components in the range 0 to 3000 cycles have been transmitted in a band width of 1500 cycles over the line ML.

As previously stated, it may be desirable in some instances to synchronize the frequency shifting arrangements at the transmitting and receiving stations by means of a pilot channel, and also to improve the performance of these arrangements in the presence of relatively high frequency wave components. Furthermore, it may be desirable to utilize a pilot channel in order to maintain the desired correspondence between the modulator frequencies at the transmitting and receiving stations. An arrangement for accomplishing these results is shown in schematic form in Figure 3 which will now be described.

In the circuit of Figure 3 the apparatus is similar to that shown in Figure 2 with the exception of the control circuit 4 at the transmitting station, and the control circuit at the receiving station. Also, the equipment for the second message band, including transmitter T' and receiver R', has been omitted for the sake of simplicity, and delay device 21 has been omitted. The changes in the control circuits are as follows:— At the transmitting station the output side of amplifier 5 leads to an arrangement of condenser 34 and resistance 35 connected in series. As is well known, the condenser 34 presents a relatively low impedance to high frequency waves and a relatively high impedance to low frequency waves. The resistance 35 may be one having a low temperature coefficient, in which case it will present a relatively constant impedance to currents of different energy levels. It will be noted that the voltage drop across the condenser 34 is the one impressed upon the input of rectifier 6. It is evident that, for a given energy level in path 4, the voltage drop applied to the input of rectifier 6 will be less when high frequencies are present than when only low frequencies are present, and that therefore this circuit arrangement will function to supply less current for actuating electromagnet 7 when high frequency wave components are present than would be the case in the corresponding circuit arrangement of Figure 2. The purpose of this arrangement of condenser 34 and resistance 35 is to make it easier for the control circuit to discriminate between

high and low frequency wave components. Other circuit arrangements for accomplishing similar results may be utilized, if desired.

To the output of rectifier 6 are connected the branch circuits 36 and 37. Circuit 36 includes the electromagnet 7. Circuit 37 is for the pilot channel. The control of the frequency shifting arrangements at the receiving station is effected by means of rectified power from rectifier 6 being transmitted over the pilot channel 37 to the electromagnet 24' at the receiving station. The pilot channel may comprise the wires 38 and 39 or it may comprise a suitable channel utilizing a separate frequency range of ML outside the message band, by connecting 38 and 39 to ML through a suitable filter. The band of frequencies comprising the pilot power may be shifted by modulation to the desired frequency range, and suitable amplifiers may be utilized at the transmitting and receiving ends.

The effect of this pilot current at the distant station may be seen by considering that an electromagnet similar to 7 has been actuated at the distant station. It is obvious that electromagnet 24' at the receiving station may be made to actuate the armature of condenser 26' in a manner similar to that produced by electromagnet 7 on the armature of condenser 9.

As in the case of Figure 2, when the electromagnet 7 actuates the armature of condenser 9, the capacity in the circuit 30 is varied to change the modulator frequency  $f$  in accordance with the energy level of the applied wave components. However, the variation in capacity of condenser 9 with energy input to electromagnet 7 may be made to follow a different law from that followed by the corresponding condensers in Figure 2 on account of the effect of the circuit arrangement of condenser 34 and resistance 35 on the currents actuating electromagnet 7. Also, as in Figure 2, it may be found desirable to cause the change in capacity of condenser 9 to follow a non-linear relationship with the currents actuating electromagnet 7. This may be accomplished in the present system by utilizing suitable shapes for the plates of condenser 9. Other arrangements for varying the modulator frequency  $f$  in accordance with certain desired relationships between modulator frequency  $f$  and electromagnet actuating current may be used. Any other desirable means for control might be utilized.

Similar means may be utilized at the receiving station for varying the modulator frequency  $f$  of modulator 28 in accordance with any desired relationship to the energy content of the received wave components.

In the case of a very long transmission line, the high frequency components are attenuated more severely than the low frequency components and therefore require greater amplification. It may also be desirable, before transmission, to increase the relative amplitude of the lower intensity components so as to enable them to override noise present on line ML. One advantage in using a pilot channel, therefore, resides in the fact that the actuation of the receiver electromagnet 24' is not dependent upon the relative levels of the consonant and vowel sounds as received over the main transmission channel, and hence the relative power variations in the pilot channel and the main transmission channel may be made to suit any requirements as to noise, attenuation, etc.

Unless the oscillators at the transmitting and

receiving stations are sufficiently stable in frequency, impaired quality may result in receiver R. It may therefore be desirable to employ a pilot channel to maintain the desired correspondence between the oscillator frequencies at the two stations. This may be accomplished by transmitting a master control frequency over conductors 38 and 39 or by transmitting this control frequency over line ML, utilizing a frequency band outside of the several message bands, and employing suitable amplifiers and band filters. This control frequency may be supplied by a master oscillator located at the transmitting station and may be arranged to control the absolute frequencies of the oscillators at both ends by means well known to the art. In systems where the carrier frequency is unsuppressed, as in some types of carrier telephone systems, the carrier frequency of one of the message bands may be utilized as the master control frequency. Other means for obtaining the desired correspondence between the oscillator frequencies at the sending and receiving stations may be used, if desired.

As previously mentioned it may be desirable in some cases to invert the frequencies of the wave components before transmission in order to increase the secrecy of transmission and also to reduce the effect of static on a radio channel. An arrangement for accomplishing these results is shown in schematic form in Figure 4 which will now be described.

In the circuit of Figure 4 the apparatus is similar to that shown in Figure 2 with the exception of the frequency inverters 40 and 41 in the message channel at the sending and receiving stations and the control circuits for the electromagnets 7 and 24. Also, the duplicate equipment for the second speech band, including transmitter T' and receiver R' has been omitted. In the message channel at the transmitting station, the output of volume control 2 is connected to the input of frequency inverter 40, which is a device well known to the art. Frequency inverter 40 may be of any desired type. For example, in the present system the frequency inverter is arranged to convert the input frequencies in such a manner that an input frequency of say 2500 cycles is shifted by means of suitable modulators and band filters to a frequency of say 500 cycles in the output, and an input frequency of say 1000 cycles may be shifted to an output frequency of say 2000 cycles. The frequency inverter may be so arranged that the relative powers of the high and low frequency wave components are not thereby substantially changed. Any other desired form of frequency inversion may be utilized, if desired.

To the output of frequency inverter 40 are connected two branch circuits 4 and 11, the former being for the control circuit and the latter for the message channel. The apparatus in the message channel following frequency inverter 40 performs functions similar to those performed by the similarly designated apparatus in Figure 2.

The arrangements for the control circuit are similar to those of the similarly designated control circuit in Figure 2 except for the following changes:—The output side of amplifier 5 leads to an arrangement of resistance 42 and condenser 43 connected in series. The resistance 42 may be one having a low temperature coefficient. It will be noted that the voltage drop across the resistance 42 is the one impressed upon the in-

put of rectifier 6. It is evident that this circuit arrangement performs the converse operation to that performed by the circuit arrangement of condenser 34 and resistance 35 in the control circuit of Figure 3. This converse operation may be desired since in the arrangements of Figure 4 the higher frequency wave, components impressed on modulator 12 are now the components having the higher energy content. The output of rectifier 6 is connected to the electromagnet 7, which performs functions similar to those described in connection with Figures 2 and 3.

As a result of the addition of frequency inverter 40 to the message channel, there will be applied to the radio circuit ML a band of frequencies say 1500 cycles wide in which the wave components having the higher frequencies will also be the components having the higher energy content. It is evident that this relationship is the reverse of that existing in the corresponding transmission channel ML of Figures 2 and 3. It is also evident that this inversion of frequencies in the transmission channel will increase the secrecy of the transmitted message. The manner in which frequency inversion may reduce the effect of static in the received speech will be explained in detail later.

In the message channel at the receiving station the output of amplifier 32 leads to the input of frequency inverter 41. In the present system, frequency inverter 41 performs the inverse operation to that performed by the frequency inverter at the sending station. For example, a received frequency of say 2500 cycles may be shifted to a frequency of say 500 cycles and a frequency of say 2000 cycles to a frequency of say 1000 cycles. The output of frequency inverter 41 is therefore composed of high frequency components of relatively low energy content and low frequency components of relatively high energy content, the relative energy and frequency relations being the same as those occurring at the input of frequency inverter 40 at the sending station. To the output of frequency inverter 41 are connected two branch circuits 19 and 20. Circuit 20 includes modulator 17 and is for the message channel. Circuit 19 includes amplifier 22 and is for the control circuit. The apparatus in these branch circuits perform functions similar to those performed by the corresponding apparatus at the sending station except that in the control circuit the voltage drop across the condenser 44 is applied to the input of rectifier 23 instead of the voltage drop across resistance 45. It is evident that this circuit arrangement of resistance 45 and condenser 44 will perform the inverse operation to that performed by resistance 42 and condenser 43 at the sending station. The purpose of this arrangement as in similar arrangements previously described, is to accentuate the difference in energy content between low and high frequency wave components. As it happens, in circuit 19 the low frequencies will have the greater energy content, and consequently the arrangement 44, 45 is designed to pass those low frequencies more readily than the higher frequencies of less energy content.

The manner in which frequency inversion may be utilized in the method of the present invention to reduce the effect of static in the message appearing in receiver R will now be described. In the transmission of speech by radio and predominant energy in the static picked up in the radio channel ML resides in the higher parts of the message band centering about a frequency in the

order of 1500 cycles. The frequency response characteristics of the human ear are such that frequencies in the order of 1500 cycles are much more audible than frequencies in the order of 500 cycles having the same energy level. It will be evident that the frequency inverter at the receiving station will tend to shift the higher frequency components of static down to a lower frequency range, thereby producing less audible response in the human ear. It will also be evident that the relatively high energy content of the static frequencies in the neighborhood of 1500 cycles will tend to actuate electromagnet 24 most powerfully, thereby reducing the frequency shift caused by modulator 28. Further, it is clear that the energy content of the higher frequency wave components applied to the input of modulator 28 will be less affected by the higher frequency static components since the latter have been shifted down to a lower frequency range. The net result will be a tendency to shift the static frequency components down among the relatively low frequency, high energy vowel components of speech and thereby remove them from the higher frequency, lower energy consonant components of speech. It will be evident to those skilled in the art that this arrangement will therefore tend to increase the intelligibility of the received speech in the presence of static.

It should be pointed out that it may be possible to reduce static interference without resorting to frequency inversion by utilizing the method of the present invention as disclosed, for example, in Figures 2 and 3. To illustrate, the arrangements of Figure 2 may be utilized to transmit a message band width of 1000 cycles, whereby the higher energy components of the static frequencies in the neighborhood of 1500 cycles are substantially eliminated.

In a similar manner, the method of the present invention as disclosed, for example, in Figures 2 and 3, may be utilized to increase the signal-to-noise ratio in the received message band, by making use of the fact that in wire telephony the predominant noise frequencies in the transmission line occupy a range below 1000 cycles. To illustrate, the arrangements of Figure 2 may be utilized to compress the message band width to say 1500 cycles at the sending station, to shift the frequency level of the compressed band so that it occupies the range say 1500 to 3000 cycles, to transmit this compressed and shifted band to a receiving station, to shift the frequency level of the received band so that it occupies the range say 0 to 1500 cycles, and to expand the shifted band to the range say 0 to 3000 cycles for transmission to the receiver. It is evident that by the use of suitable band pass filters the dominant noise frequencies may thereby be suppressed at the receiving station and that, as a result, the ratio of signal to noise energy in the received message may be increased.

It is to be noted that while separate frequency inverters have been used in the arrangements of Figure 4, it may be found desirable to eliminate them and to utilize instead the variable frequency modulators at the sending and receiving stations for this purpose. The manner in which these modulators may be used to accomplish this result is as follows:— For example, let the frequencies originating in transmitter T range from say 250 to 3000 cycles. Also, let the frequency  $f$  of the variable frequency modulators vary from say 8,750 to 10,250 cycles and let the fixed frequency  $f_d$  of the fixed frequency modulators be say 7000 cycles.

Also, let the band pass filters at the output of these modulators be arranged to transmit the lower side band and suppress all other unwanted frequencies. Also, let the variable frequency modulators be of the balanced modulator type whereby the modulator frequency may be suppressed at the output of these variable frequency modulators. By referring to the following schedule it will be seen that frequency inversion has been combined with frequency compression.

| Input frequency | Variable modulator frequency $f$ | Frequency passed by BPF #1 | Fixed modulator frequency $f_d$ | Frequency passed by BPF #2 |
|-----------------|----------------------------------|----------------------------|---------------------------------|----------------------------|
| 3000            | 10250                            | 7250                       | 7000                            | 250                        |
| 2000            | 9500                             | 7500                       | 7000                            | 500                        |
| 1000            | 9000                             | 8000                       | 7000                            | 1030                       |
| 250             | 8750                             | 8500                       | 7000                            | 1500                       |

It should be noted that the reason for employing variable frequency modulators of the balanced modulator type in this system resides in the fact that, as illustrated in the above schedule, the modulator frequency may be very close to the side band frequency transmitted by the filter connected to the output of the inverting modulator. Thus it may be difficult to suppress the modulator frequency in the filter. It should be pointed out that frequency inversion utilizing inverting modulators of fixed frequency requires that the filter connected to the output of the inverting modulator be arranged to transmit the lower side band only of said modulator. However, in the embodiment of the invention now being described, a variable modulator frequency under the control of the power level of the applied wave components is employed both as the frequency inverter and as the frequency compressor or expander. Since the frequency of said variable frequency modulator may be made to vary in any desired manner in accordance with changes in the power level, it is evident that these arrangements may be made to accomplish frequency inversion by transmitting the upper side band of said modulator through a suitable band pass filter. Of course, the above schedule has been used merely for purposes of illustration and other frequencies may be employed.

It should be pointed out that the frequency response of the average telephone transmitter is not linear but is most efficient in the frequency band centering about a frequency of about 1000 cycles. It may therefore be desirable in some instances to compensate for this non-linearity of such a transducer by providing an appropriate compensating arrangement, such as a tuned input circuit, in the control circuits of Figures 2, 3 and 4. One form of circuit for correcting for the non-linearity of the transmitter, is illustrated in Figure 7. This circuit consists of an inductance  $L$ , capacity  $C$  and resistance  $R$  in series. The inductance capacity and resistance of the circuit shown in Figure 7 are of such values that the circuit is broadly resonant at approximately the frequencies at which the transmitter is most efficient. Thus in Figure 5, plotting the response of the transmitter against the frequency, it is seen that at a frequency of approximately 1200, the transmitter has its maximum efficiency. If the inductance capacity and resistance of the circuit shown in Figure 7 are so proportioned as to be broadly resonant at this same frequency, and if the circuit shown in Figure 7 is connected across the input circuit to the amplifier-rectifier,

as shown in Figure 8, the curve shown in Figure 6 will represent the energy passed on the amplifier-rectifier for different frequencies of the same energy content. By employing this circuit in conjunction with a transmitter having the frequency characteristic, as shown in Figure 5, the resulting overall frequency response characteristics of the transmitter-amplifier-rectifier combination may be made substantially linear. Of course, in cases where a substantially linear response microphone is used, such compensating arrangements may not be required.

While in the description of Figure 4 the received message band was assumed to be first inverted in order to permit the control circuit to function on low energy wave components in a manner similar to the other control circuits described, the input message band could have been inverted in amplitude or frequency and the control circuits arranged to reduce the frequency level in the presence of high energy wave components instead of low energy wave components. Many other variations may also be introduced as to the side bands which will be retained, as to the proportion of the message band to be compressed or expanded, as to the width of the transmitted frequency band to be used, as to the frequency of the energy volume change to be employed as the control means for the frequency shifting arrangements, or as to the particular apparatus to be employed for carrying out the invention, all leading to substantially the same results, and it is to be understood that they are included in this invention.

Having now described my invention what I claim and desire to secure by Letters Patent is:

1. In a signaling system, means for generating signaling energy of varying volume for transmission over a signaling path, a frequency shifting device in said path, and controlling means operating to cause the amount of frequency shift produced by said device to be a function of the average volume of said energy over limited times so as to control the frequency level of energy passing over the signaling path.

2. In a signaling system, means to generate signaling currents having variations in amplitude, a transmission circuit, a frequency inverter circuit including a variable frequency modulator device, means to impress said signaling currents on said transmission circuit through said frequency inverter circuit, the amount of frequency inversion in said frequency inverter circuit being determined by the modulator frequency of said variable frequency modulator device, and means to control the modulator frequency of said device in accordance with the amplitude level of said signaling currents impressed on said transmission circuit.

3. In a transmission system, a source of waves of electrical energy, a transmission path supplied with said energy, and means to control the frequency level of energy transmitted over said path comprising a variable frequency modulator device having a variable impedance for varying the modulator frequency, means to produce a control current varying in accordance with the volume level of the energy from said source, means to vary said control current in accordance with the frequency level of the energy from said source, and means to apply said varied control current to said variable impedance to control the modulator frequency of said device.

4. In a transmission system, a source of energy of varying power levels, a transmission path, a

frequency inverter at the input of said path, means to impress energy from said source on said path through said frequency inverter, a variable frequency modulator device having a variable impedance to vary the modulator frequency, a fixed frequency modulator device, means to rectify a portion of the energy from said source, means to apply the rectified energy so as to vary said variable impedance to vary the frequency of said variable frequency modulator device in accordance with changes in the power level of the energy from said source, thereby shifting the frequency level of the energy from said source, a receiving circuit at the receiving end of said transmission path, a second frequency inverter for inverting the frequencies of the energy received over said path, a second variable frequency modulator device having a variable impedance to vary the frequency of said second variable frequency modulator device, means to convey a portion of said rectified energy produced at the input end of said transmission path to the output end of said path, and means to apply the conveyed rectified energy to the second variable impedance so as to vary the modulator frequency of said second variable frequency modulator device in accordance with changes in the power level of the energy from said source.

5. A system according to claim 3 including volume control means to maintain a constant maximum peak level for the transmitted signals.

6. A system according to claim 3 including means to provide a plurality of sending and receiving apparatus for simultaneous sending of plurality of messages, means to separate the several message bands at the sending and receiving stations, and means to provide separate channels in the transmission path for each of said message bands.

7. A system according to claim 3 including means to provide a tuned input circuit in the control circuit whereby compensation for non-linearity in the frequency response of the transmitter is accomplished.

8. In the operation of a transmission system having a transmitting station supplied with signals having variations in volume, for transmission to a receiving station, the method which consists in smoothly and continuously shifting the frequency level in accordance with the volume level of the signal energy so that the frequency band width required for the transmission channel is reduced and expanding said reduced band at the receiving station in accordance with the relative changes in volume level of said reduced band.

9. In the operation of a transmission system having a transmitting station supplied with signals having variations in volume for transmission to a receiving station, the method which consists in gradually and smoothly shifting the frequency level in accordance with the volume level of the signal energy so that the frequency band width required for the transmission channel is reduced.

10. In the operation of a transmission system having a transmitting station supplied with speech energy having variations in volume and frequency level, the method which consists in gradually and smoothly shifting the frequency level in accordance with the volume level of the low frequency vowel sounds and the high frequency consonant sounds whereby both vowels and consonants are transmitted in a band of

frequencies less wide than that occupied by the sounds as produced.

11. In the operation of a transmission system having a transmitting station supplied with speech energy having variations in frequency level, the method which consists in gradually and smoothly shifting the frequency level in accordance with the transient level of the low frequency vowel sounds and the high frequency consonant sounds whereby both vowels and consonants are transmitted in a band of frequencies less wide than that occupied by the sounds as produced.

12. In a signaling system, the method of signaling wherein a band of frequencies of reduced width is transmitted from a sending station to a receiving station, which method comprises modulating the message to a carrier wave whose frequency varies in accordance with the power level of the message, thereby producing a wave band of less width than the band width of the original message, transmitting the modulated wave band, suppressing the modulation components outside the transmitted wave band, and demodulating this wave band at the receiving station with a similarly varying carrier frequency.

13. In a signaling system, the method of reducing the signal frequency band of width A to one of a narrower width B which consists in modulating the message to a carrier wave whose frequency is a function of the power level of the message, this function being such that the carrier frequency varies over a range A—B as the power level varies over a predetermined range, and suppressing all frequencies except those in the band of width B.

14. In a signaling system, the method of transmitting a message of frequency band width A by one of a narrower width B, which consists in modulating the message to a carrier wave whose frequency is a function of the power level of the message, this function being such that the carrier frequency varies over a range A—B as the power level varies over a predetermined range, transmitting the band of width B and demodulating this at the receiving station with a carrier of similar varying frequency.

15. In a signaling system, the method of reducing static interference which consists in compressing the frequencies of a message band so that the frequency level of the transmitted band is considerably removed from the dominant static frequency range, transmitting the compressed message band to a receiving station, suppressing substantially all frequencies not in the received compressed message band, and expanding the received message band, whereby the dominant static power is substantially eliminated.

16. In a signaling system, the method of reducing static interference which consists in inverting the frequencies of the signal to be transmitted, shifting the frequencies of the signal so that the frequency level of the transmitted band is considerably removed from the dominant static frequency range, transmitting the inverted shifted signal frequency band to a receiving station, suppressing all frequencies not in the received signal band whereby the dominant static frequencies are removed, inverting and counter-shifting the received signal band, whereby the included static frequencies are shifted beyond the range of maximum audibility.

17. In a signaling system, the method of increasing the signal-to-noise ratio which consists in shifting the frequencies of a message band to

be transmitted so that the frequency level of the transmitted band is considerably removed from the dominant noise frequency range, transmitting said shifted band to a receiving station, suppressing all frequencies not in the received message band whereby the dominant noise frequencies are removed, and countershifting the received message band to its normal range, whereby the included noise frequencies are substantially eliminated.

18. The method of reducing the frequency band width for transmission over a signaling channel which consists in utilizing a portion of the signal energy input to the system to effect a continuous shift of the frequency band in response to relatively slow changes in the energy level below a predetermined energy level change frequency, while preventing more rapid changes of the energy level from affecting the frequency band.

19. In a transmission system of limited frequency range having a transmitting station supplied with signals having different average volume levels, the method which consists in first controlling the volume range and then compressing the frequency range by smoothly and gradually shifting the frequency level in accordance with changes in volume level of said signals.

20. In the operation of a transmission system having a transmitting station supplied with signals having variations in volume and frequency level, the method which consists in smoothly and gradually shifting the frequency level in accordance with the volume and frequency level of the signal energy so that the frequency band width required for transmission is compressed, and in expanding the frequency range of the signals at the receiving station by restoring to their former frequency level those components of the signal which were shifted in frequency.

21. In a signaling system, a signaling path, means for generating signal variations having characteristics of varying volume and frequency, means for altering the range of variations of one of said characteristics in accordance with the average variation over short periods of time of the other characteristic while preserving the relative value of the variations of said other characteristic throughout the transmission over said path, and again changing the variations of said one characteristic so as to return the variations of said one characteristic to their original value.

22. In the operation of a signaling system, a method of signaling wherein a band of frequencies of reduced width is transmitted from a sending station to a receiving station, which method comprises modulating the message to a carrier wave whose frequency is in excess of 7,000 c. p. s. and whose frequency varies smoothly and continuously in accordance with undulations of the relative power of the message thereby producing a wave band of less width than the band width of the original message and transmitting the wave band so modulated to the receiving station and demodulating in accordance with said undulations of power level.

23. In a system for transmitting a plurality of signals simultaneously over a single transmission medium, the method of transmitting messages of frequency band of width A by one of a narrower width B which consists in modulating one message to a carrier wave whose frequency is a function of the power level of said message and this function being such that the carrier wave range is A—B as the power level varies over a predeter-

mined range and in modulating a second message to a carrier wave whose frequency is a function of the power level of said second message, this function being such that the carrier frequency varies over a different range of width A—B as the power level varies over a predetermined range and transmitting to a receiving station the compressed message bands of widths B.

24. In a system for transmitting a plurality of signals simultaneously over a single transmission medium, the method of transmitting messages of frequency band of width A by one of a narrower width B which consists in modulating one message to a carrier wave whose frequency is a non-linear function of the power level of said message and this function being such that the carrier wave range in A—B as the power level varies over a predetermined range and in modulating a second message to a carrier wave whose frequency is a non-linear function of the power level of said second message, this function being such that the carrier frequency varies over a different range of width A—B as the power level varies over a predetermined range and transmitting to a receiving station the compressed message bands of widths B and demodulating the compressed message band at the receiving station with carriers of similar varying frequencies.

25. In a signaling system, a signaling path, means for generating signal variations having characteristics of varying volume and frequency, means for altering the range of variations of one of said characteristics in a manner which is a non-linear function of the average variation over short periods of time of the other characteristic while preserving the relative value of the variations of the other characteristic throughout transmission over said path and again changing the variations of said one characteristic so as to return the variations of the one said characteristic to their original value.

26. The method of reducing a frequency band of width A to one of narrower width B which consists in modulating a signal to a carrier wave whose frequency is a function of the transducing efficiency of the apparatus used in the system such that the frequency varies over the range A—B as the transducing efficiency varies over a predetermined range and suppressing all the frequencies not included in the band of width B.

27. In a wave transmission system, a source of energy of varying volume and wide frequency range, a circuit of limited frequency range supplied with said energy, means for varying the frequency level input to said circuit in conformity with undulations in volume level of said energy to bring it within the frequency limits of said circuit, means for transmitting indications of the magnitude and direction of change of the frequency level to the output of said circuit and means for varying the frequency level output of said circuit in accordance with said indications.

28. In a transmission system, a plurality of sources of energy of varying volume and wide frequency range, a plurality of circuits of limited frequency range supplied from said sources, a plurality of means for varying the frequency level inputs of said sources to said respective circuits in conformity with undulations in volume level of said energy sources, to bring them within the frequency limits of said circuits, a plurality of outputs for said respective circuits, a plurality of means for transmitting indications of the magnitude and directions of change of the frequency level to the outputs of said respective circuits

and means for varying the frequency level outputs of said circuits in accordance with said indications.

29. In a signaling system, a signaling path, means for generating signal variations having characteristics of varying volume and frequency, means for altering the range of variations of one of said characteristics in conformity with the average variation over short periods of time of the other characteristics, transmitting said altered variations of said one characteristic and variations of said other characteristic, and again changing the variations of said one characteristic in accordance with the transmitted variations of said other characteristic so as to return the variations of said one characteristic to their original range.

30. In a signaling system, an output circuit, means for generating signal variations having characteristics of varying frequency and volume, means for altering the range of variations of one

of said characteristics in conformity with the average variations, over short periods of time, of the other characteristic, delivering said altered variations to the output circuit and transmitting them to a receiving station and again changing the altered variations of said one characteristic to their original range.

31. In a signaling system, an output circuit, means for generating signal variations having characteristics of varying frequency and volume, means for altering the range of variations of one of said characteristics in conformity with the average variations, over short periods of time, of the other characteristic, suppressing all frequencies outside a prescribed range, delivering said altered variations to the output circuit and transmitting them to a receiving station and again changing the altered variations of said one characteristic to their original range.

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