

Jan. 12, 1932.

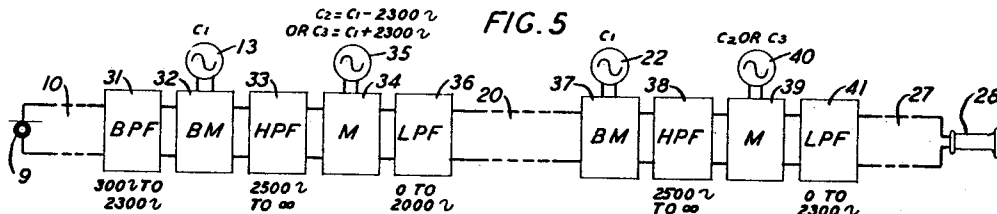
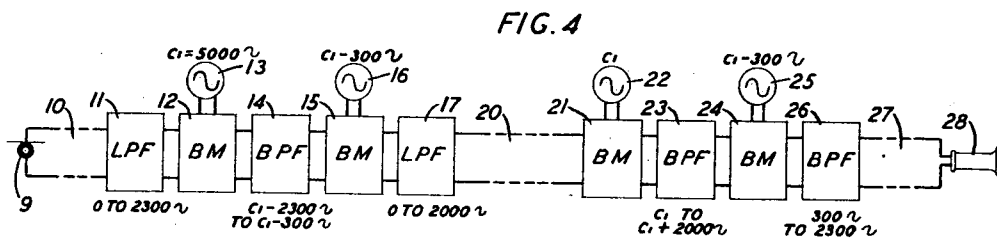
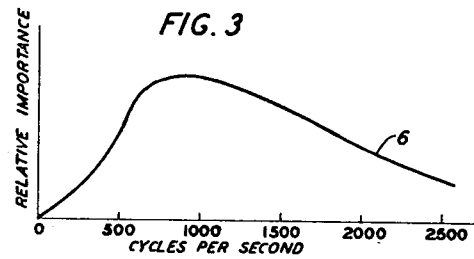
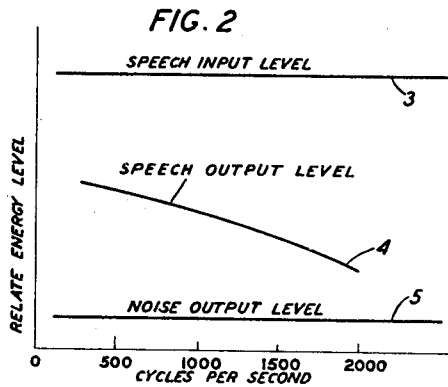
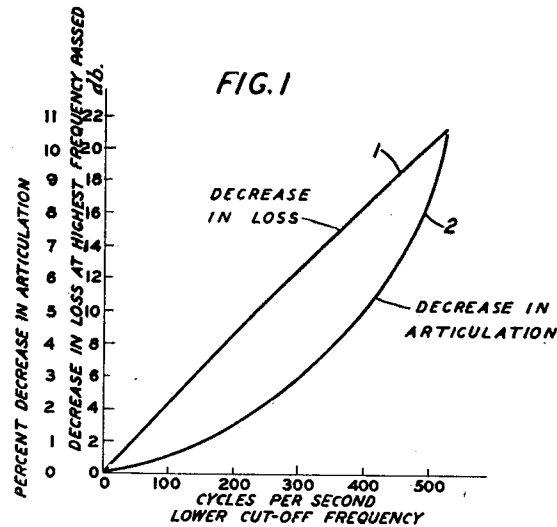
R. C. MATHES

1,841,142

WAVE COMMUNICATION SYSTEM

Filed Nov. 21, 1930

2 Sheets-Sheet 1



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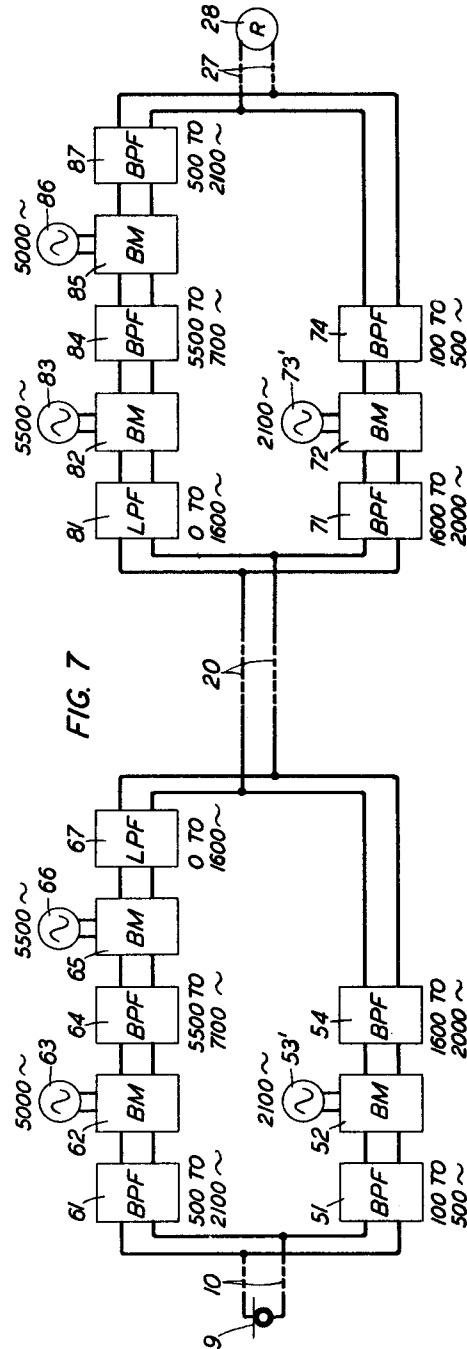
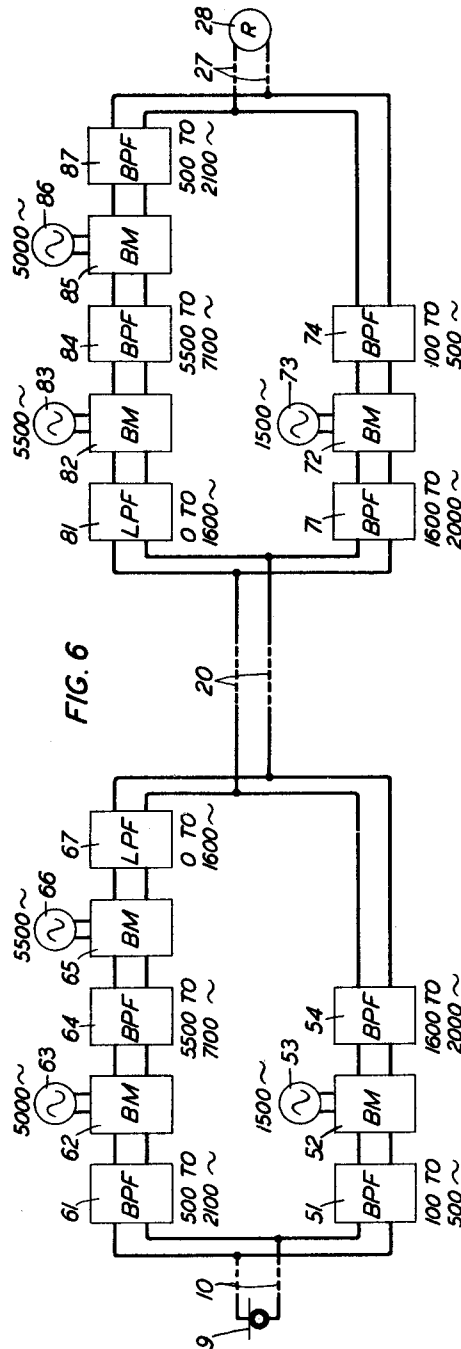
R. C. MATHES

1,841,142

WAVE COMMUNICATION SYSTEM

Filed Nov. 21, 1930

2 Sheets-Sheet 2



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WAVE COMMUNICATION SYSTEM

Application filed November 21, 1930. Serial No. 497,111.

This invention relates to wave transmission over systems in which transmission conditions are less favorable for waves having certain characteristics than for other waves, as for example, long continuously loaded submarine telephone cables having such frequency characteristics of signal input transmission level, attenuation, and received noise transmission level, that if the signal components of the various frequencies were transmitted over the cable in their normal positions in the frequency spectrum they would not be transmitted under transmission conditions favorable in degree varying in accordance with their relative importance or effectiveness, as valued by the ear or other receiver, in determining the quality of transmission.

It is an object of the invention to improve the grade or quality of transmission through such systems as for example, to improve the intelligibility of signals transmitted over such systems.

This can be accomplished, for example, by transmitting the signal over a single transmission path, in a given frequency range within the normal frequency range of the signal, as certain of its components of greater aggregate importance than those normally occupying that range. To do this, signal frequency components can be shifted for instance to such positions in the frequency spectrum that components of given importance will be transmitted over the path under transmission conditions more favorable; or signal components can be shifted for instance to such positions in the frequency spectrum that the components will be transmitted over the path under transmission conditions favorable in degree varying more nearly in accordance with, or approximately in accordance with, their relative importance or effectiveness in determining the quality of transmission.

By way of further simple illustration, in one specific aspect the invention may be a transoceanic telephone cable system in which noise and cable attenuation and load capacity limits the useful transmission frequency range of the cable to frequencies below 2000 cycles, for example, with means for suppressing from transmission to the cable all signal frequencies below 300 cycles and above 2300 cycles, shifting the frequencies of the remaining or utilized frequency range down 300 cycles in the frequency scale for transmission over a single transmission path of the cable as a frequency band extending from zero to 2000 cycles, and raising them to their original positions in the frequency spectrum after they have traversed the cable. In the speech frequency spectrum the band from zero to 300 cycles is of less importance than the band from 2000 to 2300 cycles, and moreover, a narrow frequency band of any given width is of less importance at any position in the frequency spectrum below 300 cycles than at any position between 300 cycles and 2300 cycles. Consequently the frequency shift just described can improve the quality of the signal transmission, as will be apparent from the following considerations. It may be assumed, for example, that the speech is given a flat characteristic of transmission level versus frequency before application to the cable, because overloading or maximum permissible voltages in the dielectric material of the cable, or whatever limitation prevails has set a flat characteristic as a sort of maximum input characteristic. Then the cable attenuation will give the signals delivered by the cable a transmission level decreasing with frequency increase. Assuming, for example, a flat noise level, transmission conditions in the system are then favorable in degree decreasing with frequency. That is, the attenuation of the cable has a greater effect at high frequencies than at low frequencies in lowering the value of the transmission level of the signals delivered by the cable as compared to the value of the noise or interference level and consequently the choice place in the frequency spectrum to put the signal components that are of most importance in determining signal quality is at the low frequency end of the spectrum, the desirability decreasing with frequency increase. The quality of the signal transmission is improved by the shifting downward in the frequency spectrum of the signal components in the frequency range be-

tween 300 cycles and 2300 cycles, in which any narrow subband of given width is more important than any subband of equal width in the eliminated frequency range of zero to 300 cycles.

The invention is not limited to conditions assumed above. Those assumptions merely exemplify a simple application of the invention. The low frequency band of frequency components eliminated may be, for example, from zero to 200 or from zero to 400 cycles, and the corresponding downward shift of the utilized frequency band may accordingly be 200 or 400 cycles. Also the useful transmitting frequency range of the cable and the utilized frequency range of signal components may be greater or less than assumed above and the transmission level versus frequency characteristic of the signal input to the cable and/or of the noise may be non-uniform with respect to frequency, as further considered hereinafter. Moreover, as also further considered hereinafter, a portion of the signal components eliminated at the lower end of the frequency spectrum, for example, the band from 100 to 500 cycles, may be transposed to the upper portion of the frequency range transmitted, and/or various other frequency band transpositions may be effected. Further, application of the invention is not limited to cable circuits, but may include other types of transmission systems, as for example, a radio system which may transmit best at the middle of the frequency band transmitted instead of at the lower edge as in the case of the cable referred to above, or a system employing a receiver which differs from the ear in the manner in which it values the relative importance of the various frequencies of the signal, or a system in which the signal differs from speech with respect to the relation between the importance of the various frequency components in determining the grade (for example the understandability) of the received signal.

Other objects and features of the invention will be apparent from the following description and claims:

Figs. 1 to 3 of the drawings show curves or graphs for facilitating explanation of the invention;

Fig. 4 is a circuit diagram of a system embodying one form of the invention; and

Figs. 5, 6 and 7 are circuit diagrams of systems embodying other forms of the invention.

To facilitate explanation of the principles of the invention, a few simple applications of the invention to a 1775 nautical mile length of submarine telephone cable will be considered quantitatively.

A simple means of approach to the quantitative relations is an examination of the magnitudes of the effects that some particular contemplated change produces in various

ways on the quality or grade of transmission (for example, on the articulation or on the intelligibility). A change that is very simple will be described first and then some general conclusions drawn. Such a change is to cut off the lowest frequency region, say up to 200, 300 or 400 cycles and then shift the other frequencies downward to cover this region. The attenuation characteristic of the cable does not completely determine the possibilities of improvement except under given noise conditions. However, as a uniform frequency distribution of noise is of interest here the problem will be worked out for this case with comments for more general high frequency noise relations given later.

Assuming a shift of frequency made as described in the preceding paragraph, consideration will be given the several ways in which the shift might affect the grade of transmission. One such way might be by change of loudness of the received speech and of the received noise if such changes occur. (For a treatment of the effect of changes in the received intensity of speech and of noise upon articulation, see H. Fletcher "Speech and Hearing", D. Van Nostrand Company, New York, Part IV, chapters 4 and 7.) However, there will be no change in the loudness of the received speech, since the speech will be amplified to the same final loudness value. If the noise is treated similarly, then there will be substantially no changes in loudness of received speech, nor in equivalent volume reduction of received speech due to noise. It is not unreasonable to regard this as the case, since the frequencies are cut off both from the speech and from the noise. However, further discussion of noise conditions will be given hereinafter.

Considering now what effect the frequency shift might cause in the grade of transmission by changing the per cent of the total output energy which is in the asymmetric frequencies (voice frequencies not present in the driving force or original signal), some peculiar relations are involved here in that after the frequency band is shifted, because of overloading of the magnetic material in the cable, harmonics of these frequencies are set up which later become inharmonic frequencies after each frequency band is transposed again to its normal position. Some idea as to how serious this item is can be obtained by considering a particular case. Assuming loading with loading material such as is disclosed in Elmen Patent 1,715,541, June 4, 1929, and a magnetizing force H of 1 gilbert per cm., the corresponding current is 1.5 amps. The overloading gives only odd harmonics. The third harmonic for the fundamental frequency at 500 cycles would become the frequency 1,500 cycles after transmission. Assuming $H=1$ at the sending end and that the full correction for the variation

of cable attenuation with frequency is made at the receiving end, the third harmonic at 500 cycles after such correction will be 35 to 40 db. lower than the fundamental. If the final speech is made of such value as is commonly found in commercial telephone circuits, then the noise effect would be so small as to be negligible, unless the line in all other respects were extremely quiet. This noise effect too has some counter-balancing effect in that it is intense only when speech power is intense. From these circumstances it appears that substantially no change in the grade of transmission will result from change in asymmetric distortion caused by the frequency shift if the cable is not worked to much higher energy levels than that corresponding to $H=1$. The harmonics set up and converted into inharmonic frequencies may be considered as noise, which in this case is of negligible effect.

The effect, upon the grade of the signal transmission, produced by frequency distortion resulting from the frequency shifts differs from the effects upon the grade of signal transmission produced by the factors considered above, in that the harm done depends largely on the frequency band cut out. Curve 1 in Fig. 1 shows approximately the effect on articulation. This effect is much more than counter-balanced by the increase in articulation resulting from the decrease in transmission loss or cable attenuation that the frequency shifts produce for the utilized frequency band. Curve 2 in Fig. 1 shows the decrease in loss produced by the frequency shifts for the worst signal frequency (i. e. the highest frequency signal component transmitted), assuming the cable unchanged while the upper limit on the frequency band passed is 2,000 cycles minus the lower cut-off frequency. The extent of the signal degradation produced by the frequency distortion resulting from the frequency shift depends considerably on what assumptions are made as to the terminal lines. The assumption made here was that they were probably in the nature of toll lines with a considerable amount of either loaded cable or open wire. If non-loaded cable is used the general effect is to exaggerate somewhat the values of the lower frequencies so that in such cases more harm would be done by eliminating the lower frequencies than is assumed here. However, four or five miles of cable would not be of much importance this way and as longer lengths are likely to involve loading, it is unnecessary to consider such conditions further.

In the consideration of the one particular case of cutting off completely the lower frequencies, the methods used may not give the proper concept of what is being done, unless one bears in mind the fact that it is really not the attenuation in the cable that is of

much importance by itself, but the effect of it on lowering the received signal energy level as compared to the interference levels. Fig. 2 pictures this effect. Line 3 in this figure assumes a fixed input energy level versus frequency. It is assumed that overloading or permissible voltage in the dielectric or whatever limitation prevails has set a flat characteristic as a sort of maximum input characteristic. After transmission through the cable because of the high attenuation at the higher frequencies, a cable output level curve 4 is obtained which in this case then slopes downward. Assuming a flat noise level curve 5, it is seen that the choice place to put frequencies that it is desired to transmit very well is down at the lower end, the desirability becoming less and less in proceeding up the frequency range.

On the other hand, curve 6 in Fig. 3 shows approximately how the ear values the relative frequencies, (within the volume variation limits here involved). The manner in which curve 6 is obtained is noted hereinafter. Stated approximately, an advantageous plan is then to shift the frequencies so that those which Fig. 3 indicates as having the higher weighting will occupy the position which Fig. 2 indicates as the most desirable. To do this precisely would require splitting the range of frequencies in a large number of bands which would not be advisable because each time a frequency range is split there is a loss of a small frequency band, perhaps 25 cycles. Accordingly, if too many cuts are made, the loss of this amount becomes very large. However, fortunately this frequency characteristic curve 6 indicates that very low frequencies are of almost no value and then very quickly a band of the most valuable frequencies is reached. As will appear from consideration of Figs. 5 and 6 hereinafter, the frequency band transpositions of the nature referred to above can be effected for example, by filtering and modulating methods of general type well known and illustrated in Espenschied Patent 1,546,439, July 21, 1925 for splitting frequency bands and relatively shifting the subbands to obtain privacy, and in Affel Patents, 1,595,135, Aug. 10, 1926 and 1,537,106, May 12, 1925, for shifting the frequencies of signal components to facilitate their transmission, and in Espenschied Patent 1,555,916, October 6, 1925, Nyquist et al., Patent 1,749,045, Mar. 4, 1930, and Griggs Patent 1,565,091, December 8, 1925 for changing the positions of signal components in the frequency spectrum to facilitate their transmission over a line of limited frequency range of transmission.

When the frequency band is split so as to shift the most important frequencies down into the best transmission region and some of the lower frequencies, perhaps 100 cycles to 500 cycles to the upper end of the spectrum,

a larger gain may result than the 12.5 db. indicated by curve 1 for cutting out the region zero to 300 cycles. Perhaps as much as 20 db. can be gained in this way for the particular cable assumed. It should be emphasized, however, that what can be gained in this fashion depends considerably on the noise characteristic. If it is flat, as assumed, gains of the order spoken of are obtainable. If it is of approximately the same slope as the output level of speech, little or no gain can be obtained by frequency shifts. If, on the other hand, it has a slope in the opposite direction, then even more could be obtained than indicated here. Assuming the noise limitation is thermal noise with its flat frequency spectrum and assuming a flat input is to be used, the sort of results obtained here are quite representative. If there be assumed, however, the flat thermal noise characteristic and an input level such as to correct for one-half of the differences of cable attenuation with frequency, then the gains discussed here are approximately halved.

It is of interest to note from Fig. 3 the approximate relative importance or value of frequencies in the neighborhood of the two cut-off points. The frequencies of 475 to 2,000 cycles have about equal weight. Also, it is seen that cutting out frequencies zero to 325 cycles and adding 2,000 to 2,100 just about balance each other, so that a range (325 to 2,100) that is 225 cycles less than another range (zero to 2,000) gives about the same articulation. It will give greater articulation when shifted down 325 cycles or less for transmission at a more favorable position in the frequency spectrum than its normal position, and at the same time if shifted down 100 cycles or more will permit use of a cheaper cable than would the zero to 2,000 cycle band in normal frequency position. By a cheaper cable is meant one having an effective transmitting frequency range with an upper limit below 2,000 cycles in this specific instance, as for example at 1,775 cycles when the downward shift of the 325 cycle to 2,100 cycle band is 325 cycles, or at 1,850 cycles when the downward shift of the 325 cycle to 2,100 cycle band is 250 cycles. When the effective transmitting frequency range of the cable is to extend up to 2,000 cycles, a 325 cycle to 2,325 cycle band of signal components can be employed, by shifting the band down 325 cycles, and this band will give articulation greater than could be obtained by transmitting the 325 cycle to 2,100 cycle band over the cable with a frequency shift (and greater than could be obtained by transmitting the zero to 2,000 cycle signal components in their normal positions).

As a particular item shifting the frequency range so as to cut out the first 300 cycles and allowing 25 cycles more due to the dullness of the cutting off, it is seen from Fig. 1. that

the articulation would be reduced about 3 per cent. This would correspond in an average circuit to reducing the articulation from around .50 to .485. The change in intelligibility would not be so great. The change in naturalness would probably be so small as not to be noticed. On the other hand, the gain in articulation corresponding to the above mentioned loss decrease of 12.5 db. for example, would be at least several times as great as the articulation reduction just mentioned. Where a frequency band shifting system is used the oscillators should be synchronized fairly closely, since otherwise energy at harmonic frequencies would become energy at inharmonic frequencies which might hurt articulation somewhat. Furthermore, some transmission loss due to the modulators and filters for frequency shifting would probably have to be taken into account.

It may be mentioned that curve 6 is obtained as the slope or derivative of a curve such as that labelled "Articulation L" in Fig. 136 on page 280 of the Fletcher text referred to above. As explained in the text, the latter type of curve for a frequency range from zero to a given frequency is obtained by measuring separately and plotting the values of (maximum) articulation obtainable from each of various speech frequency bands extending from zero to various upper limiting frequencies below the upper limit of the given range. Thus, such a curve is a curve of articulation versus upper limiting frequency, and since the rate at which the articulation changes at any frequency in the given range, i. e. the slope of such a curve at that frequency, gives the importance of that frequency, the derivative of such a curve is the importance function 6 which shows the relative importance of the frequencies of the given range, that is, the relative amounts that the various frequencies of the range contribute to the understandability of speech signals constituted by the given range of frequencies.

To give a simple illustration of a system for carrying out a typical group of operations considered above, to wit, eliminating from transmission the zero to 300 cycle band of signal components and transmitting the 300 to 2,300 cycle band of signal components over a cable as a zero to 2,000 cycle frequency band and raising them to their original positions in the frequency spectrum after they have traversed the cable. Fig. 4 shows diagrammatically a transoceanic submarine telephone cable system with means for performing these functions, (although in actual practice of the invention ordinarily the extremely low frequencies would not be transmitted to the cable, i. e. the frequencies transmitted to the cable would not extend below, say, 25 cycles).

The drawings indicate the pass ranges of the filters and the frequencies of the carrier generators shown. Speech currents from

telephone transmitter 9 traversing line 10 and low pass filter 11 are impressed on balanced modulator 12, in which the zero to 2,300 cycle band of signal components modulates the carrier wave C_1 , of 5,000 cycles per second for example, supplied by generator 13. The balanced modulator 13 suppresses the carrier frequency from transmission. Band pass filter 14 transmits from the output circuit of modulator 12 to the input circuit of balanced modulator 15 the frequency band extending from frequency $C_1 - 2,300$ to $C_1 - 300$ cycles, and suppresses all other frequencies. In modulator 15 this band is combined with the carrier frequency $C_1 - 300$ cycles from generator 16. The balanced modulator 15 suppresses the carrier frequency $C_1 - 300$ cycles from transmission. Low pass filter 17 selects from the output of modulator 15 the frequency band zero to 2,000 cycles, to the exclusion of all other frequencies, for transmission to the transoceanic submarine cable 20, which may be for example a loaded cable of the type referred to above. The 0 to 2,000 cycle band thus transmitted to the cable is the band of signal components normally extending from 300 to 2,300 cycles. Thus each of the original 300 to 2,300 cycle components of the signal is sent into the cable at a frequency level 300 cycles lower than its normal position in the frequency spectrum.

At the receiving end of the cable, balanced modulator 21, with its source 22 of carrier frequency C_1 , produces two side bands of the zero to 2,000 cycle band, the modulator suppressing the carrier frequency. Band pass filter 23 selects the upper side band to the exclusion of all other frequencies. (If desired the upper cut-off of this filter can be at a frequency considerably higher than indicated on the drawing, to take advantage of overtones or harmonics of the upper side band frequencies. Also, if desired, the lower cut-off of this filter can be somewhat below the frequency indicated on the drawings, to insure against loss of the speech components just above the 300 cycle component because of the dullness of the cut-off; but this will introduce noise into the circuit, since any of the frequencies of the lower side band that pass filter 23 will be changed to noise in the demodulation now to be described.) In balanced modulator 24 the upper side band selected by filter 23 is combined with a carrier frequency $C_1 - 300$ cycles from generator 25, the balanced modulator suppressing the carrier wave from transmission. Band pass filter 26 selects the resulting lower side band to the exclusion of all other frequencies. (If desired, a low pass filter, with cut-off at 2,000 cycles can be substituted for band pass filter 26, although the low pass filter will not suppress the portion of the noise just referred to which falls below 300 cycles.) The 300 to 2,300 cycle band of signal components in

their normal positions in the frequency spectrum is transmitted from filter 26 through line 27 to telephone receiver 28.

Fig. 5 shows a system which is a modification of the system of Fig. 4. In Fig. 5 the speech components are transmitted over the cable inverted as to frequency order. The 300 to 2,300 cycle components pass from transmitter 9 through line 10 and band pass filter 31 to balanced modulator 12, wherein they modulate the carrier frequency C_1 from generator 13. The balanced modulator suppresses the carrier wave. High pass filter 33 suppresses the unmodulated signal frequencies but passes both side bands to modulator 34 where they are combined with the carrier frequency from source 35. This carrier frequency may be either a frequency C_2 , equal to $C_1 - 2,300$ cycles for example, or a frequency C_3 , equal to $C_1 + 2,300$ cycles for example. In either case, low pass filter 36 selects from the output of modulator 34 and transmits to cable 20 the frequency band zero to 2,000 to the exclusion of all other frequencies. This band consists of the speech components which normally have the frequencies 300 to 2,300 cycles, inverted from their normal frequency order.

At the receiving end of the cable, balanced modulator 37 combines this band with carrier frequency C_1 from source 22. The balanced modulator suppresses the carrier wave. The high pass filter 38 with its cut-off frequency at 2,500 cycles suppresses the unmodulated signal components. Both side bands are transmitted to modulator 39, in which they are combined with carrier frequency C_2 or C_3 from source 40. In either case the lower side band resulting from this modulation includes a frequency band extending from 300 to 2,300 cycles and a frequency band extending from 2,300 to 4,300 cycles. The first band is the 300 to 2,300 cycle speech components in their normal spectrum position and frequency order, and is separated from the higher frequencies by low pass filter 41 which transmits this first band through line 27 to receiver 28. The speech components in this frequency band have traversed the cable in inverted frequency order but in the favorable frequency range below 2,000 cycles, and yield articulation considerably higher than would the zero to 2,000 cycle signal components (or the zero to 2,300 cycle signal components) if transmitted over the cable in normal frequency position.

Various modifications may be made in the systems of Figs. 4 and 5. For example, filter 38 can be omitted if modulator 37 be of a type which suppresses the unmodulated signal waves as well as the unmodulated carrier wave, (for instance the type shown in Fig. 12 of Lindridge Patent 1,675,894, July 3, 1928, instead of a more usual type such as that shown at B in Heising Patent 1,762,984, June 10, 1930). As indicated above, the frequency

transpositions employed can be varied widely. Illustrations of systems in which the band from 100 to 500 cycles is transposed to the upper portion of the frequency range transmitted, as referred to above, are given in Figs. 6 and 7.

In each of these Figs. 6 and 7 the speech components transmitted are those which normally have the frequencies 100 to 2,100 cycles, and these components are transmitted as a band extending from zero to 2,000 cycles. In each figure the 500 to 2,100 cycle components are transmitted as a 1,600 to 2,000 cycle band with these components in their normal frequency order. The 100 to 500 cycle band of components is transmitted as a 1,600 to 2,000 cycle band, with the frequency order of these components normal in Fig. 6 and inverted in Fig. 7. The inversion just mentioned produces the result that the portion of the frequency spectrum in which the higher frequency components or more important components of the 100 to 500 cycle components are transmitted is one in which transmission conditions for signal components are more favorable than the conditions in the portion of the frequency spectrum in which the less important of the 100 to 500 cycle components are transmitted, as indicated by Fig. 2 for example (in connection with Fig. 3).

In Fig. 6, the modulators shown may be of the balanced type referred to above as disclosed in Fig. 12 of the above mentioned Lindridge Patent 1,675,894. Speech currents from transmitter 9 are transmitted to filters 51 and 61. Filter 51 selects from the speech waves a band of frequency components which may be designated A, extending from zero to 500 cycles; and filter 61 selects from the speech waves a band of frequency components which may be designated B, extending from 500 to 2,100 cycles.

The band A is modulated in modulator 52 with a 1,500 cycle carrier wave from generator 53. The upper side band resulting will be designated A'. It extends from 1,600 to 2,000 cycles, and is selected by filter 54 and transmitted to the cable 20.

The band B is modulated in modulator 62 with a 5,000 cycle carrier wave from generator 63. The upper side band resulting will be designated B₁. It extends from 5,500 to 7,100 cycles, and is selected by filter 64 and combined in modulator 65 with a 5,500 cycle carrier wave from generator 66. The lower side band resulting will be designated B'. It extends from 0 to 1,600 cycles and is selected by filter 67 and transmitted to cable 20.

At the receiving end of the cable, the receiving operation is the inverse of the transmitting operation just described, and will be apparent from the drawing without further explanation.

The system of Fig. 7 is the same as that of Fig. 6 except that the carrier frequency for

modulators 52 and 72 is 2,100 cycles supplied from generators 53' and 73' instead of 1,500 cycles supplied from generators 53 and 73.

The systems of Figs. 4 to 7 are shown as one-way systems, for the sake of simplicity, since they can readily be arranged for two-way operation by well-known methods of adaptation. In these systems the cable attenuation, the noise conditions, and the frequency distribution of sending energy, may be, for example, as indicated in Fig. 2.

What is claimed is:

1. The method of transmitting over a single path a signal whose frequency components have relative importance varying with their normal positions in the frequency spectrum, which comprises transmitting the signal over said path, in a given frequency range within the normal frequency range of the signal, as certain of said components of greater aggregate importance than those normally occupying said given range.

2. The method of transmitting a signal, whose frequency components have relative importance varying with their normal spectral positions, over a single transmission path for which the transmission conditions vary with frequency, which comprises selecting components of the signal that include the major portion of the utilized signal frequency band, and that have at least a given relative importance, and that normally occupy spectral positions for which the transmission conditions are less favorable than for normal spectral positions of less important components of the signal, shifting the frequency of the selected components so that some of them occupy the latter positions, and transmitting the selected components over said path in their altered positions to the exclusion of said less important components from transmission over said path in those positions.

3. The method of transmitting a signal, whose frequency components have relative importance varying with their normal spectral positions, through a transmission medium for which transmission conditions vary with frequency, which comprises shifting components of the signal to such spectral positions that the transmission conditions are rendered more favorable for the components of greatest importance and less favorable for certain less important components, and transmitting the shifted components through the medium in their altered positions.

4. A speech transmission system comprising a speech transmission path having a limited effective frequency range of transmission, means for lowering the frequencies of those of the utilized speech frequency components normally falling between 600 and 1500 cycles per second, means for transmitting those components over said path at their lowered frequencies but with their frequency

band width substantially unchanged, and means for thereafter restoring said components to their normal frequencies.

5 5. A speech transmission system comprising a speech transmission path having a limited effective frequency range of transmission, means for lowering by the same amount the frequencies of those of the utilized speech frequency components normally falling
10 above 500 cycles per second, means for transmitting those components over said path at their lowered frequencies, and means for thereafter restoring said components to their normal frequencies.

15 6. A transoceanic submarine telephone cable system comprising means for lowering by the same amount the frequencies of those of the utilized speech components normally falling between 500 and 2000 cycles per second, means for transmitting those components over the system at their lowered frequencies, and means for thereafter restoring
20 said components to their normal frequencies.

7. The method of transmitting a signal
25 over a single path as frequency components whose importance in determining the grade of the signal transmission varies with their normal positions in the frequency spectrum, which comprises transmitting said components over said path under transmission conditions that favor the different components more nearly in accordance with their relative importance than were said components transmitted in their normal positions in the
30 frequency spectrum.

8. The method of transmitting signal frequency components whose importance varies with their normal positions in the frequency spectrum through a noise zone of a system
40 whose effective frequency range of transmission is limited, which comprises transmitting said components through said zone so transposed relatively in the frequency spectrum that the ratios of the received energy levels of the components to the levels of received
45 noise at the frequencies of the respective components are more nearly in accordance with the relative importance of the components than were the components transmitted in their normal spectral positions.

9. The method of transmitting signal frequency components whose importance varies with their normal positions in the frequency spectrum through noise zone of a system
55 whose effective frequency range of transmission is limited, which comprises transmitting said components through said zone with given frequency distribution of sending energy in said range and so transposed relatively in the frequency spectrum that the
60 ratios of the received energy levels of the components to the levels of received noise at the frequencies of the respective components are more nearly in accordance with the relative importance of the components than were

the components transmitted in their normal spectral positions with said given frequency distribution of sending energy in said range.

10. A speech transmission system having a limited effective frequency range of transmission, comprising means for lowering the frequency of those of the utilized speech components normally falling between 600 and 1500 cycles per second and raising certain speech frequencies normally lying below 600
75 cycles per second to a spectral position above the lowered spectral position of said first mentioned components, means for transmitting all of said components of altered frequency over the system at their altered frequency, and means for thereafter restoring them to their normal spectral positions.

11. The method of transmitting a signal as frequency components of varying relative importance in determining the grade of transmission, which comprises transmitting said components under transmission conditions that favor the components approximately in accordance with their relative importance.

In witness whereof, I hereunto subscribe my name, this 14th day of November, 1930.

ROBERT C. MATHES.