

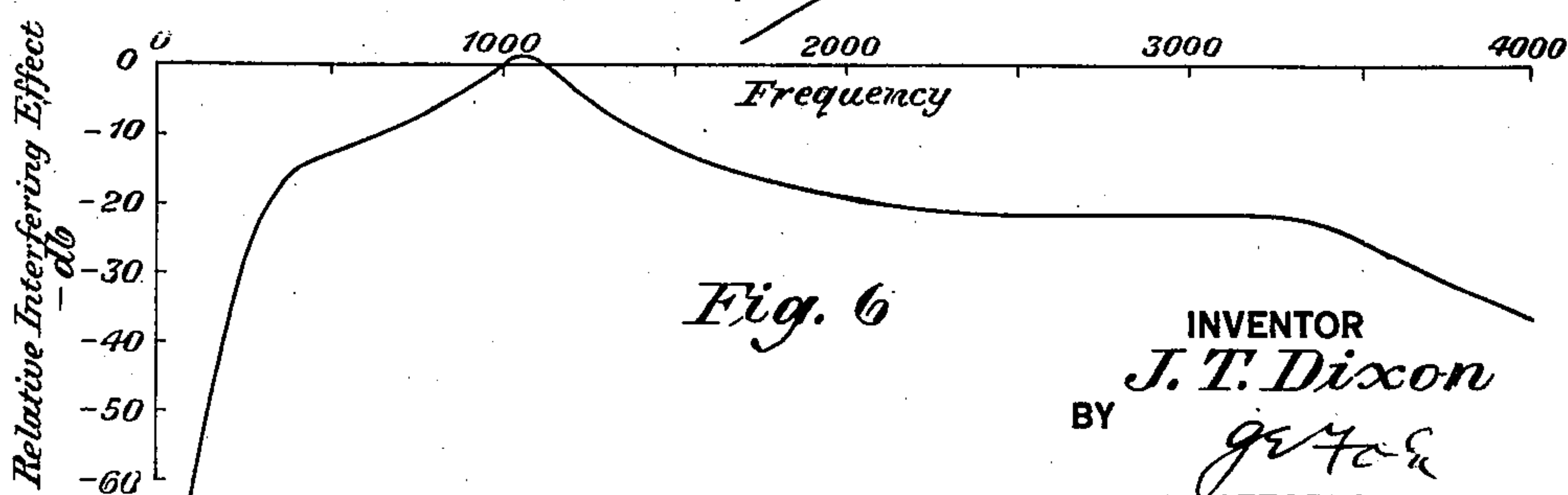
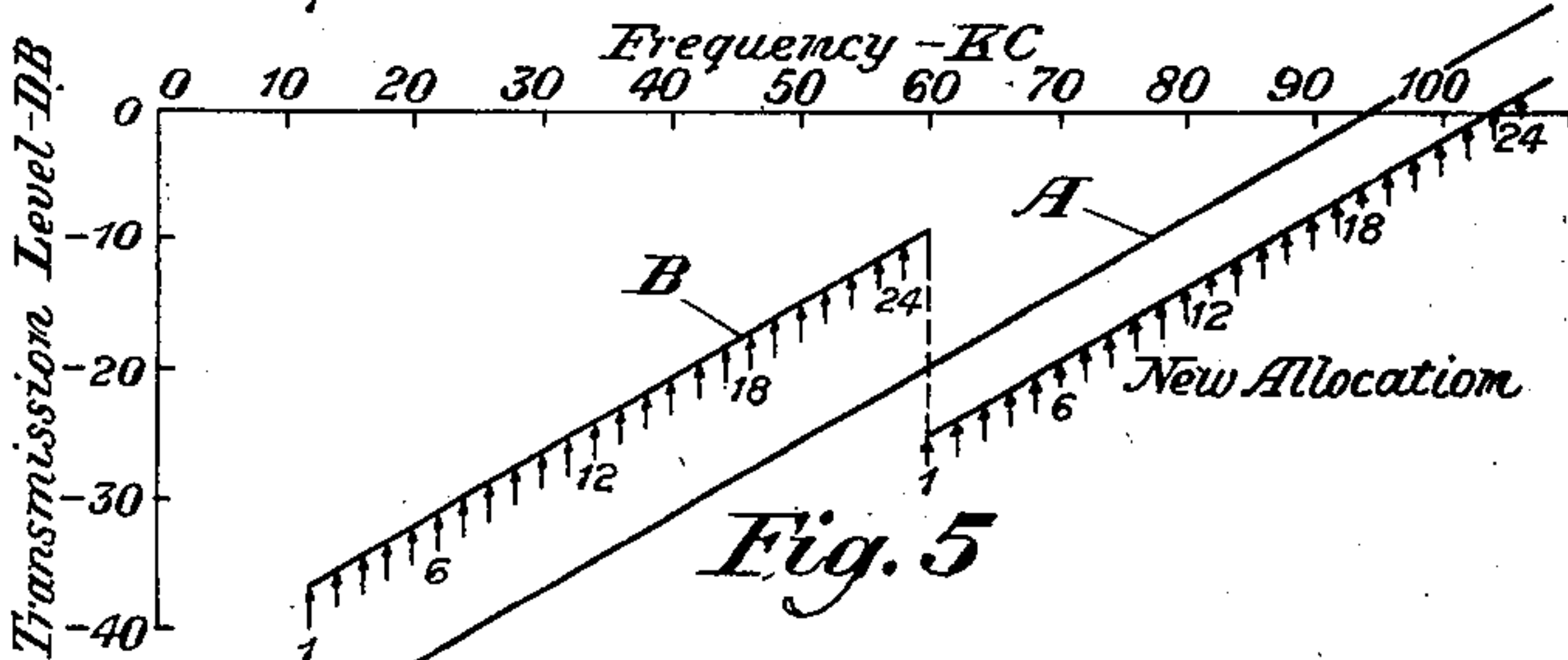
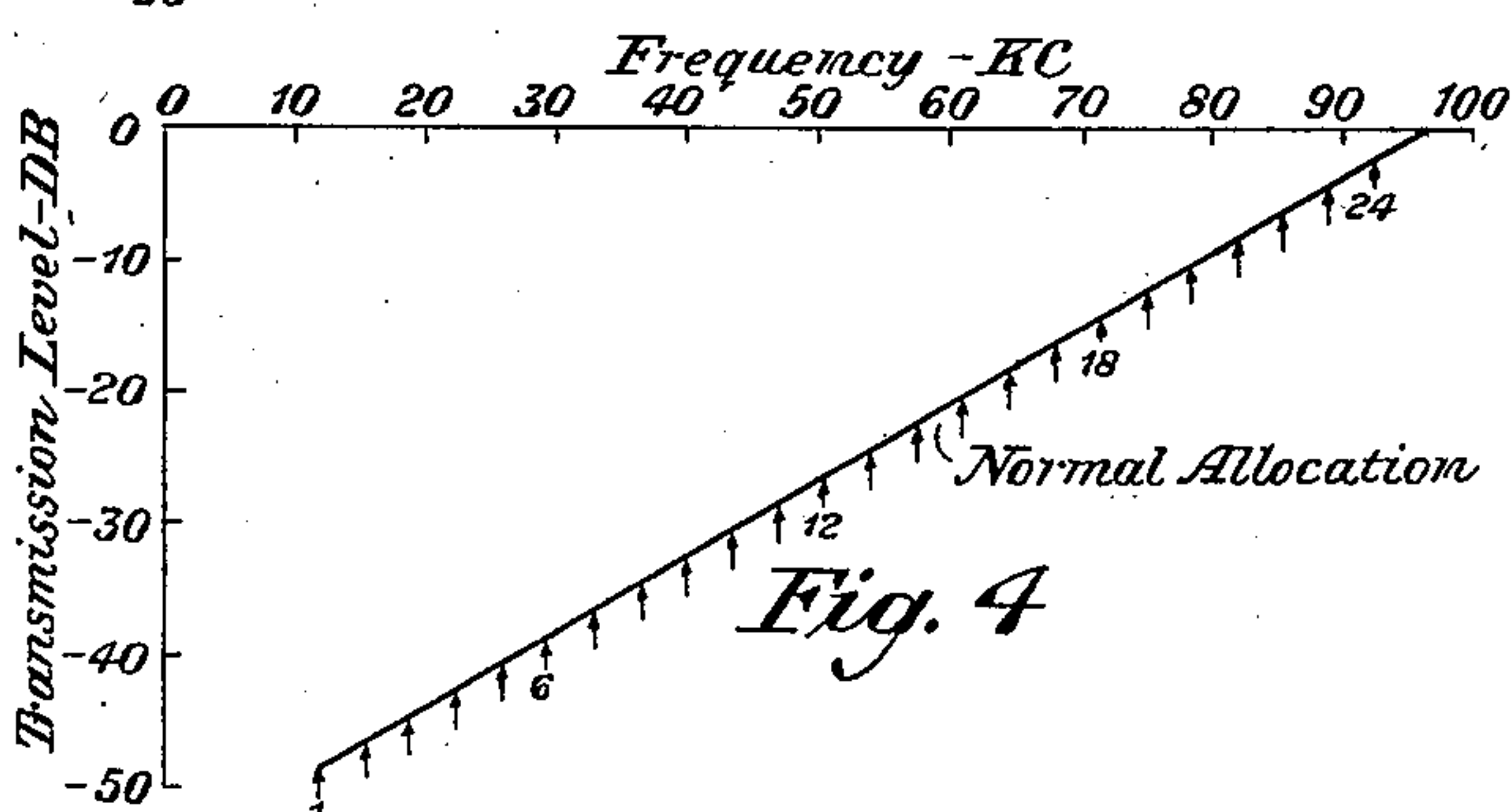
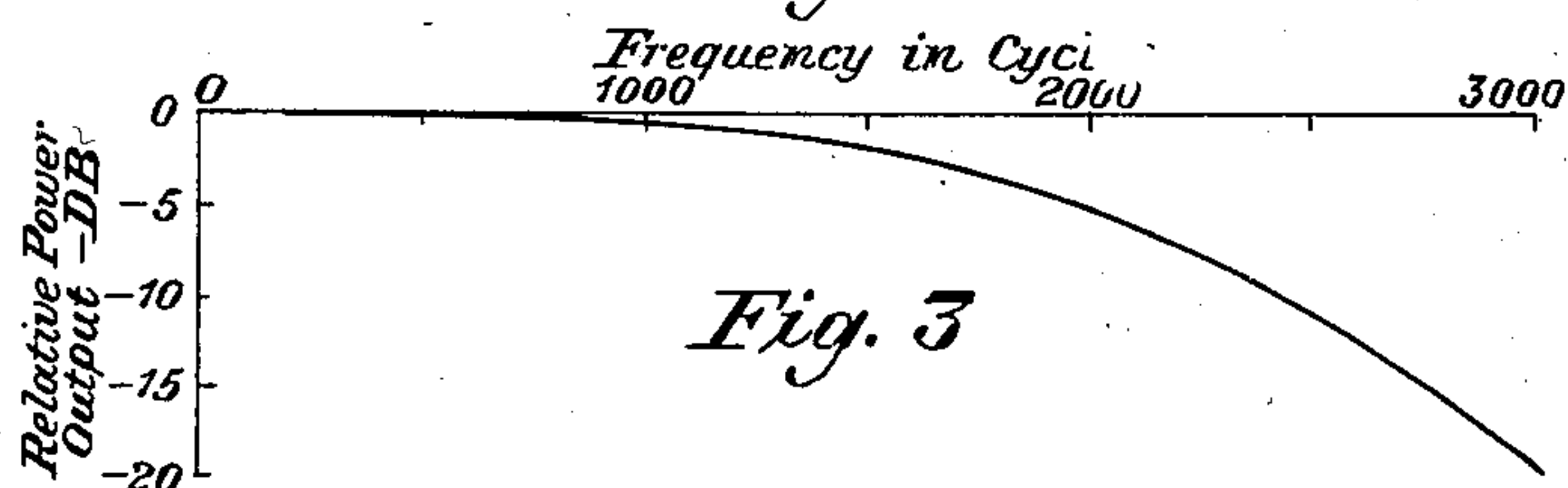
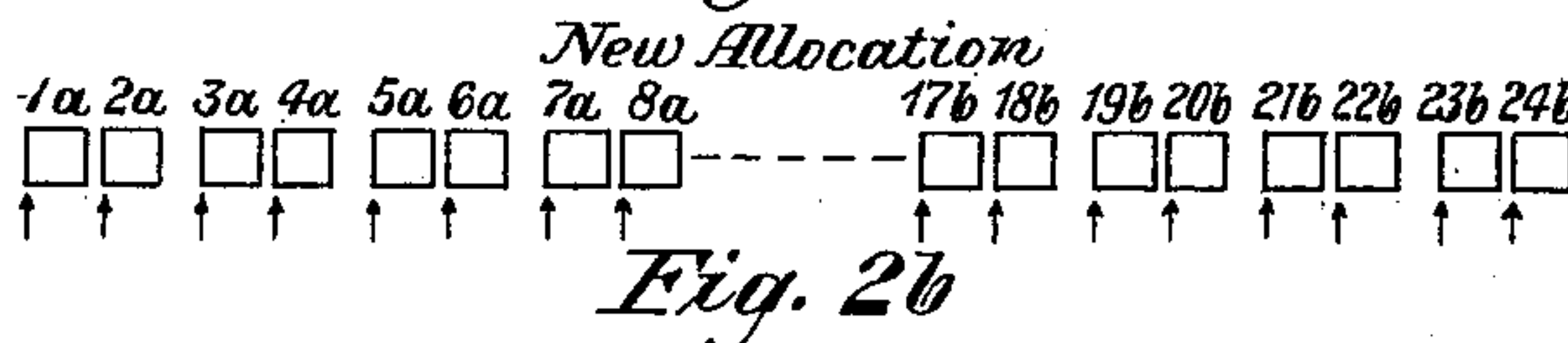
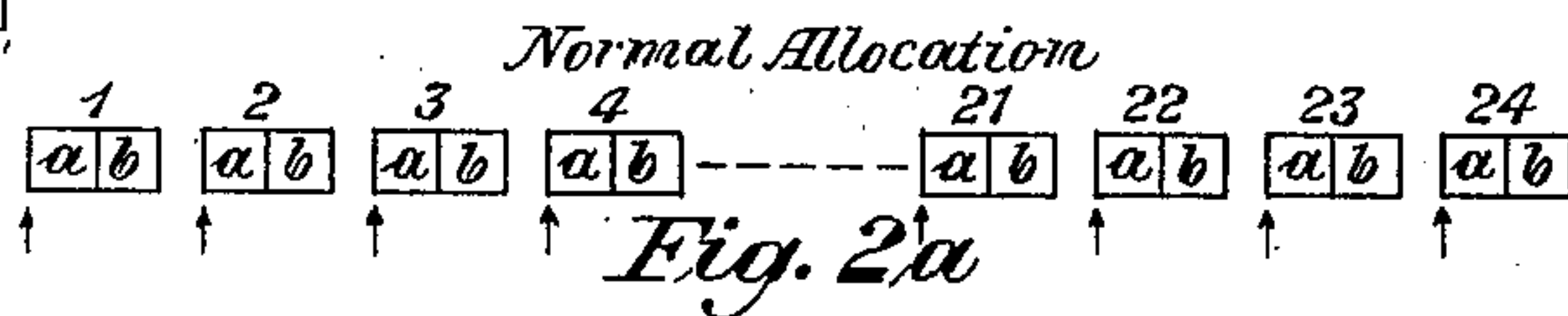
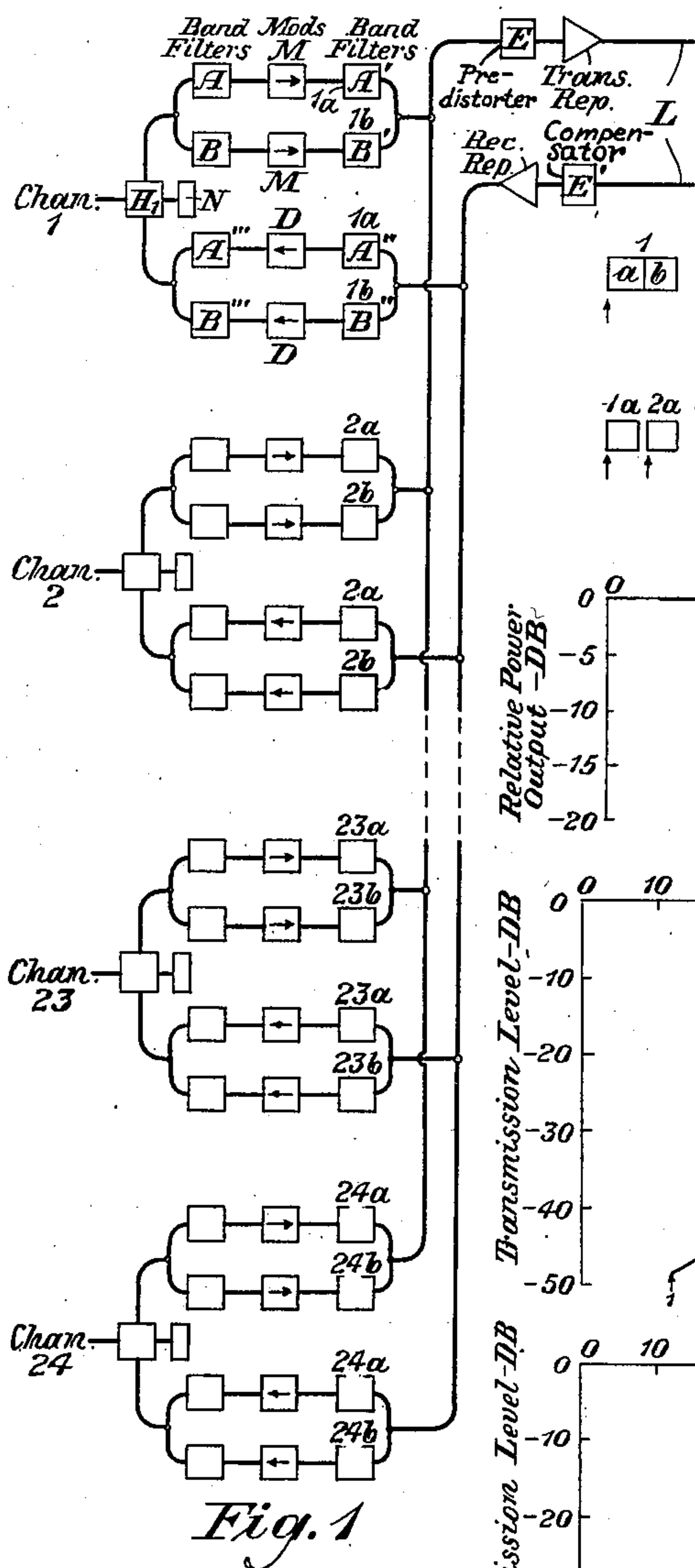
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NOISE AND CROSS-TALK REDUCTION IN TELEPHONE COMMUNICATION CIRCUITS

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NOISE AND CROSS-TALK REDUCTION IN
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This invention relates to noise and crosstalk reduction in telephone circuits and is especially applicable to conductor systems of twisted pairs, balanced pairs, coaxial conductors and submarine
5 cables using carrier frequencies to provide a plurality of channels on a given physical line.

Its purpose is to reduce the amount of noise and the amount of inter-system crosstalk which will appear at the terminals of such circuits for
10 a given frequency band or spectrum on the line conductors, or to increase the number of separate signaling channels which can be used on the line conductors without increasing the noise.

I accomplish this purpose by a certain new frequency allocation in which each signal channel or speech channel is divided into two or more distinct parts which are then transmitted over the line in different portions of the carrier frequency spectrum, these latter being chosen from
15 considerations of the noise-frequency distribution on the line, the power-frequency distribution of the separate signal channels and the relative interfering effect of different frequency components of demodulated line noise.

More particularly, in a system in which there are to be transmitted several speech messages each occupying a voice frequency band from zero to about 3,000 cycles, I divide each of these bands into two separate bands, one including frequencies from zero up to 1,500 cycles and the other including frequencies from 1,500 to 3,000 cycles, these figures being taken for illustrative purposes only. For convenience these will be termed the "low voice bands" and "high voice
25 bands", respectively. Each of these bands is applied to apparatus, including carrier frequency sources, for stepping the bands up into the carrier range. The carriers of the low voice bands are set to shift these bands to the lower half of the carrier range employed. The carriers of the
30 high voice bands, on the other hand, are set to shift these bands to the upper half of the carrier range employed. At the receiving end demodulators step the bands down to voice frequencies, and the high and low voice bands of a given channel are recombined to give the original speech.

The invention will be better understood by reference to the following specification and the accompanying drawing in which Figure 1 shows the circuit arrangement at one end of a four-wire circuit; Figs. 2a and 2b show the normal and the new allocation of frequencies on such a four-wire circuit using carrier frequencies for a
35 plurality of speech messages; Fig. 3 shows the

approximate energy distribution of a speech message as a function of frequency when it is impressed on the transmission system; Fig. 4 shows a transmission level diagram which could be used to advantage under normal frequency allocation for a plurality of speech signals on carrier frequency; Fig. 5 shows the transmission levels which I find appropriate for the new frequency allocation described in this invention; and Fig. 6
40 is a curve showing the relative disturbing effect of noise in any part of the speech frequency spectrum.

It is to be noted that in the usual carrier telephone transmission line, such as a cable circuit equipped with repeaters, the normal practice is to make the gain at each repeater station equal to the loss in the preceding cable section so that the message output of any one repeater is equal to the message output at the previous repeater. It is also a characteristic of such circuits that the attenuation increases with frequency, and it is necessary therefore to provide that each repeater shall have a greater gain at the higher frequencies than at the lower frequencies. At the receiving end of the line, then, the energy distribution for the message will be substantially the same as that at the transmitting end, and the transmission circuit may be spoken of as being distortionless. Also it is to be noted that on a cost basis it is desirable to
45 operate each repeater substantially up to its full power capacity without introducing distortion, this being done either to maintain the transmission level as high as feasible so as to obtain a more favorable signal to noise ratio or to increase the spacing between the repeaters.

Referring, now, specifically to Fig. 1, there is shown one end of a four-wire transmission line L with a transmitting side and a receiving side. This line may be used for a plurality of messages on carrier frequencies, indicated in the figure by channels 1 to 24, which, if one allows a frequency band 3,000 cycles wide for each telephone message and a spacing between channels of about 500 cycles, might occupy the frequency spectrum
50 from about 12 kc. to 96 kc.

Channel 1 is shown as being provided with the usual hybrid coil H₁ in order to transfer from a two-wire to a four-wire basis. On the transmission side of the hybrid coil the transmitted message is divided into two bands by band-pass filters A and B, so designed that the filter A passes frequencies up to 1,500 cycles and filter B passes frequencies from 1,500 to 3,000 cycles. Each path now passes to a modulator M, which in-
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cludes a generator of suitable carrier frequency and other appropriate circuit devices such that the low voice band modulates a carrier frequency of 12 kc. and the high voice band modulates a carrier frequency of 60 kc. Band-pass filters A' and B' are now provided which, from the output of each modulator, suppress all but one sideband, either the upper sideband or the lower sideband, although it may be convenient for concreteness to think in terms of passing the upper sideband. The outputs from the band filters A' and B' are now impressed on the transmission channel of the four-wire line L.

Similar equipment is provided for each of the other channels with the exception that the carrier frequencies for the two portions of channel 2 would be higher than those for channel 1 by an appropriate amount of, say, 2,000 cycles, thus allowing for a spacing of 500 cycles to take care of the fact that the filters do not have a perfect cut-off. Similarly, the carrier frequencies for each of the succeeding channels are spaced one above the other in the same way as described for channel 2 as compared to channel 1.

As a result the twenty-four messages will be impressed on the four-wire circuit but with all the low voice bands in the lower half of the frequency spectrum of the line and the high voice bands in the upper half of the frequency spectrum.

Received message goes through the reverse process, being separated by the filters A'', B'' for the one channel and then passing demodulators D and through filters A''', B''', after which the two portions of the message are combined and pass through the hybrid coil H₁ onto the two-wire channel. Similar equipment is, of course, provided for each of the other channels.

The change in the allocation is more clearly set forth by reference to Figs. 2a and 2b. If the number of the channels be indicated by 1 to 24, and if the low voice band in each channel be indicated by a and the high voice by b, then the normal allocation would be that shown in Fig. 2a. With the new arrangement, however, the allocation is that shown in Fig. 2b, from which it will be observed that the bands have been placed in order starting with the lower end of the frequency spectrum from 1a, 2a, 3a, . . . 24a and from 1b, 2b, 3b, . . . 24b.

The manner in which this frequency allocation gives a net reduction in noise will now be explained with reference to a telephone system transmitting a plurality of speech channels. It is characteristic of twisted pairs and many other conductor systems that the attenuation increases with frequency. The repeater which receives the signal from the conductors at any one point is made to have a gain which is substantially equal to the line attenuation of the preceding section at all frequencies in the useful carrier range. In consequence of this, signal frequencies transmitted over a line section consisting of the conductors and their receiving repeater appear at the output of this repeater without appreciable attenuation-frequency distortion. It is also characteristic of these conductor systems that the magnitude of the noise at the end of a section, that is at the input of the repeater, is usually substantially independent of frequency. In consequence of this condition, in conjunction with the gain frequency characteristic of the repeater, the magnitude of the noise frequencies appearing at the output of the repeater is non-uniform with respect to the frequency because the noise is uniform at the repeater input and is amplified

to a greater degree at the high frequencies than at the low frequencies.

Under the conditions described in the preceding paragraph the signal-to-noise ratio in the different speech channels of a carrier frequency system would vary from channel to channel if the message for each channel at the transmitting terminal were transmitted to the line with equal transmission levels (where throughout this specification and claims, the term "transmission level" as applying to a given point will be used to denote the gain from the switchboard at the sending terminal of the circuit to the given point under consideration in the circuit). It is advantageous, therefore, with the normal frequency allocation, to transmit the channels at unequal transmission levels, as illustrated by the level diagram shown in Fig. 4. This curve signifies the relative levels at which the different frequencies are transmitted to the line at the transmitting end of the system. It will be noted that as the carrier frequency of a channel becomes lower, the channels are transmitted at progressively lower levels to the line. This condition can be obtained by adjusting the individual channel gains and losses or by using an appropriate pre-equalizer common to all channels immediately preceding the input of the transmitting amplifier, as shown at E, Fig. 1. Complementary adjustments, of course, are provided at the receiving terminal, as indicated at E'.

The particular shape of this transmission level diagram need not be a straight line, as shown in Fig. 4, but preferably is determined by the shape of the non-uniform energy-frequency distribution of the noise at the output of the line amplifiers, and the shape is so chosen that the same signal-to-noise ratio is obtained in all channels. For the purposes of this description, however, the transmission level diagram has been shown as a straight line.

Referring still to the normal frequency allocation, it will be noted that in transmitting the low frequency channels at lower levels the power output capacity required in the amplifier is reduced, and that this reduction is obtained by permitting a reduction in the signal-to-noise ratio in these channels. This decrease of signal-to-noise ratio in the lower channels is permissible because this ratio on these channels would otherwise substantially exceed the performance requirements set in practice. In no case, however, is the signal-to-noise ratio reduced below the value set by the performance requirements for the system and, as previously stated, all channels are to be made to have the same signal-to-noise ratio. It should be understood that this level diagram refers only to the way the various channels are impressed on the line at the transmitting terminal and refers in no way to the attenuation frequency characteristic of a line section, for a line section made up of a conductor and its associated receiving repeater is made to be substantially distortionless. By virtue of this property the transmission levels shown by the curve of Fig. 4 also represent the relative levels of the channels at the output of any line amplifier.

Referring now to Fig. 3, this curve shows the general shape of the energy-frequency distribution of a typical speech input at the circuit terminals. The ordinates in this case are plotted in decibels with reference to a standard zero line and it will be understood, of course, that such a logarithmic plot gives a curve which is very greatly condensed over that if actual power units had

been used for the ordinates. It is seen that if this curve is divided into two separate bands, for example from zero to 1,500 cycles and from 1,500 to 3,000 cycles, the energy in the low voice band, that is, in the band below 1,500 cycles, will be greater than the energy in the high voice band, that is, in the band above 1,500 cycles. The ratio may be in the neighborhood of 3 to 1.

By the new frequency allocation in which all the low voice bands are placed at the low frequency end of the carrier spectrum and all of the high voice bands are placed at the high frequency end of the carrier spectrum, a condition is thereby set up in which, on using the transmission level distribution of Fig. 4, the bands having the highest energy content are impressed upon or transmitted to the line at low transmission levels i. e. with relatively small amplification and the bands having the lowest energy content are transmitted to the line at high transmission levels i. e. with relatively high amplification. This shifting of the bands having high and low energy content, in combination with the level diagram shown, reduces the load which the amplifier must handle and thus provides a margin of power available in the repeater which makes it possible to materially increase the level of all channels, giving a curve which would lie parallel to but somewhat above the curve of Fig. 4, as shown on curve A of Fig. 5. This increase in transmission level on all channels in turn gives a more favorable signal-to-noise ratio, which is equivalent to a reduction in the noise appearing at the circuit terminals.

It is to be noted, however, that with the high transmission levels at the high frequencies it is possible to lower the level in that portion and raise the level in the lower portion by a larger amount, expressed in decibels, without increasing the load in the repeater; thus, a reduction of 1 milliwatt in the power of the upper portion may be replaced by an increase of 1 milliwatt in the power of the lower portion, but a reduction of 1 milliwatt in the upper portion would correspond, shall we say, to 1 d. b. transmission level decrease, whereas the same increase of power in the lower portion would correspond to a larger transmission level increase, perhaps 20 d. b., using these figures as illustrative only.

Accordingly, a still better level diagram would be of the form but not quite the position of curve B in Fig. 5, in which it will be seen that for the portion of the spectrum which contains the high voice bands the transmission level has been lowered below that shown for the same portion in Fig. 4, and that the portion of the spectrum containing the low voice bands has been raised by an amount sufficient to make full use of the power margin of the amplifier yielded by the reduction in the upper half, and that this corresponds to a larger d. b. increase in level for the lower half than for the d. b. reduction in level of the upper half. As a result there is again a more favorable signal-to-noise ratio for the circuit as a whole.

I find, moreover, that a further favorable increase can be obtained by making use of the relations depicted by the curve of Fig. 6. This curve is plotted to show in decibels the relative interfering effect of a given amount of noise power at any one frequency as compared with that for noise at a thousand-cycle frequency taken as a standard. It will be seen that the noise at frequencies above 1,500 cycles is generally less interfering than noise in the band below 1,500 cycles. In fact, it has been found that the noise

energy can be about ten times as great in the 1,500 to 3,000 cycle band as in the zero to 1,500 cycle band for the same interfering effect. Accordingly, it is permissible to allow the ratio of signal-to-noise to fall to a lower value in the portion of the speech band from 1,500 to 3,000, and since these portions of the band for each and all of the channels have been brought together in the upper part of the spectrum band of a transmission line, it is possible to still further drop the level of the high voice bands and thus provide further margin for raising the levels of the low voice bands. This accentuates the abrupt change in the level diagram at the transition point, and yields the curve B of Fig. 5. To be sure, the drop in level of the high voice bands reduces the signal-to-noise ratio of those bands, but it is effective in reducing the load on the amplifier, which provides additional power margin. The level of the low voice bands is then increased by an amount sufficient to restore the load to its original value, and this increase results in a higher signal-to-noise ratio in these bands. An optimum adjustment of levels exists such that when a low and a high voice band are combined, a net improvement in signal-to-noise ratio has been obtained over and above that which existed before making use of the relations shown by Fig. 6.

Under these circumstances it will be noted that the preferred predistortion characteristic is such as to be substantially represented by the equation $l_1 = af - b$ for the lower portion of the frequency spectrum, and by the equation $l_2 = af - c$ for the upper portion, where l is the transmission level expressed in decibels, f is the frequency, a is a constant dependent on the slope of the curve, while b and c are constants determined by the intercepts. In this case c is numerically greater than b .

Under certain conditions, such as the necessity for coordinating line levels with paralleling systems of different types, it may not be desirable to use the optimum shape for the predistortion of the transmission levels. In such cases, the subdivision and the separation of each signal channel into separate bands, as described herein, can still be used to effect a signal-to-noise improvement. Thus, those bands least affected by noise can be placed in the portions of the frequency spectrum having the greatest noise, and those bands most affected by noise can be transferred to the portions of the spectrum having the least noise.

Finally, it is to be noted that inasmuch as more power is transmitted in the low voice bands than in the high voice bands, an improvement will be obtained in inter-system crosstalk because the crosstalk in most types of cable is less at the lower frequencies.

While it has been stated that the margin of available power from the repeaters under my system may be used for raising the transmission level for all frequencies, thus reducing the noise contribution, it is to be pointed out that the margin may be used to transmit more channels through an amplifier having a given power-carrying capacity.

The description above has been on the basis of dividing each message band into two substantially equal bands, but the invention is not to be restricted in this respect. In the first place, the bands need not be of equal width but may be divided in any manner desired. Furthermore, it is not necessary that there shall be two bands only for each message. In some cases it may be

desirable to divide the message into three or more bands, shifting or relocating these bands in various ways, as is now clearly evident from the description given. Also, it will be feasible in some cases to apply this frequency allocation to only some of the channels and still obtain a decrease in noise contribution or an increase in the number of channels which can be handled by the amplifier. Then again, the order in which the bands come in the upper half need not be the same as that in the lower half but may be the reverse of that, or may follow any other desired order. Moreover, the process of shifting the bands in frequency may involve more than one step of modulation or demodulation.

The description above has also been on the basis of transmitting telephone message channels but it is not restricted to this specific use. It is equally applicable to the transmission of program circuit channels or the transmission of one or more television channels which may be split up to obtain optimum performance. Moreover, it is not restricted to physical four-wire circuits. It applies also to one-way transmission systems or to equivalent four-wire systems, i. e. to systems utilizing two different bands of frequencies to obtain two-directional transmission over the same conductors.

This invention is particularly applicable in those cases where the cost of line conductors and repeaters is much greater than the cost of the terminal equipment. An example of such a case is a submarine cable with or without intermediate repeaters. In this case, a considerable additional expenditure for terminal equipment would be warranted in carrying out the features of this invention in order to improve the signal-to-noise ratio. This improvement would make possible the use of a smaller cable, a lower powered repeater, a longer repeater spacing, or a combination of these.

What is claimed is:

1. In a signaling system adapted for the transmission of at least two signaling channels over a transmission medium, the method of transmission which consists in dividing each signaling message into a plurality of bands, modulating these bands against suitable carriers to shift the low frequency bands of the channels to one portion of the transmission frequency spectrum and to shift the high frequency bands of the channels to another portion of the frequency spectrum before transmission to the transmission medium, demodulating these bands against suitable carriers after transmission over the transmission medium, and recombining the bands in proper frequency order to obtain the original signal inputs.

2. In a signaling system adapted for the transmission of at least two signaling channels over a transmission medium, the method of transmission which consists in dividing each signaling message into a plurality of bands, modulating these bands against suitable carriers to shift those bands of all the channels least affected by noise to the portions of the frequency spectrum having the greatest noise, and to shift those bands of all the channels most affected by noise to the portion of the frequency spectrum having the least noise, demodulating these bands against suitable carriers after transmission over the transmission medium, and recombining the bands in proper frequency order to obtain the original signal inputs.

3. In a signaling system, adapted for the transmission of at least two signaling channels over a

transmission medium and requiring a definite relation of transmission level to frequency, the method of transmission which consists in dividing each signaling message into a plurality of bands, modulating these bands against carriers to shift those bands of all the channels having the least energy content to the portion of the frequency spectrum requiring the highest transmission levels and to shift those bands of all the channels having the greatest energy content to the portion of the frequency spectrum requiring the lowest transmission levels, demodulating these bands against suitable carriers after transmission over the transmission medium, and recombining the bands in proper frequency order to obtain the original signal inputs.

4. In a transmission system adapted for at least two signaling channels, the method of transmission which consists in dividing each signaling message band into a plurality of bands, modulating these against carriers of such frequencies that bands from each message which are in one frequency range common to all the channels will all appear in consecutive frequency order as a group in one portion of the frequency spectrum, while bands from each message which are in another frequency range common to all the channels will all appear in consecutive frequency order as another group in another portion of the frequency spectrum.

5. In a transmission system adapted for the transmission of at least two signaling channels over a transmission medium, the method of transmission which consists in dividing each signaling message band into a plurality of bands, modulating these against suitable carriers to shift the high power bands of the messages to the lower portion of the frequency spectrum of the transmission medium and the low power bands to the upper portion of the frequency spectrum, predistorting the signals in a predetermined manner before transmission over the line and compensating for the predistortion at the receiving end.

6. In a transmission system adapted for the transmission of at least two signaling channels over a transmission medium, the method of transmission which consists in dividing each signaling message band into a plurality of bands, modulating these against suitable carriers to shift the high power bands of the messages to the lower portion of the frequency spectrum of the transmission medium and the low power bands to the upper portion of the frequency spectrum, predistorting the signal over the whole frequency spectrum to give lower transmission levels at the lower frequencies and compensating for the predistortion at the receiving end.

7. In a transmission system adapted for at least two signaling channels, the method of transmission which consists in dividing each signal band into a plurality of bands, modulating these against suitable carriers to shift the bands of all the channels less affected by noise to the upper part of the frequency spectrum and to shift the other bands of all the channels to the lower portion of the frequency spectrum, predistorting the signal over the whole frequency spectrum to give lower transmission levels at the lower frequencies and compensating for the predistortion at the receiving end.

8. In a transmission system adapted for the transmission of at least two signaling channels over a transmission medium, the method of transmission which consists in dividing each signal band into two separate bands, modulating these

against suitable carriers to shift the low frequency bands to the lower part of the frequency spectrum of the transmission medium and the high frequency bands to the upper part of the frequency spectrum, predistorting the signal over the whole frequency spectrum to give lower transmission levels at the lower frequencies and compensating for the predistortion at the receiving end.

9. In a signaling system adapted for the transmission over a cable of at least two signaling channels, the method of transmission which consists in dividing each signaling channel into two bands, one band comprising all frequencies below a predetermined frequency and the other band comprising all frequencies above this same predetermined frequency, modulating these against suitable carriers to shift each of those bands comprising the low frequencies to the lower portion of the frequency spectrum of the cable and to shift each of those bands comprising the high frequencies to the upper portion of the frequency spectrum of the cable, predistorting the signaling frequencies in a predetermined manner before transmission to the cable, compensating for the predistortion after transmission over the cable, and recombining the bands in proper frequency order to obtain the original signal inputs.

10. In a transmission system adapted for a plurality of voice channels, the method of transmission which consists in dividing each message band into a low voice and a high voice band, modulating these against suitable carriers to shift the signal bands such that all the low voice bands fall in the lower portion of the transmission frequency spectrum of the transmission system and the high voice bands fall in the upper portion of the frequency spectrum.

11. In a carrier cable system for speech, the method of transmission of a plurality of speech messages which consists in dividing each message frequency band into two separate bands, the one containing the frequencies of high power and the other containing the frequencies of low power, allocating these bands in the available frequency spectrum of the cable system in such order that the high power bands come in the lower portion of the spectrum and the low power bands come in the upper portion of the spectrum, and predistorting the transmission level throughout the spectrum in a predetermined manner.

12. The combination of claim 6 characterized by the steps of demodulating the various signal bands and recombining at speech frequencies the message portions which originally belonged together.

13. In a communication system, a circuit adapted for the transmission of at least two communication channels, means at the transmitting end for impressing a message on each channel, means for dividing each message band into a plurality of bands, means for shifting each such band to a position in the frequency spectrum of

the circuit such that the low voice bands of all the channels fall in the lower portion of the frequency spectrum and the high voice bands of all the channels fall in the upper portion of the spectrum, a predistortion device for distorting the resultant wide band in a predetermined manner, and means for impressing the output of the distortion device on the transmission circuit.

14. The combination of claim 13 characterized by the fact that there are means at the receiving end to compensate for the predistortion, to demodulate and to recombine the appropriate bands to yield the original messages.

15. The combination of claim 13 characterized by the fact that the distorting device is one which gives a gain throughout the wide band substantially proportional to the carrier frequency of each band.

16. The combination of claim 13 characterized by the fact that the transmission system includes amplifiers and that the distorting device is one which has a gain characteristic given by $l_1 = af - b$ for the lower portion of the frequency spectrum and $l_2 = af - c$ for the upper portion, where l is the transmission level expressed in decibels f is the frequency a is a constant dependent on the slope of the curve while b and c are constants determined by the intercepts, c being numerically greater than b .

17. The combination of claim 13 characterized by the fact that the transmission system includes amplifiers and that the distorting device is one which has a gain characteristic given by $l_1 = af - b$ for the lower portion of the frequency spectrum and $l_2 = af - c$ for the upper portion, where l is the transmission level expressed in decibels f is the frequency a is a constant dependent on the slope of the curve while b and c are constants determined by the intercepts, the constants b and c being so adjusted as to give minimum interfering noise-to-signal ratio when the repeaters are carrying their full normal power load.

18. In a transmission system adapted for at least two signaling channels, the method of transmission which consists in dividing each signaling message band into a plurality of bands, modulating these against carriers of such frequencies that bands from each message which are in one frequency range common to all the channels will all appear in consecutive frequency order as a group in one portion of the frequency spectrum, while bands from each message which are in another frequency range common to all the channels will all appear in consecutive frequency order as another group in another portion of the frequency spectrum, predistorting the signals in a predetermined manner before transmission over the line, compensating for predistortion, demodulating these bands against suitable carriers at the receiving end, and recombining in proper frequency order to obtain the original signal inputs.

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