

May 28, 1935.

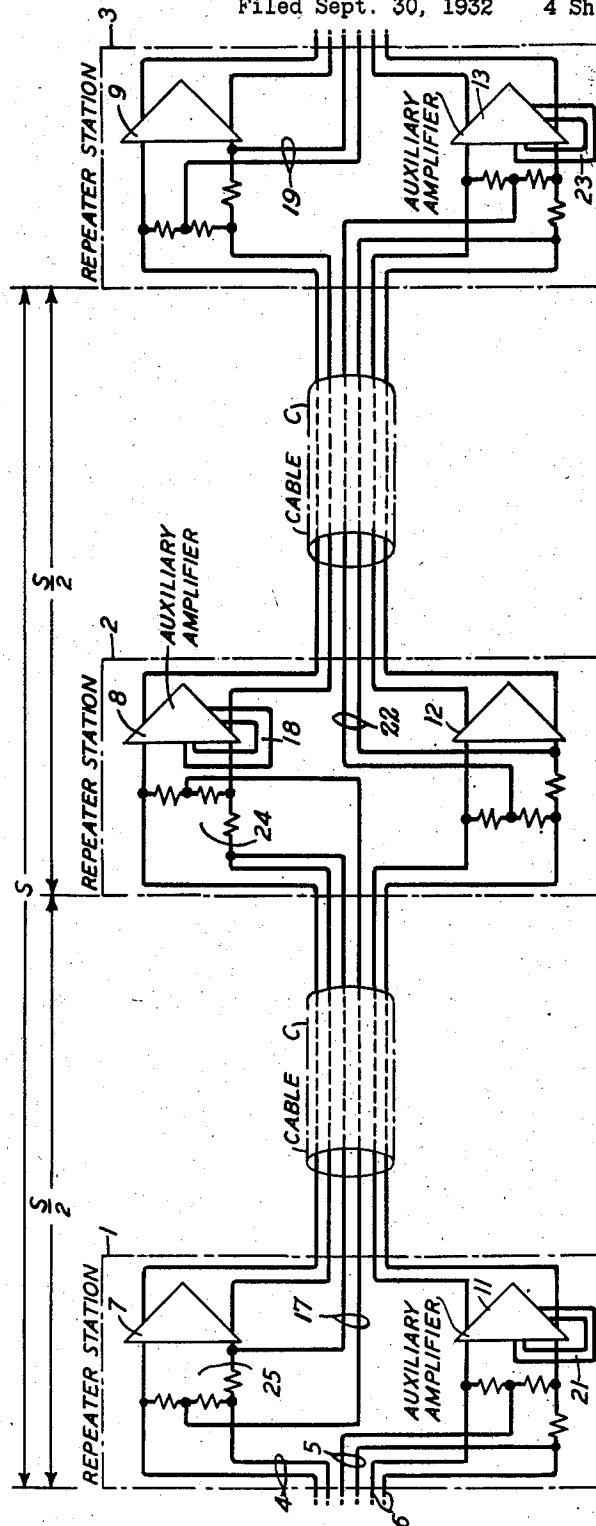
H. S. BLACK

2,002,499

WAVE TRANSLATION SYSTEM

Filed Sept. 30, 1932 4 Sheets-Sheet 1

FIG. 1.



INVENTOR
H. S. BLACK
BY *H. A. Burgess*
ATTORNEY

May 28, 1935.

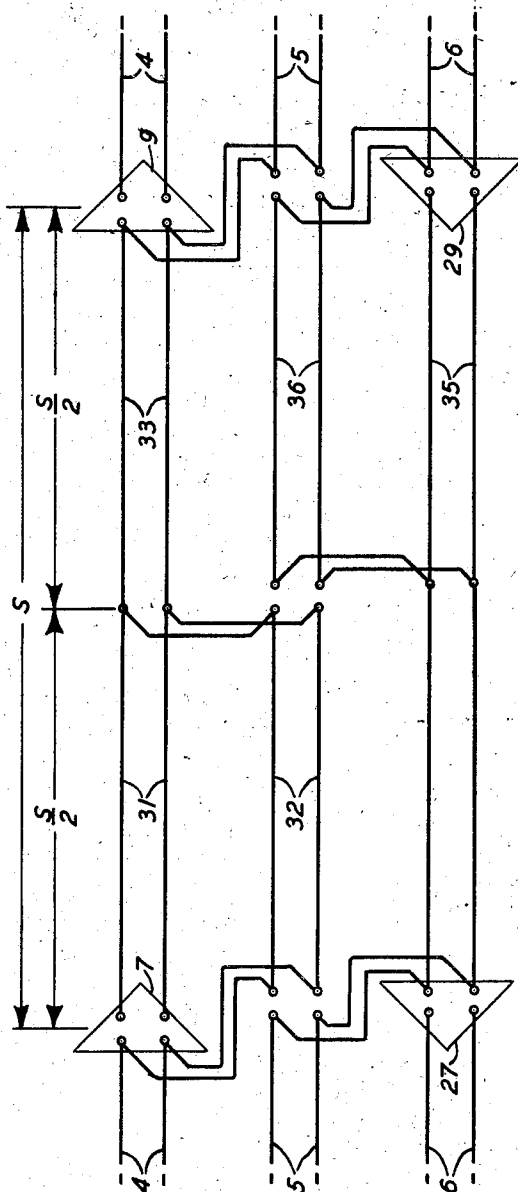
H. S. BLACK

2,002,499

WAVE TRANSLATION SYSTEM

Filed Sept. 30, 1932 4 Sheets-Sheet 2

FIG. 2



INVENTOR
H. S. BLACK
BY *H. A. Burgess*
ATTORNEY

May 28, 1935.

H. S. BLACK

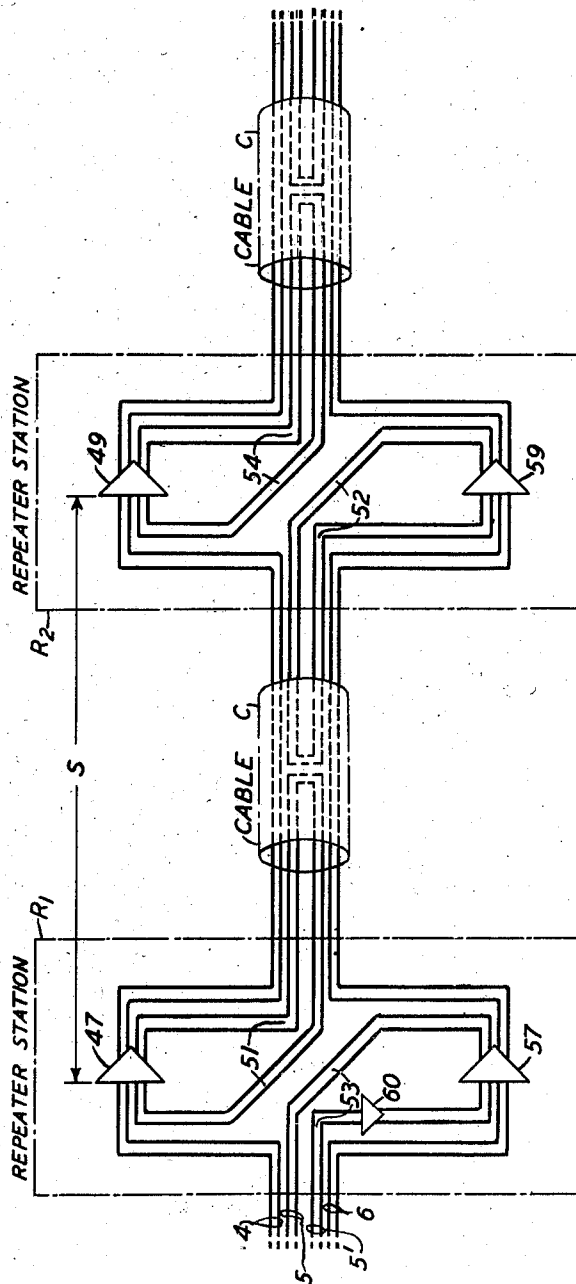
2,002,499

WAVE TRANSLATION SYSTEM

Filed Sept. 30, 1932

4 Sheets-Sheet 3

FIG. 3



INVENTOR
H. S. BLACK
BY *H. A. Burgess*
ATTORNEY

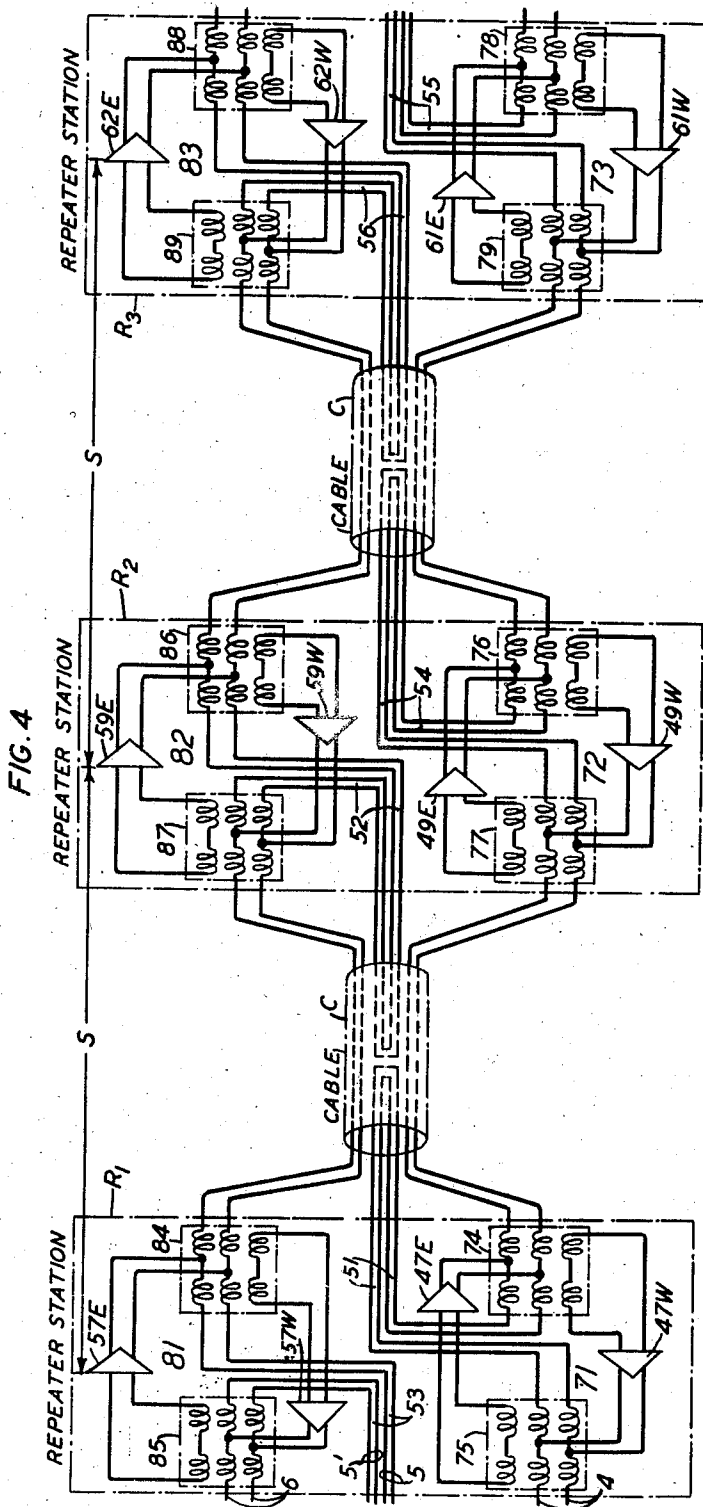
May 28, 1935.

H. S. BLACK

2,002,499

WAVE TRANSLATION SYSTEM

Filed Sept. 30, 1932 4 Sheets-Sheet 4



INVENTOR
H. S. BLACK
BY *H. A. Burgess*
ATTORNEY

UNITED STATES PATENT OFFICE

2,002,499

WAVE TRANSLATION SYSTEM

Harold S. Black, Westfield, N. J., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application September 30, 1932, Serial No. 635,525

16 Claims. (Cl. 173—44)

This application is in part a continuation of application Serial No. 606,871, filed April 22, 1932, for Wave translation systems.

This invention relates to wave translation and relates especially to retroaction or feedback in wave translation systems, as for example feedback in systems involving amplifiers, i. e. sources of gain or means for increasing the power level of waves.

An object of the invention is to control transmission in such systems, for example with regard to amplitude or phase relations, or both.

It is especially an object of the invention to effect such control of non-localized transmission; as for instance to compensate for transmission changes that variations of temperature produce in long communication circuits whose conductors are subject to the temperature variations; or for instance to compensate for transmission variations in such circuits due to frequency, aging, humidity, etc. as well as temperature, irrespective of whether the transmission variation or transmission-frequency variation being corrected is attenuation, phase shift or delay distortion.

As explained in the above mentioned application Serial No. 606,871, the attenuation and the phase distortion of a section of transmission line can be neutralized over a desired frequency range by inserting in the line section a negative feedback amplifier whose feedback path has the transmission characteristics of the line section. Such a feedback path can be regarded as an equalizing net work or means.

In one specific aspect the present invention is a cable carrier telephone or signaling system whose repeater amplifiers have feedback paths which produce negative feedback and which include spare conductors of the cable as gain regulating and line attenuation equalizing and phase distortion correcting means.

For example, the output from the amplifying elements of the repeater amplifier or source of gain can be propagated over a cable pair to a point halfway to the next equalizing amplifier in the pair. At this halfway point a portion of the energy can be picked off from this signaling or forwardly transmitting pair and fed back to the input of the first of the two amplifiers over half of a section of a second and similar pair extending between the locations of the two amplifiers and contained in the same cable, this half section of the second pair serving as a feedback path for the first amplifier. Since the first feedback amplifier (i. e. the closed feedback loop of the first amplifier) then extends halfway from the in-

put of this first amplifier to the next equalizing amplifier, and includes in its forwardly transmitting path half the length of the signaling pair between the amplifying elements of the two amplifiers or between the inputs of the two amplifiers, the portion of the signaling pair that extends between the feedback loop, and the second equalizing amplifier has the same length as the feedback path. Therefore the closed feedback loop of the first feedback amplifier produces, in the manner explained in the above mentioned application Serial No. 606,871, amplification (i. e. change in amplitude and phase of waves in their passage from the incoming circuit for the feedback loop to the outgoing or load circuit for the feedback loop), substantially equal to the negative reciprocal of the amplitude and phase change produced by the portion of the signaling pair that extends between the feedback loop and the second equalizing amplifier. So the amplitude and phase of waves at the input of the second equalizing amplifier is the same as at the input to the first amplifier (except for a phase shift of 180°). Thus, without requiring knowledge of the exact propagation characteristics of the cable, attenuation and phase shift, even though they are variable with cable temperature, aging, humidity, etc. as well as with frequency, are automatically corrected without equalizers (other than the cable conductors), and as a result the system is self-compensating, over the utilized frequency range, for transmission variations and transmission-frequency variations in attenuation, phase shift and delay distortion. Each equalizing repeater in the signaling pair operates in the same manner as the one described. That is, the second operates in the same manner as the first, to render the input to the next succeeding equalizing repeater the same as the input to the second, etc., the second mentioned conductor pair in the cable being divided into half sections insulated from each other, a full section being a length extending between the locations of the inputs of two of the consecutive equalizing amplifiers that are connected in the signaling pair described. Alternate half-sections are used as feedback paths for these equalizing amplifiers, as described above. The other alternate half sections can similarly be used as feedback paths for other equalizing amplifiers, connected in another pair of signaling conductors for transmitting, in the cable, either in the same direction as the first pair of signaling conductors or in the opposite direction. Where the transmission is in the same di-

rection (the amplifying elements of) these other amplifiers may be, for example, at the halfway points referred to above. Where the transmission is, on the other hand, in the opposite direction, these other amplifiers may be, for example, in the same repeater stations as the equalizing amplifiers of the first pair of signaling conductors. Each of these two forms of this type of system is further described hereinafter.

The temperature changes to which each feedback path is subjected are sufficiently nearly like those to which the next succeeding half-section is subjected to avoid any material error in the transmission compensation.

While the system as described above has the inputs to all of the repeaters the same, any of these inputs can be made to differ from each other if desired. For example, non-equalizing amplifiers giving any desired gain can be inserted between each feedback loop and the signal conductors that the loop feeds.

Designating as a section-pair a length of conductor pair extending between consecutive equalizing amplifiers that are connected in a given signaling pair, the type of system specifically described above uses for each section of compensated signaling pair one and one-half section-pairs of conductor (i. e., one section of a signaling pair and a feedback path of one half-section length). Each signaling pair transmits in only one direction, though the same cable can as readily be used for opposite directions of transmission (over different pairs), without materially affecting crosstalk between pairs.

A second type of system differs in that the feedback loops of the amplifiers do not include half sections of a signaling pair but are formed each of two half-sections of conductor pairs. That is, for each equalizing amplifier the closed feedback loop is separate from the signaling pair in which the amplifier is connected and extends from the output of the amplifier as a half-section of a second pair in the cable to a point halfway to the next equalizing amplifier that is connected in the signaling pair and returns to (the input of) the first amplifier as a half-section of a third pair in the cable. The other two half-sections of these second and third pairs between the location of these two amplifiers can be correspondingly used as a feedback path for another amplifier at the location of the second amplifier, connected in another signaling pair in the cable and transmitting in the same direction for example and having its feedback path extending backwardly instead of forwardly along the cable.

Each section of any given signaling pair is equalized in the same way as every other section of the pair. This type of system, operating as described above, uses for each section of compensated signaling pair two section-pairs of conductors (i. e. one section of signaling pair and a feedback path of two half-section-pairs of conductors). In this second type of system, as in the first type, each signaling pair transmits in only one direction, though the same cable can as readily be used for both directions of transmission (over different pairs).

Other types of systems can be used. For example, this second type of self-compensating system can be developed into a third type, more economical of cable conductors than either the first or second type. This can be done by taking advantage of the fact that, as pointed out in the above mentioned application Serial No. 606,371, a path can serve as a feedback path common to a plu-

ality of amplifiers or to their forwardly transmitting paths, for example, as a feedback path forming a common gain control network or attenuation equalizer for the two oppositely directed amplifiers of a two-way two-element repeater. This third type of system can be like the second but with each amplifier and its feedback path having associated therewith an oppositely directed amplifier, the two amplifiers serving as the amplifiers of a two-way two-element repeater and the feedback path serving as a common feedback path for the two amplifiers. In this 22-type repeater this feedback path can replace the line balancing networks customarily used in 22-type repeaters; and the bridge networks (for example bridge transformers or hybrid coils), customarily used to connect the oppositely directed amplifiers to the two-way line and the line balancing networks yet maintain the oppositely directed amplifiers conjugate to each other, can be used to likewise connect the amplifiers to the line and the common feedback path and maintain the amplifiers conjugate to each other.

This third type of system uses for each section of compensated signaling pair two section-pairs of conductors, i. e., one section of (two-way) signaling pair and a (two-way) feedback path of two half-section-pairs of conductors; but each signaling pair transmits in both directions. Thus each two section-pairs of conductors suffice for a compensated section of two-way circuit, instead of for a compensated section of only a one-way circuit as in the second type of system.

A fourth type of system that may be mentioned by way of further example is like the second form of the first type referred to above, except that the feedback path for an amplifier in one pair is used as the feedback path for an oppositely directed amplifier located in the same repeater station but in another pair. This can be done by using a bridge network at each end of the feedback path, to maintain the forwardly transmitting paths of the two amplifiers conjugate. This type of system gives one compensated one-way circuit for each one and one-quarter pairs of conductor.

Other objects and aspects of the invention will be apparent from the following specification and claims:

Figs. 1 and 2 show two above mentioned forms of the first type of system described above; and

Figs. 3 and 4 are illustrative of the second and third types, respectively.

Fig. 1 shows a fraction of the length of a system which may be a multiplex cable carrier telephone system. The length shown comprises three repeater stations 1, 2 and 3 at which amplifiers are connected in the cable C. The cable may comprise a large number of like pairs of conductors, three pairs 4, 5 and 6 being shown by way of illustration. In pair 4 are connected amplifiers 7, 8 and 9, with their amplifying elements at stations 1, 2 and 3 respectively; and in pair 6 are connected amplifiers 11, 12 and 13 with their amplifying elements in stations 1, 2 and 3 respectively. Amplifiers 7 and 9 and amplifier 12 are negative feedback amplifiers equalizing line attenuation by virtue of their feedback paths 17, 19 and 22, respectively. These feedback paths are formed by portions of the pair 5. The amplifier 8 and the amplifiers 11 and 13 are auxiliary amplifiers furnishing any desired gain. They may be omitted if desired. They are indicated as having feedback paths 18, 21 and 23, respectively. All of the amplifiers 7, 8, 9, 11, 12 and 13 may be amplifiers with negative or gain-reducing feedback

stabilizing their operation and reducing their modulation or distortion in the manner explained for example in the above mentioned application Serial No. 606,871. The distance (along the cable) between repeater stations 1 and 3 is designated S; and the distance between consecutive repeater stations is

$$\frac{S}{2}$$

The output of the amplifying elements of amplifier 7 is transmitted over pair 4 to station 2. At the entrance to this station a balanced bridge 24 is shown connected in this pair, by which a portion of the energy is picked off and fed back to the input of amplifier 7 at station 1 over the portion of the pair 5 (the next to the top pair) connecting stations 2 and 1, the connection between pair 5 and the input of amplifier 7 being through a balanced bridge 25 similar to the bridge 24. As explained for example in the above mentioned application Serial No. 606,871, these bridges are advantageous in rendering the feedback path of the closed feedback loop conjugate to the incoming circuit and the outgoing or load circuit between which the loop is connected.

The closed feedback loop of amplifier 7 includes in its forwardly transmitting portion the amplifying elements of the amplifier and the portion of pair 4 connecting stations 1 and 2, and has in its feedback path the portion of pair 5 connecting those stations. Thus (the closed feedback loop of) amplifier 7 extends from station 1 to station 2, or halfway to station 3.

This length of this feedback path is equal to the length of the portion of the like pair 4 connecting stations 2 and 3; so the transmission characteristics of the feedback path are the same as those of that portion, considering amplifier 8 omitted. (Amplifier 8, if present, introduces its gain in that portion, the transmission properties of amplifier 8 and that portion then differing by the amount of that amplification from the transmission properties of the feedback path.) As indicated above and explained for example in the above mentioned application Serial No. 606,871, when a feedback amplifier that is not self-oscillating at any frequency has its loop gain $\gg 1$ over the utilized frequency range, (loop gain meaning gain produced in waves by their passage once around the closed feedback loop), the amplification of the feedback amplifier (i. e. the change that the amplifier produces in amplitude and phase of waves in their passage from the incoming circuit for the closed feedback loop to the outgoing or load circuit for the loop) is substantially the negative reciprocal of the transmission change that occurs in waves in their passage through the feedback path. Therefore, (disregarding amplifier 8), the amplification of amplifier 7 is the negative reciprocal of (a transmission change equal to) the transmission change produced by the portion of pair 4 between stations 2 and 3. Consequently, transmission of waves over pair 4 from the input of amplifier 7 to the input of amplifier 9 does not alter the amplitude of the waves nor their phase relations, but merely changes their phase 180° .

The operation may be considered as use of a portion of pair 5 to pre-equalize transmission over the next succeeding equal length of pair 4, another equal length of pair 4 being included in the forwardly transmitting path of the closed feedback loop of amplifier 7 and thereby being compensated for due to the fact that the forwardly

transmitting path is self-compensating as explained in the above mentioned application Serial No. 606,871.

Amplifier 9 operates in the same manner as amplifier 7, to render the input to the next succeeding equalizing amplifier the same as the input to the amplifier 9 except for any amplification introduced by a non-equalizing amplifier similar to the amplifier 8. This next succeeding equalizing amplifier is not shown, but is spaced a distance S beyond amplifier 9, along the cable. The other equalizing amplifiers in pair 4 operate in the same manner. The pair 5 is divided into half-sections or lengths

$$\frac{S}{2}$$

insulated from each other, at the repeater stations. Alternate half-sections are used as feedback paths for these equalizing amplifiers in the manner described for the amplifier 7. The other alternate half-sections are likewise used as feedback paths for other equalizing amplifiers, such as amplifier 12, in other signaling pairs, such as the pair 5. For example, the half-section between stations 2 and 3 is used as a feedback path for amplifier 12 in pair 6. Each signaling pair, such as the pairs 4 and 6, and its amplifiers such as amplifiers 7, 8 and 9 of pair 4 and amplifiers 11, 12 and 13 of pair 6, is a multiplex carrier transmission line circuit transmitting a large number of telephone communications, for example, occupying a wide frequency range, as for instance 4 to 40 kilocycles or 8 to 100 kilocycles, the multiplexing being accomplished by any usual or suitable terminal equipment at the terminals of the circuit (which are not shown).

Fig. 2 shows a portion of a transmission system which may be a multiplex cable carrier telephone system generally similar to that of Fig. 1, though the cable sheath for the conductor pairs such as 4, 5 and 6 is not shown. In signaling pair 4, a large number of negative feedback amplifiers, such as 7 and 9, are pointed east. In signaling pair 6, a large number of negative feedback amplifiers, such as 27 and 29 which are like amplifiers 7 and 9, are pointed west. The amplifying elements of the amplifiers for the different signaling pairs are located in the same repeater stations, which have the spacing S along the cable.

The closed feedback loop for amplifier 7 extends from the input of the amplifying elements of that amplifier through those elements and over a portion 31 of the pair 4, of length

$$\frac{S}{2}$$

to the halfway point between the inputs of amplifiers 7 and 9; and thence returns to the input of the amplifier 7 over a portion 32 of pair 5, of length

$$\frac{S}{2}$$

which portion, at its east end, is bridged across pair 4 at the halfway point just mentioned, and, at its west end, is bridged across the pair 4 at the input of the amplifier 7.

Since the portion 31 is in the forwardly transmitting portion of the feedback loop the overall transmission is stabilized against variation of attenuation and phase in this portion (and against variation of transmission-frequency characteristics of this portion). Since the portion 32 of pair 5 is in the feedback path of am-

plifier 7, this portion 32 will give to the overall attenuation and phase characteristics slopes equal and opposite to those of the portion 33 of pair 4 that connects portion 31 to amplifier 9.

5 This means that the loop has pre-equalized for the portion 33 of pair 4 and the overall transmission from the input of amplifier 7 to the input of amplifier 9 is zero except for a phase shift of 180°, or in other words transmission equaliza-
10 tion or compensation of the kind indicated above has been accomplished for the circuit through pair 4 between the inputs of amplifiers 7 and 9.

Transmission compensation for the next succeeding section of the circuit through pair 4 is likewise achieved by amplifier 9; and transmission compensation for the other sections is likewise achieved by the other amplifiers connected in pair 4.

Similarly, amplifier 29, having a feedback loop comprising forwardly transmitting path 35,
20 formed of a length

$$\frac{S}{2}$$

of pair 6, and feedback path 36, formed of the same length of pair 5, provides transmission compensation for the section of pair 6 extending from the input of amplifier 29 to the input of amplifier 27. Likewise, amplifier 27 provides compensation for the next succeeding section,
30 etc.

Fig. 3 shows a portion of a transmission system which may be multiplex cable carrier telephone system generally similar to that of Fig. 1. Of the large number of like conductor pairs in the cable, the figure shows portions of not only the pairs 4, 5 and 6 but also a pair 5', since in this system two conductor pairs 5 and 5', instead of one, are used to equalize transmission over the two signaling pairs 4 and 6.

40 In signaling pair 4 a large number of negative feedback amplifiers, such as 47 and 49, are pointed east. In signaling pair 6 a large number of negative feedback amplifiers such as 57 and 59, which are like amplifiers 47 and 49, are also
45 pointed east. The amplifying elements of the amplifiers for the different signaling pairs are located in the same repeater stations, such as R₁ and R₂, which have the spacing S along the cable.

The amplifiers have closed feedback loops such as loops 51, 52, 53 and 54 for amplifiers 47, 59, 57 and 49, respectively. These loops are separate from the signaling pairs in which the amplifiers are connected. Loop 51 extends from the output of amplifier 47 as a length
50

$$\frac{S}{2}$$

(i. e. a half-section) of pair 5 (the next to the top pair) to a point halfway to amplifier 49 and extends back to the input of amplifier 47 as a half-section of pair 5' (the next to the bottom pair). The other two half-sections of these pairs between stations R₁ and R₂ are correspondingly used in the closed feedback loop 52 for amplifier 59, which equalizes the section of pair 6 between stations R₁ and R₂. This closed feedback loop 52 extends from the output of amplifier 59 halfway back to station R₁ as a half-section of pair 5, and returns to the input of the amplifier
70 as a half-section of pair 5'.

Each section of any given signaling pair can be equalized in the same way as every other section of the pair. Thus, the section of pair 4 to the right of station R₂ is equalized by the
75 negative feedback action of amplifier 49 through

its feedback loop 54. Similarly the section of pair 6 to the left of station R₁ is equalized by the negative feedback action of amplifier 57 through its closed feedback loop 53. An auxiliary amplifier 60 is shown in this feedback loop 53. It increases the loop gain and thereby reduces the gain of amplifier 57 in case such action is needed, as for example in case the length of loop 53 is too great to properly equalize or compensate for the section of pair 6 at the left of station R₁ because of the wiring required at station R₁ to connect the loop to the amplifier 57 or because of other reasons. Such auxiliary amplifiers can be inserted in any of the feedback loops which require them.

The loop gain of a feedback amplifier and the loop phase shift of the amplifier (i. e. the phase shift produced in waves in their passage once around the closed feedback loop of the amplifier) should be carefully controlled to insure against singing at any frequency in the entire frequency spectrum, especially when the loop gain in the utilized frequency range is large in order to produce large distortion reduction by the feedback as explained for example in the above mentioned application Serial No. 606,871. The requirements necessary in order to preclude singing are given for example in that application. Meeting those requirements in practice usually means that the loop phase shift should not be zero or any multiple of 360° at any frequency for which there is a loop gain, this condition being always sufficient to preclude singing. Satisfying this condition in the case of the equalizing amplifiers of the systems described herein can be facilitated by close spacing of the repeater stations along the cable, since this tends to reduce loop phase shift. The close spacing of the repeaters also tends to reduce the maximum power level differences in the cable and thereby reduces the crosstalk between pairs.
40

Moreover, with close spacing, every equalizing repeater is like every other because of the uniformity of spacing which results directly from the spacing being close. The equalization is practically perfect because the equalizer for a portion of a cable pair is an equal length of a like pair and the longer the system the more nearly perfect become the results. Moreover, because the equalizer is located in the feedback path it compensates automatically and ideally (and also by itself) for the effect of temperature changes. That is, as the cable temperature rises, for example, the cable loss increases, which decreases the feedback and consequently increases the amplifier gain, and as the loop gain is made large compared to unity the compensation approaches perfection.
55

Further, for a given number of communication channels, the number of conductor pairs required in a given cable varies inversely as the square of the repeater spacing, and moreover the size of the conductors required decreases at the same time.

Fig. 4 shows a portion of a transmission system which may be a multiplex cable carrier telephone system like that of Fig. 3, but with each signaling pair, such as 4 and 6, transmitting in both directions, and with the portions of cable pairs (such as pairs 5 and 5') that are used in the amplifier feedback paths transmitting in both directions also.
70

In signaling pair 4 a large number of negative feedback amplifiers are pointed east as indicated by amplifiers 47E and 49E, corresponding to amplifiers 47 and 49 of Fig. 3, and another such
75

amplifier 61E. Also in this pair are westwardly pointed amplifiers, for example 47W, 49W, 61W, etc. Amplifiers 47E and 47W form the oppositely directed amplifiers of a 22-type repeater 71, amplifiers 49E and 49W form the oppositely directed amplifiers of a second 22-type repeater 72, amplifiers 61E and 61W form the oppositely directed amplifiers of a 22-type repeater 73, etc.

Similarly, in signaling pair 6 are a 22-type repeater 81 comprising negative feedback amplifiers 57E and 57W, a 22-type repeater 82 comprising negative feedback amplifiers 59E and 59W, a 22-type repeater 83 comprising negative feedback amplifiers 62E and 62W, etc., the amplifiers 57E and 59E corresponding respectively to the amplifiers 57 and 59 of Fig. 3.

The amplifying elements of the amplifiers for the various repeaters are located in repeater stations such as R₁, R₂ and R₃, which have the spacing S along the cable.

The repeaters have the customary bridge transformers (i. e. hybrid coils) for separating oppositely directed transmissions through the repeater. These bridge transformers are 74 and 75 for repeater 71, 76 and 77 for repeater 72, 78 and 79 for repeater 73, 84 and 85 for repeater 81, 86 and 87 for repeater 82, and 88 and 89 for repeater 83.

The closed feedback loop of amplifier 47E has feedback path 51 corresponding to the path 51 in Fig. 3 but connected to the amplifier through the bridge transformers 74 and 75 and serving as line balancing networks for the line constituted by pair 4. This feedback path extends from station R₁ halfway to station R₂ as a half-section of pair 5 (the next to the bottom pair) and back to station R₁ as a half-section of pair 5' (the next to the top pair), as in the case of Fig. 3. This feedback path serves also as the feedback path in the closed feedback loop for amplifier 47W. The feedback for amplifier 47E is from the output of the amplifier 47E through bridge transformer 74, eastward over the portion of pair 5 in closed feedback loop 51, westward over the portion of pair 5' in this loop to the bridge transformer 75, and through this transformer to the input of the amplifier 47E. The feedback for amplifier 47W is from the output of the amplifier 47W through bridge transformer 75, eastward over the portion of pair 5' in the closed feedback loop 51, westward over the portion of pair 5 in this loop to the bridge transformer 74, and through this transformer to the input of the amplifier 47W.

Each of the repeaters operates in this way to equalize a section of circuit consisting of a length S of the pair, such as pair 4 or pair 6, in which the repeater is connected.

While the systems shown have been described with especial reference to cable carrier systems with a large number of multiplexed circuits in the cable, it is emphasized that the invention is not restricted to such systems. For example, either with a non-loaded cable or coaxial conductor system, by doubling the number of cable conductors and employing them in the circuit of Fig. 4, the complete cable is made self-equalized with respect to transmission variations due to frequency, temperature, aging, humidity, etc., irrespective of whether the transmission-frequency variation being corrected is attenuation, phase shift or delay distortion.

When cable conductors are used as an equalizing network in the manner hereinbefore described, the length of the conductors so used need

not in all cases be equal to the length of the cable conductors for which the equalization is accomplished, but may be either greater or less. For example, a given length of a 16 gauge pair may equalize attenuation of a different length of a 20 gauge pair between a cable terminal and the nearest equalizing amplifier connected in the pair.

What is claimed is:

1. A wave translating system comprising a wave propagation path extending from one of two geographically separated points to the other, a wave amplifying device in said path, said amplifying device having a feedback path extending from one of two geographically separated points to the other and feeding back gain-reducing waves in said amplifying device.

2. A wave translating system comprising a long transmission circuit and an amplifier in said circuit having its gain of the order of magnitude of the transmission loss of said circuit for compensating for said loss and having a feedback path for feeding gain-reducing waves back in said amplifier, said path connecting points geographically separated from each other and comprising means for compensating for transmission changes in said circuit.

3. A wave translating system comprising a wave transmission path from one location to a location remote therefrom, an amplifier connected in said path, and a gain-reducing feedback path for said amplifier, said feedback path having a portion providing a path from one of said locations to the other, and said portion having substantially the same transmission properties as an equal length of said first mentioned path.

4. A wave transmission system comprising a circuit extending between geographically remote locations and comprising an amplifier, and a wave path from one of said locations to the other, located throughout its length in proximity to said circuit and feeding back gain-reducing waves in said amplifier.

5. A wave translating system comprising a circuit having variation of transmission characteristics with temperature, an amplifier in said circuit, and a wave path producing gain-reducing feedback in said amplifier and having variation of transmission characteristics thereof in response to changes in its temperature substantially the same as said circuit.

6. A wave translating system comprising a circuit subject to varying weather conditions which produce variations in its transmission characteristics, an amplifier in said circuit, and means comprising a feedback path producing negative feedback in said amplifier, said means producing in response to weather variations substantially the same variation of the transmission characteristics of said path as said variations in the transmission characteristics of said circuit.

7. A transmission system comprising a cable, like conductors in said cable, and an amplifier connected in a pair of said conductors, portions of others of said conductors forming a transmission equalizing feedback path for said amplifier for equalizing transmission in said pair.

8. A wave translating system comprising a circuit, an amplifier connected in said circuit, and means for compensating for transmission changes in said circuit comprising a feedback path for feeding back gain reducing waves in said amplifier, said path connecting points in said circuit geographically separated from each other.

9. A wave translating system comprising a cir-

cuit, an amplifier connected in said circuit, and means for compensating for transmission changes in said circuit comprising a feedback path for said amplifier connecting points of said circuit half the length of said circuit apart.

10. A wave translating system comprising a long transmission line and an amplifier connected in said line for compensating for the transmission loss in said line, said amplifier having its gain of the order of magnitude of said loss and having a gain-reducing feedback path connecting points geographically separated from each other and feeding back waves from a point of the output circuit of said amplifier to a neighboring point of the input circuit of the amplifier.

11. A wave translating system comprising a circuit, an amplifier connected in said circuit, and means for compensating for transmission changes in said circuit comprising a feedback path for said amplifier extending in proximity to said circuit half the length of said circuit and back and feeding back waves from a point of the output circuit of said amplifier to a neighboring point of the input circuit of the amplifier.

12. A wave translating system comprising two long transmission lines and two gain sources associated with said lines, respectively, for compensating for transmission loss in said lines, each gain source having its gain of the order of magnitude of the loss of its associated line, and said gain sources having a common gain-reducing feedback circuit connecting points geographically separated from each other.

13. A wave translating system comprising two amplifiers having a common feedback circuit, and means feeding back waves in one of said amplifiers in one direction through said circuit and feeding back waves in the other amplifier in the opposite direction through said circuit.

14. A wave translating system comprising two two-way wave transmitting paths, a two-way wave transmitting circuit, two one-way transmitting paths, and means connecting said one-way paths and said two-way circuit between the two first mentioned two-way paths for two-way transmission over said two latter paths and said two one-way paths and two-way transmission throughout the length of said two-way circuit,

with said one-way paths conjugate to each other and with said two-way circuit conjugate to the two first mentioned two-way paths.

15. A cable carrier telephone system comprising a cable, like conductors therein, a two-way two-element repeater for transmitting in opposite directions in one pair of said conductors, a neighboring two-way two-element repeater for transmitting in opposite directions in a second pair of said conductors, a feedback path common to the amplifiers of the first mentioned repeater extending in one direction from that repeater half the length of a section of said first pair and back for compensating for transmission changes in said section of said first pair and balancing the impedances presented to that repeater by that pair, a second feedback path common to the amplifiers of the second repeater extending in the opposite direction from that repeater half the length of a section of said second pair and back for compensating for transmission changes in said section of said second pair and balancing the impedances presented to that repeater by that pair, said first feedback path being formed of portions of third and fourth pairs of said conductors, and said second feedback path being formed of other portions of said third and fourth pairs of said conductors, two bridge networks connecting the amplifiers of said first repeater to said first pair and to the ends of said first feedback path with those amplifiers conjugate to each other, and two bridge networks connecting the amplifiers of said second repeater to said second pair and to the ends of said second feedback path with those amplifiers conjugate to each other.

16. An electrical wave amplifier for use in connection with a transmission line, said amplifier having an input and an output coupled respectively to an incoming and an outgoing portion of said line, and a feedback circuit from said output to said input including a transmission line lying adjacent to said first line and having transmission characteristics respectively corresponding thereto and variable in similar manner therewith, said feedback operating to reduce the gain of said amplifier.

HAROLD S. BLACK.