

July 8, 1924.

1,500,552

L. ESPENSCHIED
MULTIPLEX TRANSMISSION SYSTEM

Filed June 17, 1919

5 Sheets-Sheet 1

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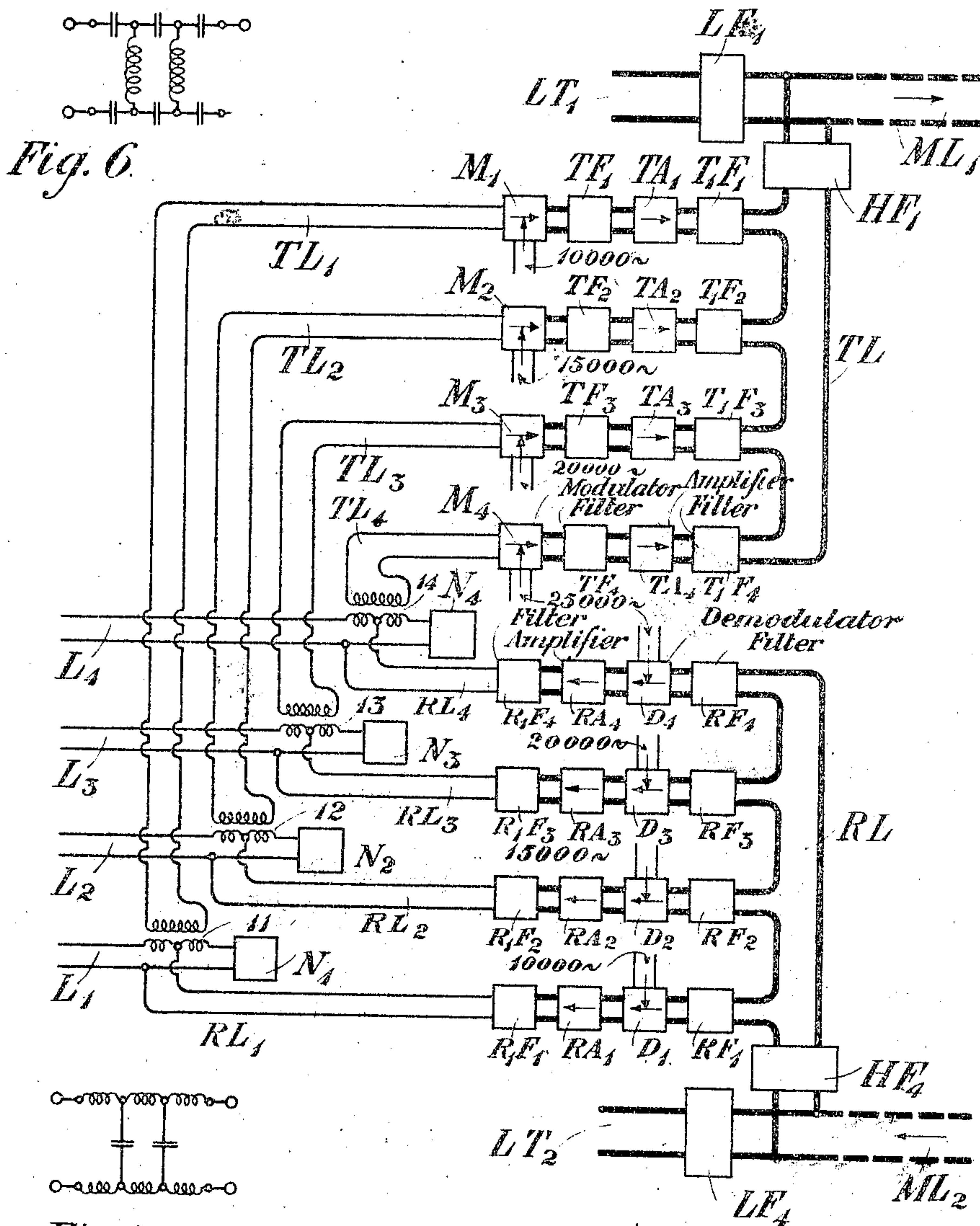


Fig. 7.

Fig. 1.

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5 Sheets-Sheet 2

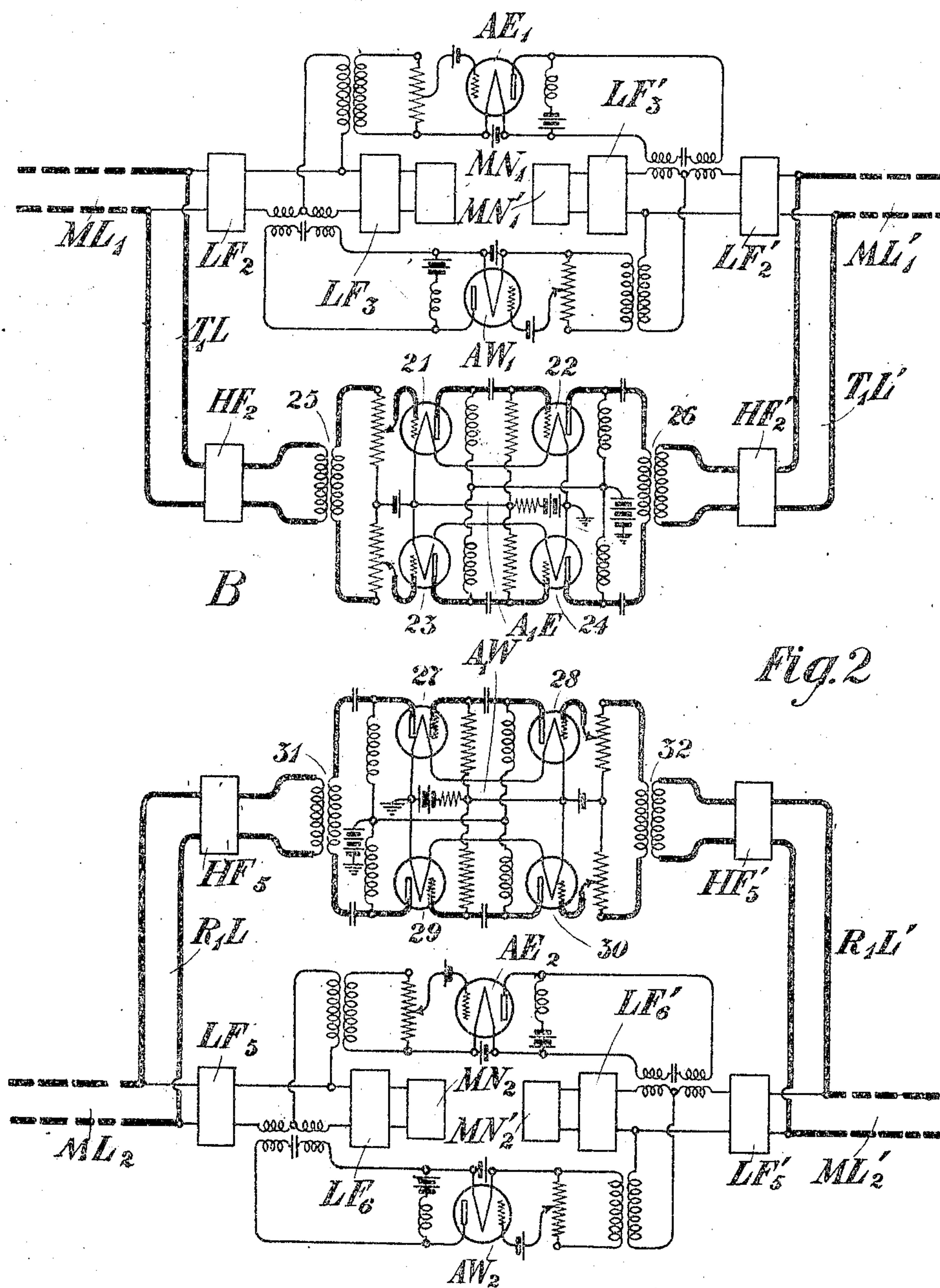


Fig. 2

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MULTIPLEX TRANSMISSION SYSTEM

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5 Sheets-Sheet 3

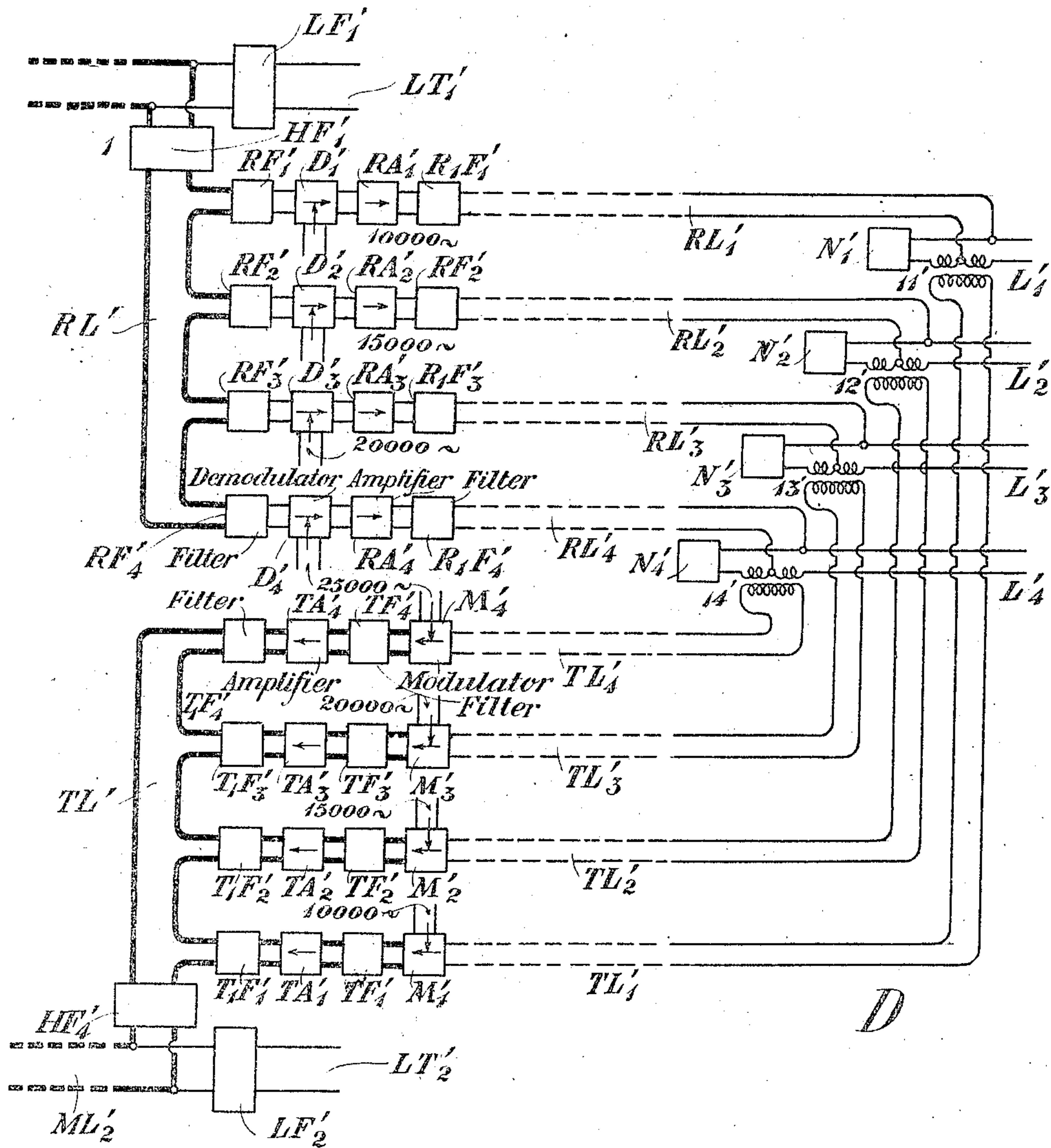


Fig. 3

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MULTIPLEX TRANSMISSION SYSTEM

Filed June 17, 1919

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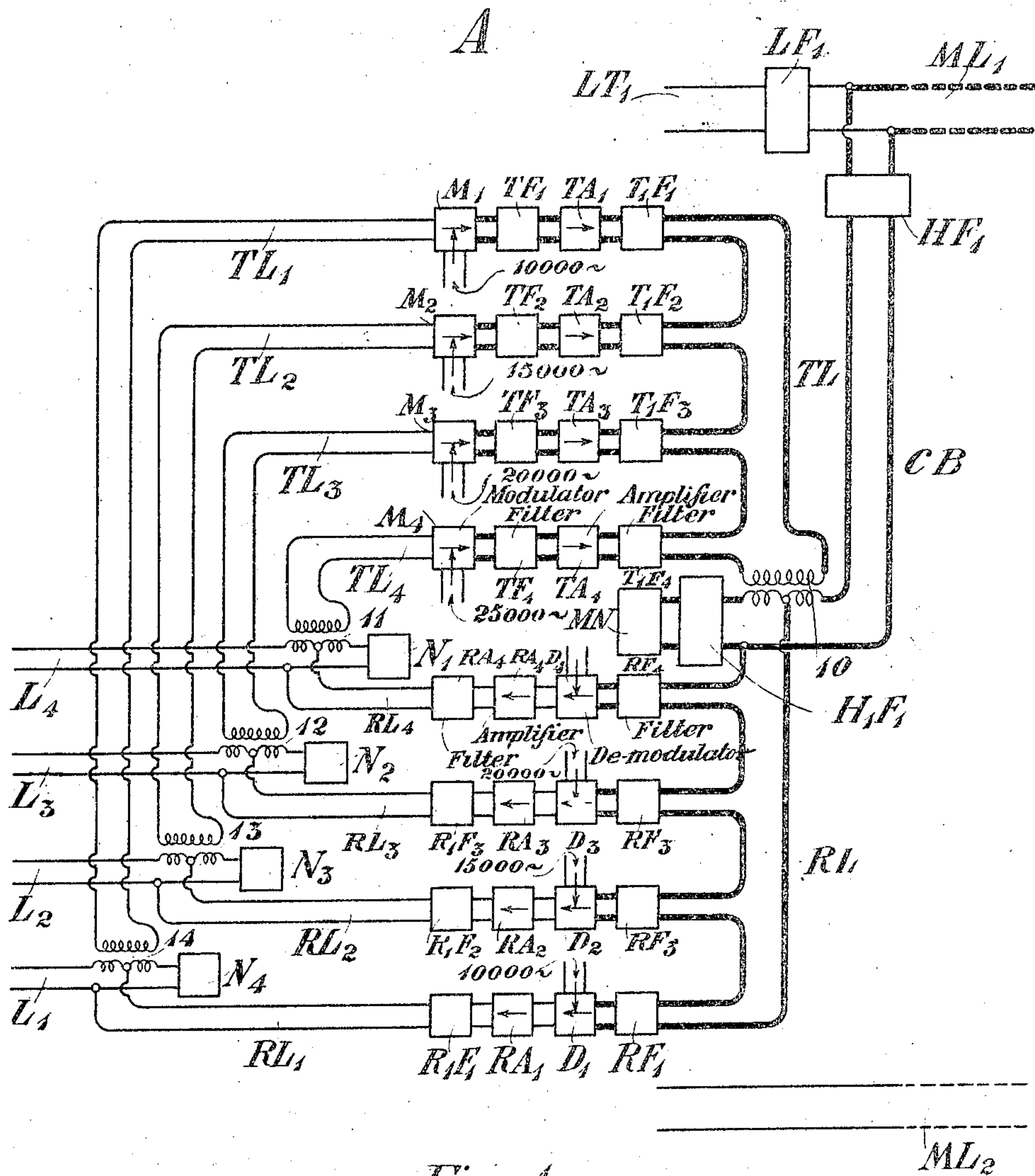


Fig. 4

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5 Sheets-Sheet 5

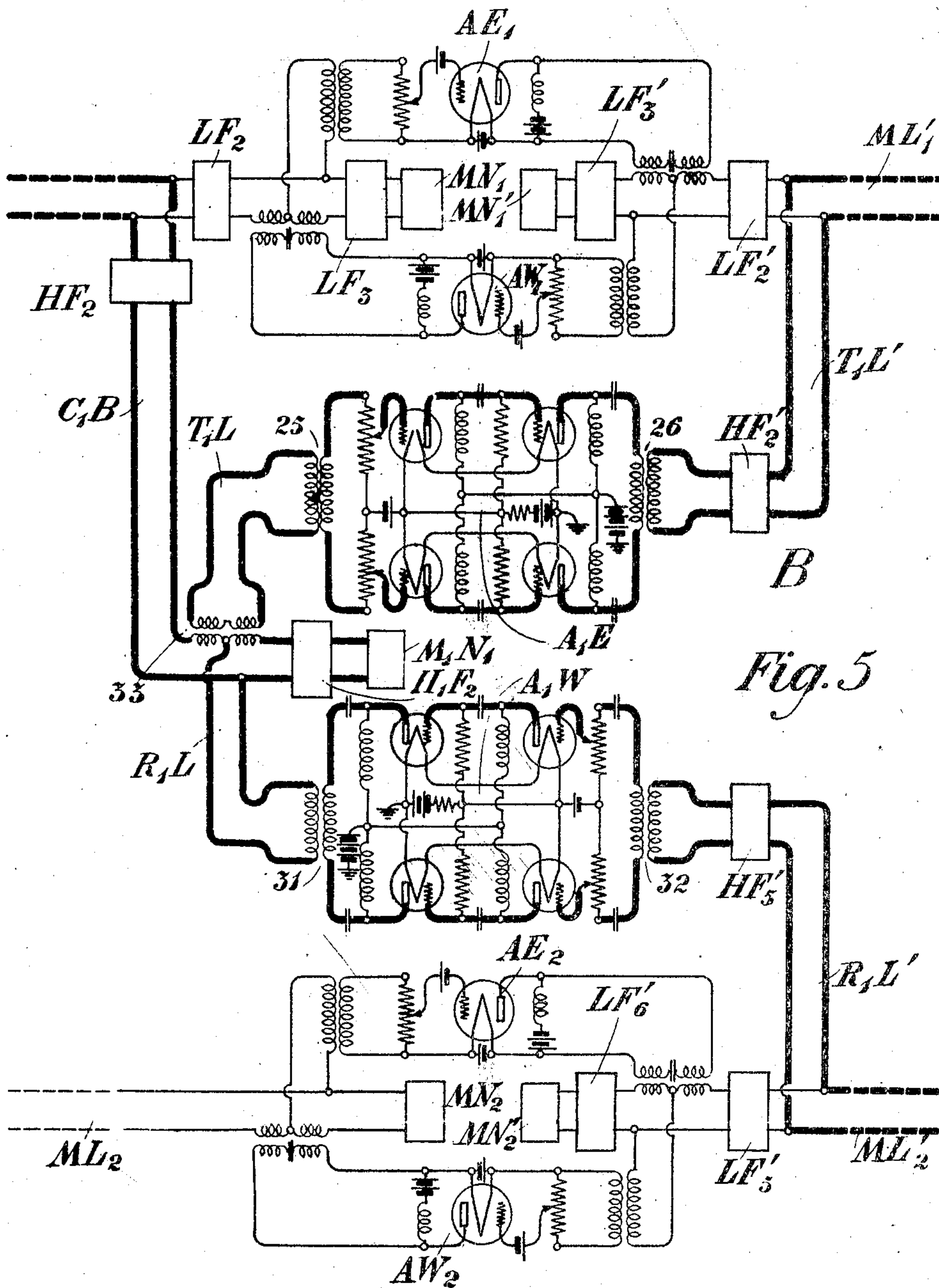


Fig. 5

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UNITED STATES PATENT OFFICE.

LLOYD ESPENSCHIED, OF HOLLIS, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

MULTIPLEX TRANSMISSION SYSTEM.

Application filed June 17, 1919. Serial No. 304,791.

To all whom it may concern:

Be it known that I, LLOYD ESPENSCHIED, residing at Hollis, Long Island, in the county of Queens and State of New York, have invented certain Improvements in Multiplex Transmission Systems, of which the following is a specification.

This invention relates to multiplex transmission, and more particularly to multiplex systems in which carrier currents are used for the transmission of signals.

The invention comprises a system in which multiplex transmission is applied to a circuit of the four-wire type, that is, a circuit in which one transmission line is used for transmission in one direction, and another transmission line is used for transmission in the opposite direction.

It also comprises a system in which multiplex transmission is applied to a transmission path which may be in part a two-way path and in part a four-wire one-way transmission path.

It further comprises a transmission system in which signals from a plurality of signaling stations may be simultaneously transmitted in one direction to a distant station over a common signaling path, while signals from the distant station may be simultaneously transmitted over another signaling path in the opposite direction, and individually transmitted to the corresponding signaling stations.

Another feature of the invention consists in a transmission system in which a plurality of signals simultaneously transmitted in one direction may be separated at some desired point and separately transmitted over one-way lines to distant signaling stations, while signals from such distant signaling stations may be transmitted in the reverse direction over another set of one-way lines, and then combined for simultaneous transmission over a common path.

The invention also provides a transmission system in which a plurality of signals may be simultaneously transmitted over a common conductor to an intermediate station, and there separated into individual channels so that they may be transmitted over individual lines to a distant point.

The invention furthermore has reference to the provision of a transmission circuit which is so arranged that frequencies lying within certain limits may be transmitted in

either direction over said circuit, while frequencies lying within other limits may be transmitted in one direction only.

And the invention likewise concerns the provision of a transmission path having a two-way repeater for the amplification of a transmission of a certain character, and a one-way repeater in parallel therewith for the amplification of transmission of a different character.

In order that the above results, as well as other aims of the invention may be secured, it is proposed to utilize two low frequency signaling lines, either or both of which may normally be used for two-way transmission, and to superpose upon said lines a carrier system so organized that a plurality of carrier frequencies will be transmitted in one direction over one line, and in the opposite direction over the other line. At the repeater points in these lines the usual two-way repeaters, which are provided for the purpose of amplifying low frequency signals, will not be interfered with, but one-way repeaters adapted for the amplification of the carrier frequencies will be connected in parallel with the two-way repeaters, and will be arranged to repeat in the proper direction. Suitable means will also be provided to separate the low frequency currents from the carrier currents, so that each type of transmission is routed through the proper repeater. At terminal stations, the carrier frequencies may be separated from the low frequencies, and transmitted through suitable carrier apparatus which operates to separate the transmissions corresponding to the several channels and transmit them over separate receiving and transmitting circuits to terminal lines or stations. Where the terminal lines or stations are at points distant from the point at which the carrier apparatus is located, the separate transmitting and receiving lines may be extended as one-way transmission lines so that each signaling station is provided with a four-wire circuit extending to the point at which the carrier apparatus is located.

In certain instances it may be desirable to combine at some point the two sets of oppositely directed transmissions which are separately transmitted over the two sides of a four-wire circuit and transmit them over a two-way circuit to some distant point

at which carrier apparatus is located. At this point the two sets of oppositely directed transmissions may be again separated, and the several transmissions of each set directed to proper transmitting and receiving channels through which the carrier system is connected with individual terminal lines or stations. In this case also the signaling stations may, if desired, be each associated with the carrier apparatus through separate four-wire circuits.

The advantages attending the application of the four-wire principle to carrier transmission arise from the fact that the attenuations of the high frequency carrier currents on open wire lines are relatively great, and where sections of cable occur in the transmission circuits the impedance characteristics of the lines at high frequency is markedly irregular. Under these conditions, the use of two-way circuits with two-way repeaters would require a very frequent spacing of the repeaters for satisfactory transmission because the repeaters cannot be adjusted to give the amplifications required to make up losses in long sections of line. This becomes at once apparent when it is considered that the irregular characteristics of the line sections prevent the attainment of anything approaching an exact balance at the repeater points, thereby causing the repeaters to sing if adjusted so as to give high amplifications. By using four-wire circuits, the necessity for balancing the transmission lines at the repeater points is obviated, and the one-way repeaters may be adjusted to any amplifications desired, so long as the amplification around the four-wire path does not exceed the attenuation around said path by an amount sufficiently great to cause singing due to the unbalance existing at the terminal points of the four-wire circuit.

The four-wire arrangement is similarly advantageous where it is desired to apply a carrier system to lines constructed entirely of cable. In this case the four-wire circuit permits the use of larger gains and the consequent greater separation of the repeater stations than would be possible with a two-wire circuit. Furthermore it avoids the high degree of capacity balance required between two-wire cable circuits for high frequencies. This requirement may be obviated in the case of a four-wire circuit by grouping together respectively the east and west bound circuits, and electrically separating the groups by choosing non-adjacent pairs of conductors in the cable, by shielding the two groups of conductors, or by employing separate cables for the two groups. These methods of separation form no part of the present invention, however, and need not be described herein being fully considered in

the U. S. application of O. B. Blackwell, Serial No. 235,680 filed May 20, 1918.

The principles underlying four-wire circuits in general are fully discussed in the U. S. patent to Van Kesteren, 1,189,411, of July 4, 1916, and the U. S. application of George A. Campbell, Serial No. 72,606, filed January 17, 1916, patented Sept. 14, 1920, No. 1,352,786, and in view of these disclosures it is unnecessary to further discuss them here. In the application of these principles, one of the disadvantages incident to the use of four-wire circuits for ordinary low frequency transmission may be eliminated, namely: the utilization of two transmission paths for four-wire transmission as compared with the utilization of but one transmission path for two-wire transmission. This requirement may not be a disadvantage in the case of carrier transmission for the reason that, due to the severe cross talk conditions it is impossible to superpose carrier transmission channels of a given frequency upon more than one, or at most, a few low frequency lines of the same pole line, unless special transpositions or other changes are made to reduce cross talk. Since, for the reasons just given, all of the lines of a given pole line may not be available for two-wire carrier transmission, there is no disadvantage from the point of view of duplication of apparatus, in using an additional line, so that one line may be used for transmission in one direction and the other for transmission in the opposite direction.

The invention may now be understood by reference to the following description when read in connection with the accompanying drawing, Figures 1, 2 and 3 of which, when placed side by side in the order named constitute a circuit diagram of one embodiment of the invention, Figs. 4, 5 and 3 of which, when placed side by side in the order named, constitute a circuit diagram of another embodiment of the invention, and Figs. 6 and 7 of which illustrate forms of wave filters employed in connection with the invention.

Referring to Figs. 1, 2 and 3 of the drawing, a four-wire carrier system is disclosed embodying special apparatus at four stations, A, B, C and D. Ordinary low frequency signaling lines, such as telephone lines ML_1 and ML_2 are shown extending between stations A and B, while similar lines ML_1' and ML_2' extend from stations B to C, the two sets of lines being interconnected at station B by means of repeater apparatus hereinafter described.

In order to provide for four-wire carrier transmission over the lines above referred to, a common carrier transmitting circuit TL is branched from the line ML_1 at station A, through a filter HF_1 . The filter HF_1 is preferably an apparatus so designed as to

freely allow the passage of frequencies within the range employed in carrier transmission, while substantially preventing the transmission of frequencies lying outside or below said range, thereby insuring that the low frequency telephone currents which are ordinarily transmitted over the line will not be diverted into the carrier branch, but will be transmitted to the terminal low frequency portion of the line LT_1 . A low frequency filter LF_1 is included in the low frequency terminal portion of the line LT_1 , said filter being so arranged as to freely transmit the low frequency signaling current, such as telephone currents, while substantially preventing the transmission of the higher frequency carrier currents. These filters are of the general type disclosed in U. S. patents to George A. Campbell 1,227,113 and 1,227,114, dated May 22, 1917, and as set forth in said patents may be designed to transmit any desired range of frequencies. The high frequency filter HF_1 may be of the type shown in detail in Fig. 6 in which case it consists of a plurality of sections, each including series capacity and shunt inductance. The low frequency filter LF_1 may be constituted structurally as indicated in Fig. 7, in which case it comprises a plurality of sections, each having series inductance and shunt capacity.

In a similar manner a common carrier receiving circuit RL may be branched from the main line ML_2 through a high frequency filter HF_4 in all respects similar to the filter HF_1 , while a low frequency filter LF_4 similar in character to the filter LF_1 may be inserted in the terminal portion LT_2 of the line ML_2 . The filter HF_4 prevents the transmission of low frequency current such as telephone currents to the carrier branch, while filter LF_4 prevents the transmission of carrier frequencies to the low frequency terminal apparatus.

A plurality of low frequency signaling lines, as, for instance, telephone lines L_1 , L_2 , L_3 and L_4 , are shown associated through transformer arrangements 11, 12, 13 and 14, with individual carrier transmitting channels TL_1 , TL_2 , TL_3 , and TL_4 , as well as with individual carrier receiving channels RL_1 , RL_2 , RL_3 and RL_4 . In order that the individual transmitting and receiving channels may be conjugate with respect to each other, that is, may be so arranged electrically that electromotive forces arising in the one circuit will be substantially without effect in the other circuit, the transformers 11, 12 etc. are of the well known balanced type, and each of the lines L_1 , L_2 etc. are balanced by means of networks N_1 , N_2 , N_3 and N_4 .

Each of the individual transmitting channels TL_1 , TL_2 etc. includes means for translating low frequency signaling currents re-

ceived from the corresponding low frequency line into high frequency oscillations for carrier transmission purposes, as well as means for maintaining a frequency separation between the transmitting channels. For this purpose, modulating devices M_1 , M_2 , M_3 , and M_4 , are inserted in the channels TL_1 , TL_2 etc., these modulating devices being of any type well known in the art, but preferably vacuum tube modulators of the general character disclosed in the U. S. application of B. W. Kendall, Serial No. 125,349, filed October 13, 1916, or in the United States application of John R. Carson, Serial No. 157,413, filed March 26, 1917. Each modulator has impressed upon it, in addition to the modulating signal current, a carrier current having a frequency individual to each particular channel. These frequencies may be of any desired value, but should be so chosen as to maintain good frequency separation between the channels. For purposes of illustration, frequencies of 10,000, 15,000, 20,000 and 25,000 are assigned to the channels TL_1 , TL_2 , TL_3 , TL_4 respectively.

In the output of each of the modulators, filters, such as TF_1 , TF_2 , TF_3 and TF_4 , are provided. These filters are also of the general type disclosed in the Campbell patents above referred to, and are so designed as to transmit a band of frequencies lying in the region of the carrier frequency assigned to the corresponding channel, the band having a width sufficient to allow for the frequency variation due to the modulation of the carrier currents by the low frequency signal currents. In the case of telephone transmission, the width of the band would be substantially equal to the frequency range employed in ordinary telephone transmission. In order to amplify the modulating carrier frequencies, amplifying means TA_1 , TA_2 , TA_3 and TA_4 , are provided in the several channels, these amplifying means being of any well known type, but preferably of the well known vacuum tube type. If desired, filters T_1F_1 , T_1F_2 , T_1F_3 , and T_1F_4 may be included in the output circuits of the amplifiers for the purpose of further increasing the selectivity. These filters may be of the same type as the filters TF_1 , TF_2 etc.

Coming now to the receiving portion of the carrier apparatus, it will be noted that the receiving channels RL_1 , RL_2 etc. contain filters RF_1 , RF_2 , RF_3 and RF_4 . These filters may be of the same type as the filters TF_1 , TF_2 etc. and are so designed as to transmit the carrier frequencies of each channel as modulated by signaling currents at distant stations. These detectors may be of any well known type, but are preferably of the vacuum tube type illustrated and described in the application of John R. Car-

son, Serial No. 157,414, filed March 26, 1917. The detecting or demodulating arrangement of the said application of John R. Carson employs the so-called homodyne method of detecting, thereby necessitating that the carrier frequency characteristic of each particular channel be supplied to the demodulating arrangement of each channel. Accordingly, frequencies of 10,000, 15,000, 20,000 and 25,000 cycles are supplied to the demodulators D_1 , D_2 , D_3 and D_4 . It will be understood, of course, that these frequencies are given merely for purposes of illustration, and that other frequencies may be assigned to the channels, the essential requirement being that for telephonic purposes the same frequency be supplied to the demodulator as that used at the originating station for transmission purposes.

In order to amplify the low frequency waves which appear in the output circuits of the modulating arrangements, amplifiers RA_1 , RA_2 , RA_3 and RA_4 are provided in the several receiving channels. These amplifiers may be of any well known type, but are preferably vacuum tube amplifiers. In order to purify the low frequency currents from any high frequency components, low frequency filters such as R_1F_1 , R_1F_2 , R_1F_3 , R_1F_4 are provided in the output circuits of the amplifier. These filters may be of the same character as the low frequency filters LF_1 , and LF_4 in the terminal lines LF_1 and LF_2 , and are of the general type disclosed in the patents to Campbell above referred to. The amplified low frequency signal waves from the several receiving channels, after being filtered, are impressed through the transformers 11, 12, 13 and 14 upon the low frequency lines L_1 , L_2 , L_3 and L_4 respectively.

At the station B amplifying arrangements are provided for the various currents transmitted over the main lines. Between the main line sections ML_1 and ML_1' , the usual two-way repeater employed for telephone transmission is provided, said repeater including an amplifying tube AE_1 for repeating in one direction and an amplifying tube AW_1 for repeating in the opposite direction. By means of this repeater the low frequency signaling current such as telephone currents may be transmitted over the main line sections ML_1 and ML_1' in both directions.

Since carrier frequencies are transmitted over the main line sections ML_1 and ML_1' in the direction from station A to station C only, a one-way repeating arrangement A_1E is provided for amplifying the carrier oscillations. This amplifier is connected in parallel with the two-way repeater just described through carrier circuits T_1 and T_1' , branched from the main line sections ML_1 and ML_1' at the repeater point. In or-

der to prevent the transmission of carrier frequencies to the two-way repeater filters LF_2 and LF_2' are provided, these filters being of the same type as the filter LF_1 already described. In order to prevent the transmission of low frequency signaling currents through the circuit of the one-way amplifier A_1E , filters HF_2 and HF_2' are provided in the carrier circuits T_1 and T_1' . These filters are of the same type as the filters HF_1 previously described, and are so designed as to freely transmit carrier frequencies while suppressing other frequencies. In order to balance the filters LF_2 and LF_2' with regard to the two-way repeater, devices LF_3 and LF_3' are provided in the balancing circuit of said repeater. These devices may either be duplicate filters of the same type as the filters which they are intended to balance, or they may be networks so designed as to have electrical characteristics simulating those of the filters.

The one-way repeater A_1E is a duplex two-stage arrangement comprising amplifying tubes 21 and 22 connected in tandem with each other and in parallel with tandem tubes 23 and 24. The amplifying tubes and the circuits therefor are so balanced that variations impressed upon the input circuits of the amplifying arrangement produce no change in the current flow in the common portions of the parallel circuits of the two sets of tubes, so that the resultant effect is that of current variations flowing in series over the portion of the amplifying circuit shown in heavy lines. The result of this arrangement is that minute variations impressed upon the amplifying arrangement through the transformer 25 appear upon the output side of the transformer 26 as amplified variations which are faithful copies of the original variations, since the balanced arrangement of the amplifier tends to minimize the distortion which might otherwise occur.

The repeating arrangements associated with the main line sections ML_2 and ML_2' are in all respects similar to those already described, and comprise a two-way repeater, including amplifiers AE_2 and AW_2 for amplifying low frequency, signaling currents in either direction, and a one-way amplifier A_1W for amplifying carrier frequencies transmitted from station C to station A. The one-way amplifier A_1W is connected in parallel with the two-way repeater through the carrier branches R_1L and R_1L' . In order to maintain a separation between the carrier frequencies and the ordinary signaling frequencies, filters HF_3 and HF_3' are included in the branches R_1L and R_1L' and filters LF_3 and LF_3' are included in circuit with the two-way repeater. These filters are similar to the corresponding filters of

the other repeating arrangement. In order to balance the filters LF_5 and LF_5' with respect to the two-way repeater, balancing arrangements LF_6 and LF_6' are provided, while balancing networks MN_2 and MN_2' are included in the balancing circuits of the repeater for simulating the main line sections, and other apparatus external to the filters LF_5 and LF_5' .

The one-way repeater A_1W comprises tandem tubes 27 and 28 connected in parallel with tandem tubes 29 and 30. The repeater is associated with the carrier branches R_1L and R_1L' through transformers 31 and 32. This one-way amplifying arrangement functions in a manner similar to that of the amplifying arrangement A_1E already described.

Coming now to the apparatus at station C, the arrangement of the carrier apparatus is in general the same as that already described with reference to station A, and similar pieces of apparatus are designated by the same reference characters as used in connection with the apparatus at station A, with the exception that in each instance the reference character is primed. The arrangement at station C differs from that at station A in that the common carrier receiving branch RL' is associated with the line section ML_1' and the common transmitting branch TL' is associated with the main line section ML_2' , this arrangement being just the reverse of that at station A. The apparatus in the several carrier transmitting channels, such as TL_1' , TL_2' etc., and in the several carrier receiving channels RL_1' and RL_2' etc. is similar to that at station A, and need not be further described.

As illustrated in Fig. 3, the terminating transmission lines L_1' , L_2' , L_3' and L_4' do not terminate at the station C, but terminate at a distant station D, at which point they are associated by means of transformers 11', 12', 13' and 14' with the carrier receiving and transmitting channels, which, instead of being local circuits at the station C are extended to the distant station D. The terminal transmission lines are also balanced at station D by means of artificial lines or networks N_1' , N_2' , N_3' and N_4' . It will be seen, therefore, that each low frequency transmission line, such as L_1' , L_2' etc. is connected with station C by means of a four-wire circuit so that transmission takes place between the station C and a given terminal line at station B in one direction over a transmitting channel, and in the other direction over a receiving channel. If, however, the transformers and artificial lines be brought up to the same point as the carrier apparatus at station B, and the conductors of the several transmitting and receiving channels be correspondingly shortened, the arrangement is identical with that shown at

station A in Figure 1. It will be apparent that these two arrangements of the terminating carrier apparatus are interchangeable, and either the four-wire arrangement or the arrangement shown at station A may be used at either station, the two forms of apparatus being shown differently at the two stations for the purpose of illustrating two possible modifications, without unnecessary duplication of the drawing.

Further details of the invention will now be clear from a description of the operation, which is as follows: Low frequency signaling currents, such as telephone currents, coming in over the terminating line LT_1 are passed through the filter LF_1 , over the line section ML_1 and through the filter LF_2 to the two-way repeating apparatus. These currents upon being amplified by the amplifier AE_1 of the repeating apparatus are transmitted through the filter LF_2' over the line section ML_1' and through the filter LF_1' to the terminating line LT_1' . Transmission in the opposite direction takes place through the same path, except in this case the amplifier AW_1 of the two-way repeater is used to amplify the signals. It will be seen, therefore, that the line sections ML_1 and ML_1' operate as two-way transmission lines for ordinary signaling currents.

Low frequency signaling currents coming in over the line L_1 at station A are transmitted through the transformer 11 and over the carrier transmitting channel TL_1 to the modulator M_1 where they are combined with currents of the carrier frequency assigned to this channel, for instance 10,000 cycles, and the carrier frequency currents are modulated in accordance with the signaling currents. The modulated carrier currents are then transmitted through the filter TF_1 , are amplified by the amplifier TA_1 and are then transmitted through the filter $T_1 F_1$ to the common carrier branch TL . In a similar manner, currents from the lines L_2 , L_3 , L_4 are transmitted through the corresponding carrier channels where they modulate the corresponding carrier frequencies, and the modulated frequencies are impressed upon the common carrier branch TL . The several modulated carrier frequencies are now transmitted through the high frequency filter HF_1 over the line section ML_1 to the station B.

At the station B the modulated carrier frequencies are separated from the low frequency telephone currents transmitted between the terminal line sections LT_1 and LT_1' by means of the filters LF_2 and HF_2' , the carrier frequencies passing through the latter filter to the one-way amplifier A_12 . The several modulated carrier frequencies are amplified by the one-way amplifier, and are transmitted through the transformer 26 and the high frequency filter HF_2' to the

main line section ML_1' . After being transmitted over said main line section to station C, the carrier frequencies are again separated from the low frequency signaling currents by means of the filters LF_1' and HF_1' .

The several carrier frequencies are transmitted through the filter HF_1' to the common carrier circuit RL' , and the modulated carrier currents corresponding to the several channels are selected by means of the filters RF_1' , RF_2' etc. and impressed upon the detectors or modulators D_1' , D_2' etc. At the same time, unmodulated oscillations of the carrier frequency assigned to each channel are impressed upon the several modulators, and in a manner well known in the art the low frequency signaling currents, by means of which the carrier frequencies at station A were originally modulated appear in the output circuits of the demodulators. These low frequency currents, after being amplified by the amplifiers RA_1' , RA_2' etc. are transmitted through the low frequency filters R_1F_1' , R_1F_2' etc., and over the one-way lines RL_1' , RL_2' etc. to station D. At this station the low frequency currents are transmitted through the transformer and artificial line arrangements to the terminating low frequency lines L_1' , L_2' , L_3' and L_4' .

Low frequency signaling currents coming in over these four low frequency lines are transmitted through the transformers $11'$, $12'$ etc. to the carrier channels TL_1' , TL_2' etc., and over these carrier channels to station D. By means of the carrier apparatus in the channels, these low frequency signaling currents modulate the corresponding carrier frequencies, are amplified and filtered and then simultaneously impressed upon the common carrier transmitting circuit TL' . From this point they are transmitted through the high frequency filter HF_4' and over the main line section ML_2' to station B.

At station B the modulated carrier frequencies are separated from the low frequency signaling currents transmitted between line sections LT_2 and LT_2' by means of the filters HF_5' and LF_5' . The low frequency currents are amplified by means of the two-way repeater comprising the amplifiers AE_2 and AW_2 . The carrier frequencies, however, are transmitted through the filter HF_5' to the amplifying arrangement A_1W . After being amplified by means of this amplifying arrangement, they are transmitted through the transformer 31 and the high frequency filter HF_5 to the line section ML_2 .

The several modulated frequencies after being transmitted over said main line ML_2 are separated from the low frequency signaling currents by means of the filters LF_4 and HF_4 , the carrier frequencies being transmitted through the latter filter to a common receiving circuit RL at station A.

The several modulated frequencies are now separated by means of the filters RF_1 and RF_2 , and after being detected the resultant signaling currents are amplified, filtered and transmitted through the carrier receiving channels RL_1 , RL_2 etc. to the terminating lines L_1 , L_2 , L_3 and L_4 .

It will thus be seen that the carrier frequencies are transmitted simultaneously over two main transmission lines comprising a four-wire circuit, said transmission lines operating as one-way transmission circuits. At the same time the two transmission lines comprising the four-wire circuit for carrier purposes are used as two-wire lines for two-way low frequency transmission. The several low frequencies may also, if desired, be transmitted over four-wire circuits to the carrier apparatus as shown in Fig. 3. It will also be noted that the carrier apparatus at both the terminal stations and the repeater points is separate and distinct from the low frequency transmission apparatus, and may be superposed upon low frequency transmission lines without any material change in the latter, and without affecting the operation of the latter in any essential detail.

A modified arrangement in which a four-wire transmission circuit is combined with a two-wire transmission circuit is illustrated in Figs. 4, 5 and 3. For more readily understanding the diagram, the three sheets including these figures should be placed side by side in the order named. In this modification carrier transmission between stations B and C takes place over a four-wire circuit, while carrier transmission between stations A and B takes place over a two-wire circuit. The apparatus at stations C and D is, of course, identical with that described in connection with the previous modification and, as stated in connection with said modification, the terminal low frequency lines may terminate at station D and be connected with station C by means of four-wire channels, or by bringing the apparatus at station D up to station C the arrangement may become a simple two-way transmission circuit.

The two-way and one-way amplifiers at station B are in all respects similar to those described in connection with the previous modification, and are associated with the main line section ML_1' and ML_2' in the same manner.

Since, however, station B is connected with station A for carrier transmission, by means of a two-way circuit herein illustrated as the main line section ML_1 , the association of the opposite ends of the repeaters with the transmission circuit between stations A and B is somewhat different from that previously described. In order

to separate the carrier frequencies from the low frequency signaling currents, a common carrier circuit C_1B is branched from the main line section ML' through a high frequency filter HF_2 which may be similar in all respects to the filter HF_2' . A low frequency filter LF_2 , similar to the filter LF_2' , is inserted between the main line section ML_1 and the two-way repeater comprising amplifiers AE_1 and AW_1 .

The common carrier circuit C_1B is associated with common carrier transmitting and receiving circuits T_1L and R_1L through a balanced transformer arrangement 33. In order that the circuits R_1L and T_1L may be made conjugate with respect to each other, the filter HF_2 is balanced by means of a balancing arrangement H_1F_2 which may be either a duplicate filter or a network whose electrical characteristics simulate those of the filter. The main line ML_1 and other apparatus external to the filter HF_2 may be balanced by means of a network M_1N_1 . The circuits T_1L and R_1L are associated with the one-way amplifiers, A_1E and A_1W through transformers 25 and 31 respectively.

At station A, the carrier frequencies are separated from the low frequency signaling currents transmitted over the line ML_1 by means of filter LF_1 and HF_1 which are similar in all respects to the corresponding filters at station A of Fig. 1. The carrier frequencies upon being separated by means of this filtering arrangement are impressed upon the common carrier branch CB which is associated by means of a balanced transformer arrangement 10 with common carrier transmitting and receiving circuits TL and RL . In order to render these two circuits conjugate with respect to each other, the filter HF_1 is balanced by a balancing arrangement H_1F_1 which may be either a duplicate filter or a network simulating the electrical characteristics of the filter. A balancing network MN is also provided to balance the main line ML_1 , and the other apparatus external to the filter HF_1 .

Carrier transmitting channels TL_1 , TL_2 , TL_3 and TL_4 are associated with the common carrier transmitting circuit TL and include modulating, amplifying and filtering apparatus similar to that described in connection with Fig. 1. In a similar manner, carrier receiving channels RL_1 , RL_2 , RL_3 and RL_4 are associated with the common carrier receiving circuit RL , and contain high frequency filters, demodulating apparatus, amplifying apparatus and low frequency filters similar to the corresponding apparatus described in connection with the station A of Fig. 1. The several transmitting and receiving channels may be connected to the terminating low frequency lines L_1 , L_2 , L_3 and L_4 either at the station A directly or at a distant station to which

they are extended as four-wire circuits in a manner similar to that shown at station D. In either case the means for associating these circuits comprises transformers 11, 12, 13 and 14 and the balancing artificial lines or networks N_1 , N_2 , N_3 and N_4 .

The operation is as follows: Low frequency signaling currents may be transmitted between the terminal lines LT_1 and LT_1' in either direction over the transmission line sections ML_1 and ML_1' through the low frequency filters and through the two-way repeater comprising amplifiers AE_1 and AW_1 . Low frequency signaling currents incoming from the terminal lines L_1 , L_2 , L_3 and L_4 are transmitted through the transformers 11, 12, 13 and 14 to the carrier transmitting channels TL_1 and TL_2 etc., and by means of the carrier apparatus already described these low frequency currents modulate oscillations of the carrier frequency assigned to each channel, such modulated oscillations being amplified, filtered and simultaneously impressed upon the common transmitting circuit TL . The several modulated frequencies are then transmitted through the transformer 10 over the carrier branch CB and through the high frequency filter HF_1 to the main line section ML_1 .

After being transmitted over the main line section ML_1 , the several carrier frequencies are separated at station B by means of filters LF_2 and HF_2 , and are impressed upon the common carrier branch C_1B .

From this circuit the several frequencies are transmitted through the transformer 33 to the common transmitting circuit T_1L and thence through the transformer 25 to the one-way repeater A_1E . After being amplified by said repeater they are transmitted through the transformer 26, through the high frequency filter HF_2' and over the main line section ML_1' to station C. At station C the carrier frequencies are separated from the low frequency signaling currents and are then selected into the proper channels, detected, modified, filtered and transmitted to the terminal lines L_1 , L_2' etc. in a manner already described.

Low frequency signaling currents incoming from the terminal lines L_1' , L_2' etc. are transmitted to the carrier transmitter channels TL_1' , TL_2' etc., and after modulation, amplification and transmission through the filters in a manner already described, they are impressed upon the common transmitting circuit TL' . From this circuit the modulated carrier frequencies are transmitted through the filter HF_1' and over the main line section ML_2' to station B.

At station B the high frequency carrier currents are separated from the low frequency signaling currents by filters LF_5' and HF_5' and are then impressed through the transformer 32 upon the one-way am-

plifier A₁W. After being amplified the modulated carrier frequencies are transmitted through the transformer 31 and over the common receiving branch R₁L to the common carrier branch C₁B.

After passing through the filter HF₂ and over the main line section ML₁, the carrier frequencies are separated from the low frequency currents at station A by means of the filters LF₁ and HF₁, the carrier frequencies passing into the common carrier branch CB. From this branch the received modulated carrier frequencies are transmitted to the common receiving circuit RL from which point they are filtered, detected, amplified, etc., the resulting low frequency signaling currents being then transmitted to the terminal lines L₁, L₂, L₃ and L₄.

It will be seen that by means of this invention, multiplex carrier transmission may take place over a four-wire circuit which is superposed upon ordinary low frequency transmission lines, which, for low frequency purposes, function as two-way lines. Furthermore, while the invention has been generally described as applied to telephonic transmission, the same principles are equally applicable to telegraphic or other forms of signal transmission. Thus, the low frequency terminal lines LT₁, L₁, L₂, L₃ and L₄ may be either telegraph or telephone lines, or combinations of both.

In general, while the invention has been illustrated as embodied in certain specific forms, it will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated, without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a transmission system, a pair of transmission paths extending between two geographically separated offices, one path being adapted for transmission in one direction and the other path being adapted for transmission in the opposite direction, a plurality of signaling stations, signaling channels from each station superposed on one of said paths for transmission in one direction, and separate signaling channels from each station imposed on the other path for transmission in the opposite direction; the attenuation of said paths being sufficiently great to require amplification of energy transmitted thereover.

2. In a transmission system, a pair of transmission paths extending between two geographically separated offices, one path being adapted for transmission in one direction and the other path being adapted for transmission in the opposite direction, a plurality of signaling stations, signaling channels from each station superposed on one of said paths for transmission in one direction, and

separate signaling channels from each station imposed on the other path for transmission in the opposite direction and one-way repeaters in each path for amplifying the transmitted currents corresponding to each channel.

3. In a transmission system, a pair of transmission lines interconnecting two geographically separated offices, the attenuation of said lines being sufficiently great to require amplification of energy transmitted thereover, a plurality of terminating lines, and means for simultaneously interconnecting corresponding ends of both of said transmission lines with each of said terminating lines so that transmission may take place from all of the terminating lines over each transmission line of said pair.

4. In a transmission system, a pair of transmission lines interconnecting two points, a plurality of terminating lines, means for connecting each of said terminating lines with one of said transmission lines so that transmission from said terminating lines will take place over said transmission line in one direction only, means for connecting said terminating lines to the other transmission line so that transmission over said other line to said terminating lines will take place in the opposite direction only.

5. In a transmission system a pair of transmission lines extending between two geographically separated offices, a plurality of signaling stations, means for associating each of said signaling stations with one of said lines so that transmission between said stations and said line will take place over said line in one direction only, and means for connecting the other line with each of said stations so that transmission between said line and said stations will take place over said line in the opposite direction only, the attenuation of said lines being sufficiently great to require amplification of energy transmitted thereover.

6. In a transmission system, a plurality of signaling stations at one point, a corresponding plurality of signaling stations at a distant point, a common transmission line extending from said first mentioned point to an intermediate point, a pair of transmission lines for opposite transmission between said intermediate point and said distant point, said pair of transmission lines, each having attenuation sufficiently great to require amplification of energy transmitted thereover, means whereby transmission in both directions may simultaneously take place between a plurality of signaling stations at said first mentioned point and said intermediate point over said common transmission line, means for separating opposite transmissions at said intermediate point and directing simultaneous transmissions in one direction over one line extending to said

distant station and simultaneous transmissions in the opposite direction over the other line, and means at the distant stations for separating simultaneous transmissions of
5 either direction for separate transmission to individual signaling stations.

7. In a transmission system for transmission between two geographically separated offices, a two way line extending from one
10 office to an intermediate office, a pair of transmission lines for transmission in opposite directions between said intermediate office and a distant office, said pair of transmission lines, each having attenuation sufficiently great to require amplification of
15 energy transmitted thereover, means for transmitting a plurality of oppositely directed transmissions over said two way line between said first office and said intermediate
20 office, means for separating oppositely directed transmissions at said intermediate office and transmitting simultaneous transmissions having the same direction over one of said pair of transmission lines to said
25 distant office, while transmitting simultaneous transmissions opposite in direction from said distant office to said intermediate office over the other of said pair of transmission lines.

8. In a transmission system for transmission between two points, a two way transmission line extending from one point to an intermediate point, a pair of one-way
30 transmission lines extending from said intermediate point to a distant point, means for interconnecting said one way lines at said intermediate point with said two-way
35 line, means for associating a plurality of two-way channels with said two-way line at said first point and means for associating a plurality of one-way channels with
40 each of said one-way lines at said distant point.

9. In a transmission system for transmission between two points, a two way transmission line extending from one point to an intermediate point, a pair of one-way
45 transmission lines extending from said intermediate point to a distant point, means for interconnecting said one-way lines at said intermediate point with said two-way
50 line, means for associating a plurality of two-way channels with said two-way line at said first point, means for associating a plurality of one-way channels with
55 each of said one-way lines at said distant point, and means for associating pairs of one-way channels associated with said one-way lines with terminal transmission lines.

10. In a transmission system, a plurality
60 of terminating transmission lines, a pair of one-way lines adapted for multiplex transmission extending between two geographically separated offices and associated with
65 said plurality of terminating lines, said one-

way lines having attenuation sufficiently great to require amplification of energy transmitted thereover, means whereby outgoing transmission from each of a plurality
70 of said terminating lines may be simultaneously transmitted over one of said one-way lines, and means whereby simultaneous incoming transmissions for said terminating lines may be transmitted over the other one-way line and separately directed to the
75 proper terminating lines.

11. In a transmission system, a plurality of terminating transmission lines, a pair of one-way lines adapted for multiplex transmission extending between two geographically
80 separated offices and associated with said plurality of terminating lines, said one-way lines having attenuation sufficiently great to require amplification of energy transmitted thereover, means for translating
85 low frequency signaling currents from said terminating lines into high frequency carrier oscillations having frequencies characteristic of individual terminating lines, means for simultaneously transmitting the
90 translated frequencies over one of said one-way lines in one direction, means whereby a plurality of high frequencies may be transmitted over the other one-way line in the
95 opposite direction, and means for translating said high frequencies into low frequency signaling currents and for segregating and directing them to said terminating lines.

12. In a transmission system for transmission between two points, a pair of multiplex one-way transmission lines extending
100 from one point to an intermediate point, one line being used for transmission in one direction and the other being used for transmission in the opposite direction, a plurality of signaling stations at a distant point, terminating one-way lines extending from each
105 of said stations to said intermediate point, means at the intermediate point for associating said terminating lines with one of said multiplex lines whereby transmissions from said stations may be transmitted in one direction over said terminal lines and then
110 simultaneously transmitted in one direction over said multiplex line, other terminating one-way lines extending from the other multiplex line to said signaling stations for transmission in the opposite direction, and means whereby a plurality of transmissions
115 over said other multiplex line in such opposite direction may be separated at the intermediate point and separately transmitted over said other terminating lines to said signaling stations.

13. In a transmission system, a plurality
125 of signaling stations, transmission lines for transmission in one direction extending one from each station to a distant point, the currents transmitted over said lines to said point being sufficiently attenuated to require
130

amplification, transmission lines for transmission in the opposite direction extending from said distant point to each of said stations, and means whereby the ends of all of said lines may be interconnected.

14. In a transmission system, a plurality of signaling stations, transmission lines for transmission in one direction extending one from each station to a distant point, the currents transmitted over said lines to said point being sufficiently attenuated to require amplification, transmission lines for transmission in the opposite direction extending from said distant point to each of said stations, said means being so arranged that transmissions to and from said stations will be separated so as to take place over separate lines.

15. In a transmission system, a plurality of signaling stations, transmission lines for transmission in one direction extending one from each station to a distant point, transmission lines for transmission in the opposite direction extending from said distant point to each of said stations, a pair of multiplex lines having sufficient attenuation to require amplification of currents transmitted thereover, means whereby the individual lines associated with said stations for transmission in one direction may be connected with one end of one of said multiplex lines, and means whereby the individual lines associated with said stations for transmission in the opposite direction may be connected with one end of the other multiplex line.

16. In a transmission system, a plurality of signaling stations, transmission lines for transmission in one direction extending one from each station to a distant point, transmission lines for transmission in the opposite direction extending from said distant point to each of said stations, a pair of multiplex lines having sufficient attenuation to require amplification of currents transmitted thereover, means whereby the individual lines associated with said stations for transmission in one direction may be connected with one end of one of said multiplex lines, and means whereby the individual lines associated with said stations for transmission in the opposite direction may be connected with one end of the other multiplex line, said multiplex lines having their opposite ends so interconnected that opposite transmissions thereover will be maintained separate.

17. In a transmission system, a multiplex transmission line over which a plurality of transmissions may take place simultaneously, said transmission line extending between two points, a plurality of terminal lines extending from one of said points to distant points, currents transmitted over said terminal lines to said distant point being sufficiently attenuated to require amplification, means for associating said terminal lines

with said multiplex line, and means to separate into individual terminal lines for transmission to said distant points without change in frequency the simultaneous transmissions taking place over said multiplex line.

18. In a transmission system, a transmission line, means associated with said line permitting the transmission of low frequencies in both directions over said line, and means associated with said line whereby frequencies above the voice range may be transmitted over said line in one direction only.

19. In a transmission system, a transmission line, means associated with said line whereby frequencies within a certain range may be transmitted over said line in both directions, and means associated with said line whereby frequencies above the voice range and within a range different from said first mentioned range may be transmitted over said line in one direction only.

20. In a transmission system, a transmission line, a two-way repeater in said line, and a single one-way repeater associated with said line in parallel with said two-way repeater, means whereby only frequencies within the voice range will be transmitted through said two way repeater, and means whereby only frequencies above the voice range will be transmitted through said one-way repeater.

21. In a transmission system, a pair of independent circuits, one circuit being adapted for transmitting signals to a distant point and the other circuit being adapted to receive signals from said distant point, said circuits having attenuation sufficiently great to require amplification of currents transmitted thereover, a plurality of signaling stations, signaling channels from each station superposed upon one of said circuits for transmission to a distant point, and separate signaling channels to each station superposed upon the other of said circuits for transmission from said distant point.

22. In a transmission system, a transmission path over which carrier frequencies may be transmitted to a station, a second station, a plurality of lines, one corresponding to each carrier frequency and extending between said stations for transmission in one direction, currents transmitted over said lines to said second station being sufficiently attenuated to require amplification, and an equal number of lines extending between said stations for transmission in the opposite direction, all of said lines being interconnected at said first mentioned station with said transmission path.

In testimony whereof, I have signed my name to this specification this 16th day of June, 1919.

LLOYD ESPENSCHIED.