Dec. 22, 1925. **1,566,311**

A. B. CLARK ET AL.

TELEPHONE REPEATER CIRCUITS

Filed Oct. 3, 1921 2 Sheets-Sheet 1

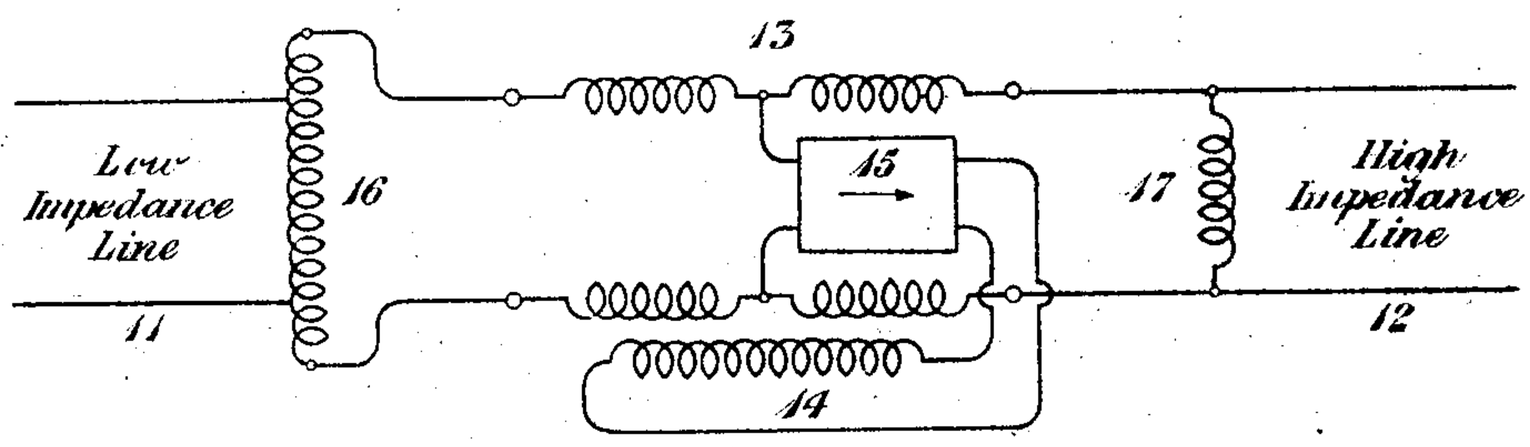

Fig. 1

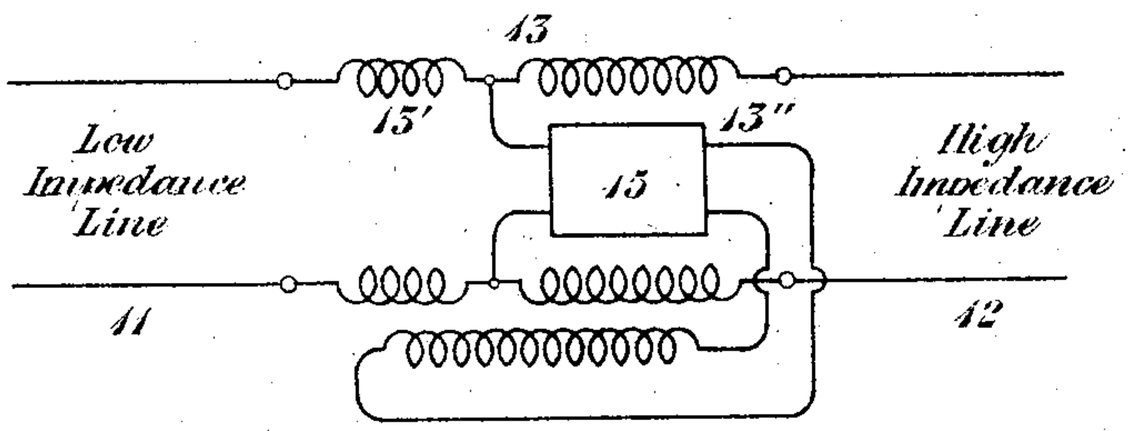

Fig. 2

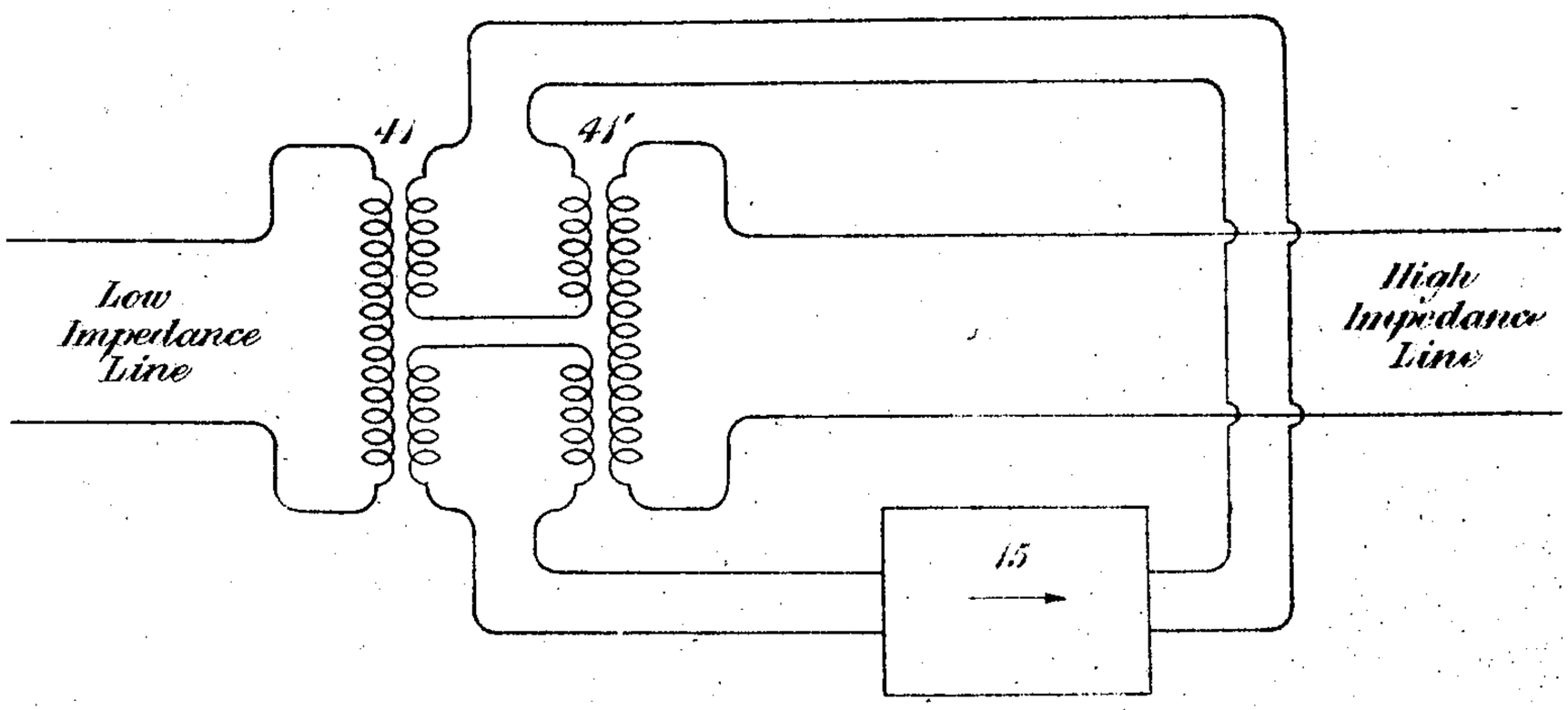

Fig. 2a

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1,566,311

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2 Sheets-Sheet 2

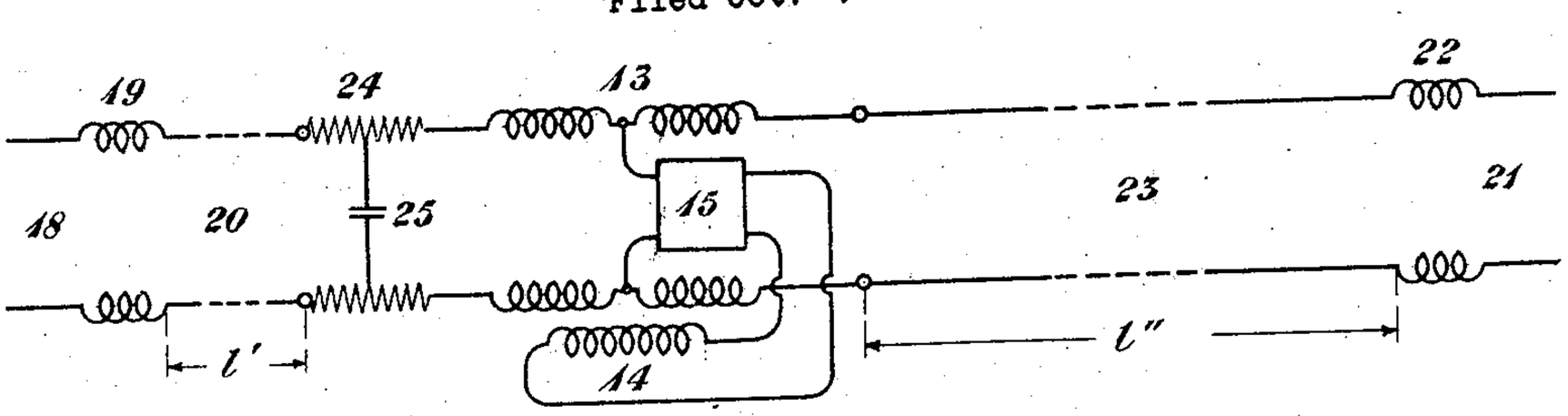

Fig. 3

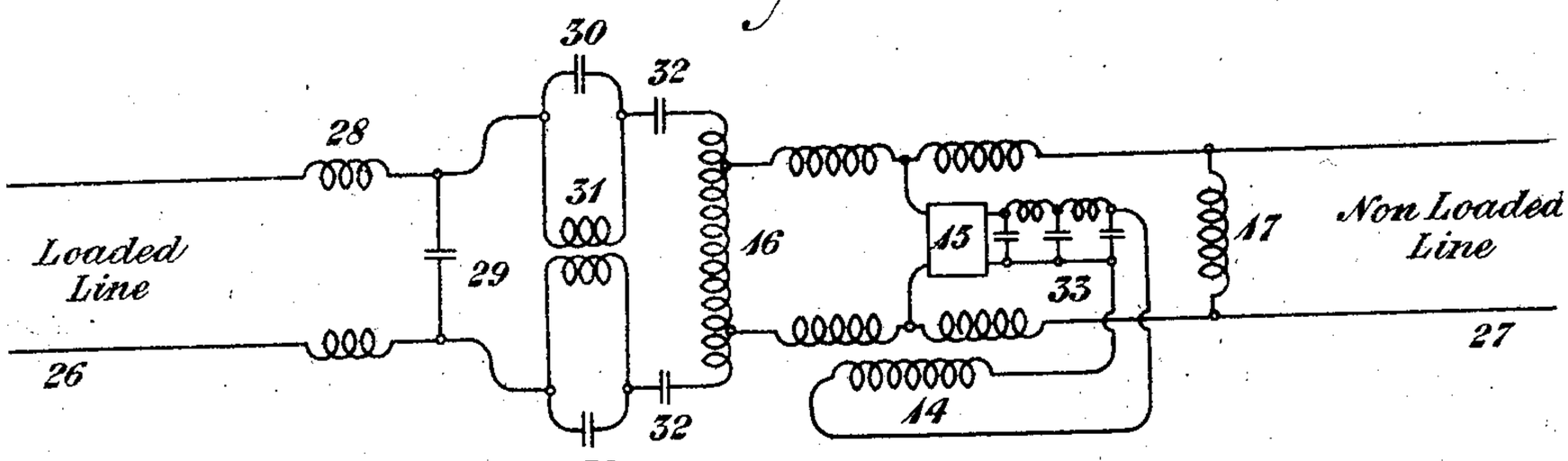

Fig. 4

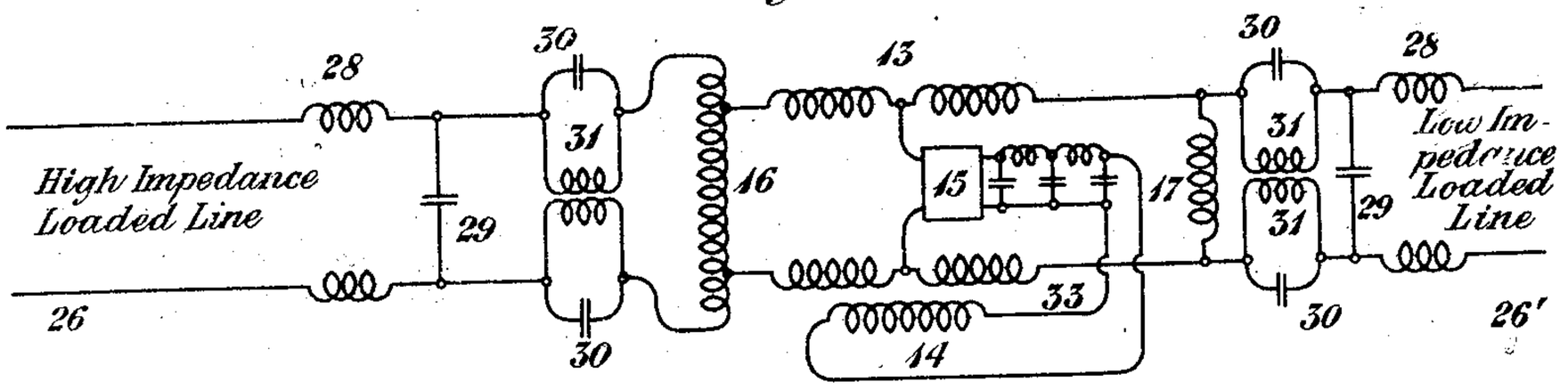

Fig. 5

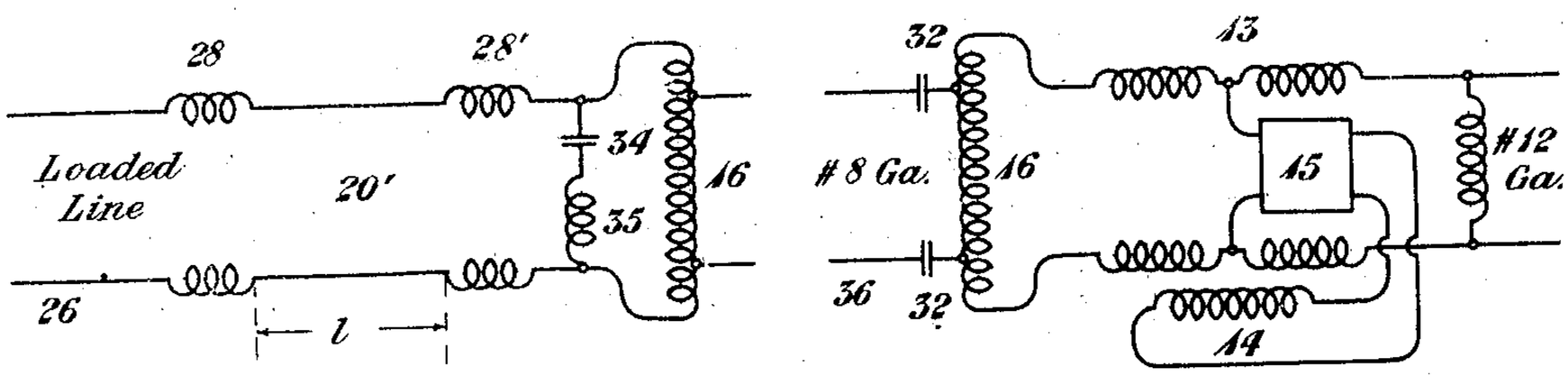

Fig. 6

Fig. 7

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UNITED STATES PATENT OFFICE.

ALVA B. CLARK, OF BROOKLYN, NEW YORK, AND RAY S. HOYT, OF RIDGEWOOD, NEW JERSEY, ASSIGNORS TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

TELEPHONE-REPEATER CIRCUITS.

Application filed October 3, 1921. Serial No. 504,976.

To all whom it may concern:

Be it known that we, ALVA B. CLARK and RAY S. HOYT, residing at Brooklyn and Ridgewood, in the counties of Kings and Bergen and States of New York and New Jersey, respectively, have invented certain Improvements in Telephone-Repeater Circuits, of which the following is a specification.

The principal object of our invention is to provide a new and improved arrangement of apparatus for the operation of a telephone repeater between dissimilar transmission lines. Another object of our invention is to combine a 21-type repeater with dissimilar lines in such a manner that there will be equal impedances on each side of the repeater. Still another object of our invention relates to the interposition of suitable networks between a 21-type repeater and one or both of two dissimilar lines connected thereto, so that the impedances of the lines may be equalized and transmission through the repeater may be effected without impedance unbalance. These and other objects of our invention will become apparent on consideration of a limited number of specific embodiments of the invention which we have indicated in the accompanying drawings and will now proceed to discuss, with the understanding that the invention will be defined in the appended claims.

Referring to the drawings, Figure 1 is a diagram illustrating equalization of impedances for the case of two lines having a constant and real impedance ratio, Figs. 2 and 2ª are diagrams illustrating alternative systems for the same case, Fig. 3 is a diagram illustrating the equalization of two similar loaded lines having different lengths of end sections at the repeater, Fig. 4 is a diagram illustrating equalization of impedances for a loaded line and a non-loaded line, Fig. 5 is a diagram illustrating the case of two loaded lines of different impedances, Fig. 6 is a diagram illustrating a modification of detail in Figs. 4 or 5, and Fig. 7 is a diagram for two smooth open-wire lines of different characteristic impedances.

It will be understood that the so-called 21-type repeater is of the character shown in Fig. 1. The input terminals of the repeating element 15 are bridged across the line, being connected to the middle points of the series windings 13. The amplified current delivered by the repeater element 15 goes to the winding 14 which stands in inductive relation with the series windings 13; the current induced therein is sent equally in each direction along the line. In order that none of the amplified energy delivered from the repeater element 15 through the coil 14 to the coils 13 shall get back to the input side of the repeater 15, it is highly important that the lines shall be balanced, that is, that they shall offer the same impedance looking each way from the middle points of the coils 13. If this condition is not realized, some of the amplified energy from the repeater element 15 will get back to the input circuit and "singing" will result.

Accordingly, unless some provision is made such as disclosed in the following specification, the use of the 21-type repeater will be restricted to those cases in which the two lines are similar, at least to the extent that they have substantially the same characteristic impedance. By our invention it becomes possible to connect the 21-type repeater in between two lines of decidedly different characteristic impedance.

The invention will be explained by considering certain simple cases at the outset and then utilizing the principles developed, in connection with more general and complex cases. Fig. 1 assumes the case of two lines having different characteristic impedances but subject to the condition that the ratio of these impedances is constant and real for all frequencies within the useful range. An example would be afforded by a pair of loaded lines having a different weight of loading but having the same fractional end sections adjacent to the repeater and having equal critical frequencies.

Under the condition here supposed, an auto-transformer 16 is interposed between the low impedance line 11 and the repeater. This has the proper ratio so that it equalizes the impedances looking each way from the repeater along the two lines 11 and 12.

In practical cases the auto-transformer 16 will not merely change the apparent imped-

ance of the line, but will require an appreciable exciting current, and thus will introduce a departure of impedance which will require correction. For example if the impedance of the low impedance line 11 is a pure resistance R_1, the auto-transformer 16 will raise this to R_2, looking from the repeater, but subject to a departure which may be represented as due to an inductance L in parallel to the resistance R_2. The value of L in this case is the inductance of the auto-transformer windings between the terminals connected to the repeater. To balance the impedance departure introduced by the auto-transformer 16, a retardation coil 17 is bridged across the high impedance line 12. The coil 17 would have the inductance L and the same resistance as the auto-transformer winding between the terminals connected to the repeater. The retardation coil 17 would then take from the repeater the same exciting current that the auto-transformer 16 takes from the repeater.

It will be evident that the auto-transformer 16 and the retarding coil 17 could be interchanged in location. In this case the auto-transformer would step down the higher line impedance instead of stepping up the lower. Furthermore, instead of an auto-transformer, a transformer of separate windings inductively related, a so-called repeating coil, could be employed, and a unity ratio transformer could be employed in place of the retardation coil 17. This would have the advantage that the lines could be used for phantom purposes, and the whole repeater circuit would be completely insulated from the line.

An alternative system for connecting two such lines as those of Fig. 1 is diagramed in Fig. 2. Here the windings 13 are unequally divided, the number of turns in the parts 13′ and 13″ being respectively proportional to the impedances of the adjacent lines. This arrangement causes the magnitude of the current delivered to the amplifying element 15 to depend on the direction of transmission and gives a larger gain when repeating from the low impedance line to the high impedance line, than when repeating in the opposite direction. If the input and output terminals of the amplifying element 15 are interchanged, the larger gain will be obtained when repeating from the high to the low impedance line.

In some types of repeater systems there are separate transformer windings for one or both lines, as for example in Fig. 2ª. The three windings on each of the transformers 41 and 41′ are constructed in the usual way to work efficiently between the impedances involved. The number of turns in the winding of transformer 41′ connected to line 12 should be greater than in the winding of transformer 41 connected to line 11 in a ratio which is the square root of the line impedance ratio. The system of Fig. 2ª is free from the unsymmetrical transmission effects that occur in the arrangement shown in Fig. 2.

In Fig 3 the case is taken up of two loaded lines similar in all respects except that the line 18 has a short section 20 between its last load coil 19 and the repeater, and the line 21 has a longer section 23 between its last load coil 22 and the repeater. In this case we build out the short section 20 by means of the series resistances 24 and the shunt condenser 25 at the middle point of the elements 24. We make the magnitude of the resistance 24 equal to the excess in line resistance of the section 23 over the section 20, and we make the capacity of the condenser 25 equal to the shunt capacity of the excess length of the line 23 over 20. Under the conditions assumed for Fig. 3 it will be seen that this construction equalizes the two lines.

In Fig. 4 we have presented the case of a loaded line and a non-loaded line. Here, unless the line happens to end at exactly 0.8 section, that is, with a length to the first loading coil which is 0.8 of a normal interval between loading coils, we build the line out in the manner indicated in connection with the elements 24 and 25 of Fig. 3, so as to make the ending equivalent to 0.8 section. This accounts for the condenser 29 in Fig. 4. The result obtained by a 0.8 section is that the resistance component of the impedance becomes substantially constant for about 85% of the transmitting range of the loaded line, that is to within 15% of its critical frequency. The presence of resistance 24 in association with condenser 25 as compared with its absence with condenser 29, represents a mere difference of degree. It is assumed that a long piece of small gauge cable whose resistance is considerable, is to be simulated in Fig. 3, but in Fig. 4 it is assumed that a short piece of large gauge cable is involved, whose resistance may be neglected.

Next we interpose reactance annulling networks comprising the condensers 30 and coil 31 in parallel in each side of the line. These have magnitudes so chosen that they completely neutralize the reactance of the line, reducing its impedance to a pure resistance which, as heretofore stated, is substantially constant over 85% of the frequency range.

At 32 we interpose a pair of balanced condensers in series with the line to give it a capacity reactance of such value that the impedance will have the same phase angle as the non-loaded line on the other side of the repeater. Then we put in the auto-transformer 16 and the retardation coil 17, as de-

scribed for the earlier figures. The capacity of a condenser to balance the reactance of a non-loaded line is given by the formula

$$C_1 = \frac{2\sqrt{LC}}{R}$$

where L, C and R are respectively the distributed inductance, capacity and resistance of the line per unit length. The capacity so found is divided by the impedance ratio of the auto-transformer 16, to find the joint capacity of the two condensers 32 in series.

Between the amplifying element 15 and the output winding 14 we put a low pass filter 33 with its critical frequency at 85% of the critical frequency of the loaded line 26. As we have just stated, the 0.8 section ending of the loaded line that was secured by the condenser 29 equalized the resistance component only for about 85% of the range up to the critical frequency of the loaded line. The filter 33 is designed to cut off all frequencies above the frequency at which the resistance component becomes inconstant.

Fig. 5 presents the case for two loaded lines of different characteristic impedances. It will be seen that in the same manner stated for Fig. 4, we build each loaded line out to a 0.8 section termination to make its resistance component as nearly uniform as possible, then introduce a reactance annulling network on each side, thus reducing the case to that of Fig. 1.

An alternative arrangement by which the impedance of the line can be made to approximate a pure resistance over 85% of the range within the critical frequency is shown in Fig. 6. In this case the line is terminated by a loading coil 28′ having 0.8 of the inductance of the normal coil 28 and a combination consisting of a condenser 34 and inductance 35 in series is bridged across the terminals. From this point the equalization of the impedance will be the same as in Figs. 4 or 5.

The impedance of different non-loaded lines may differ in magnitude. Their reactances will differ from each other in such a way that the difference can be compensated by means of series condensers 32 as illustrated in Fig. 7, which assumes an 8-gauge open-wire line 36 on the left and a 12-gauge open-wire line 37 on the right. The condensers 32 of suitable capacity interposed in the line 36 serve to compensate for the difference in reactance. This leaves the case of two lines with their impedance ratio a real constant for which the construction shown in Fig. 1 suffices to complete the diagram. The capacity of the condensers 32 is computed as follows. Compute the capacity C_1 necessary to balance the reactance of the line 36, and the capacity to balance the reactance of the line 37. Multiply the latter by the impedance ratio of the auto-transformer 16 and call the result C_2. Then the joint capacity of the condensers 32 in series is

$$C_3 = \frac{C_1 C_2}{C_1 - C_2}$$

What we claim is:

1. In combination, two dissimilar lines, a 21-type repeater connecting them, a network or networks to reduce the impedances of the lines to substantially pure resistances over the essential frequency range, and means to equalize the resultant impedances of the two lines.

2. In combination, two dissimilar lines, a 21-type repeater connecting them, a network or networks to reduce the impedances of the lines to substantially pure resistances over the essential frequency range, means to equalize the resultant impedances of the two lines, and a wave filter associated with said repeater and having a critical frequency corresponding to said essential frequency range.

3. In combination, two dissimilar lines, a 21-type repeater connecting them, and an interposed transformer on one side to equalize the impedances of the two lines.

4. In combination, two dissimilar lines, a 21-type repeater connecting them, an interposed transformer on one side to equalize the impedances of the two lines, and a retardation coil or transformer on the other side to match said interposed transformer.

5. In combination, two dissimilar lines, at least one of them being a loaded line, and means to equalize their impedances comprising elements to build out the loaded line to the proper fractional sectional ending.

6. In combination, two dissimilar lines, at least one of them being a loaded line, elements building the loaded line out to 0.8 of a normal element thereof, a reactance annulling network associated therewith, a repeater, a transformer between one line and the repeater, a retardation coil or transformer across the other line, and a low pass wave filter associated with the repeater.

In testimony whereof, we have signed our names to this specification this 27th day of September, 1921.

ALVA B. CLARK.
RAY S. HOYT.