Aug. 5, 1924. 1,504,135

H. NYQUIST

TELEPHONE REPEATER CIRCUITS

Filed Sept. 2, 1921 2 Sheets-Sheet 1

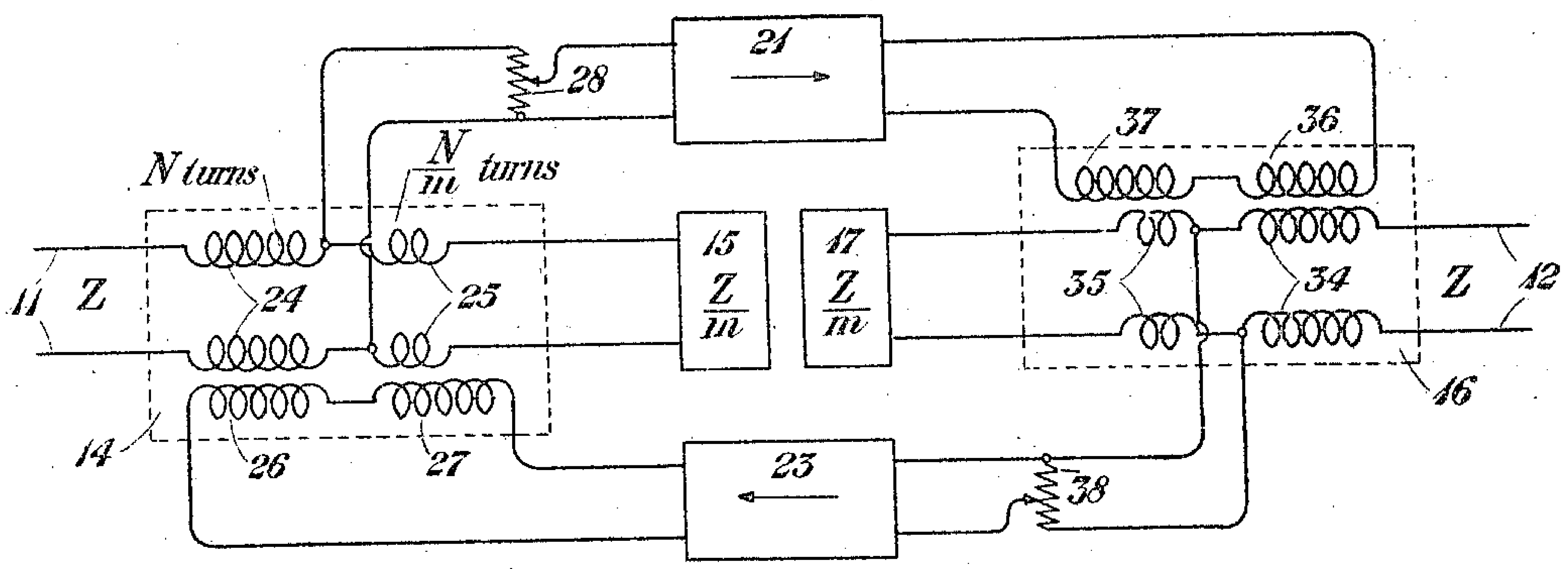

Fig. 1

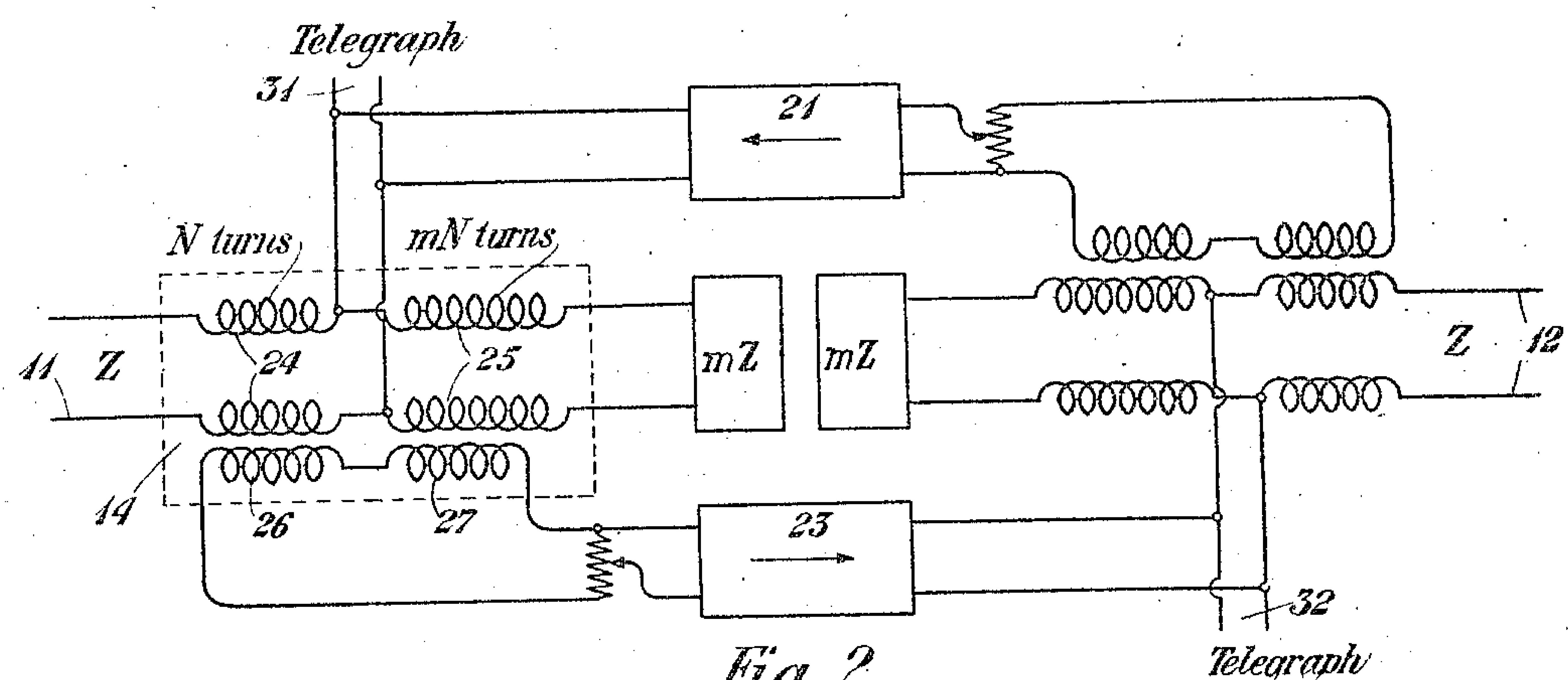

Fig. 2

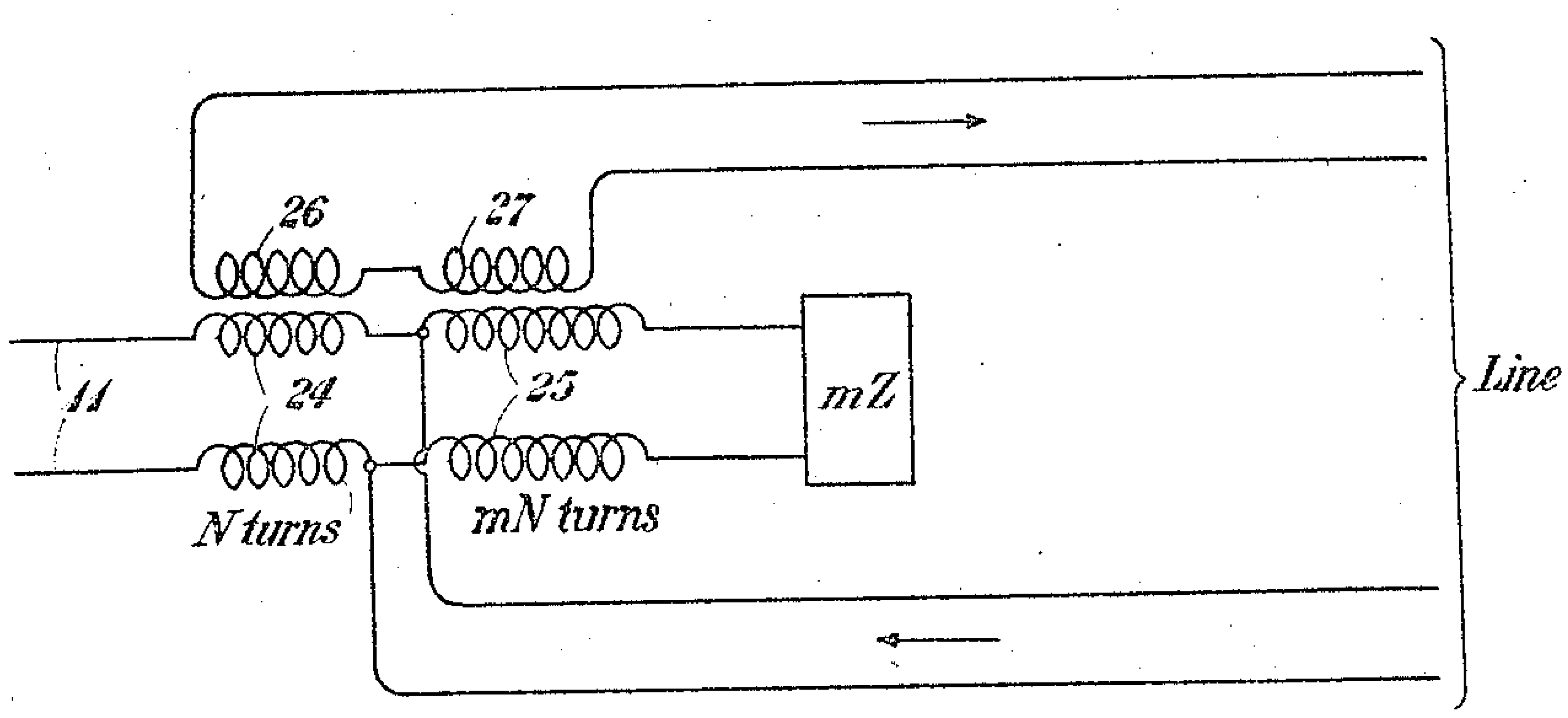

Fig. 3

INVENTOR
H. Nyquist
BY G. E. Folk
ATTORNEY

Aug. 5, 1924.

1,504,135

H. NYQUIST

TELEPHONE REPEATER CIRCUITS

Filed Sept. 2, 1921

2 Sheets-Sheet 2

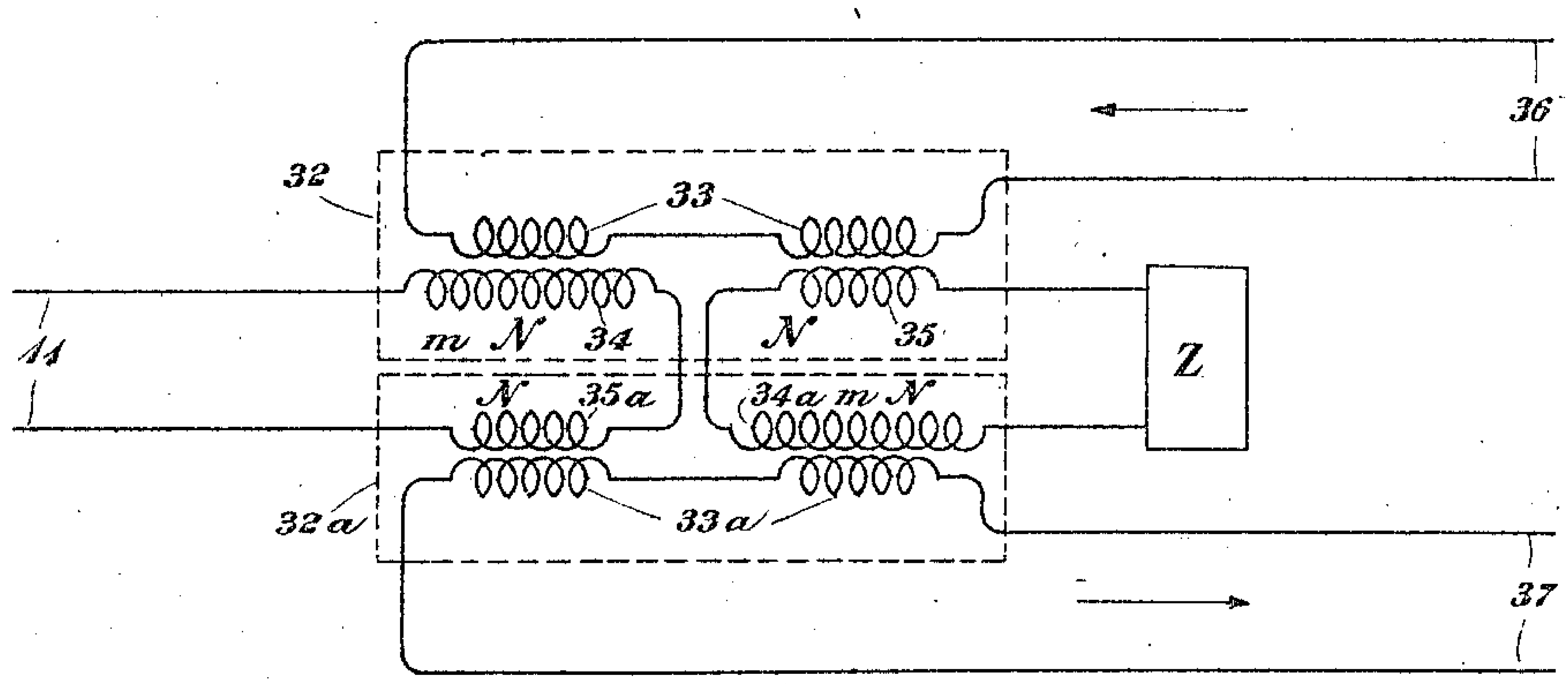

Fig. 4

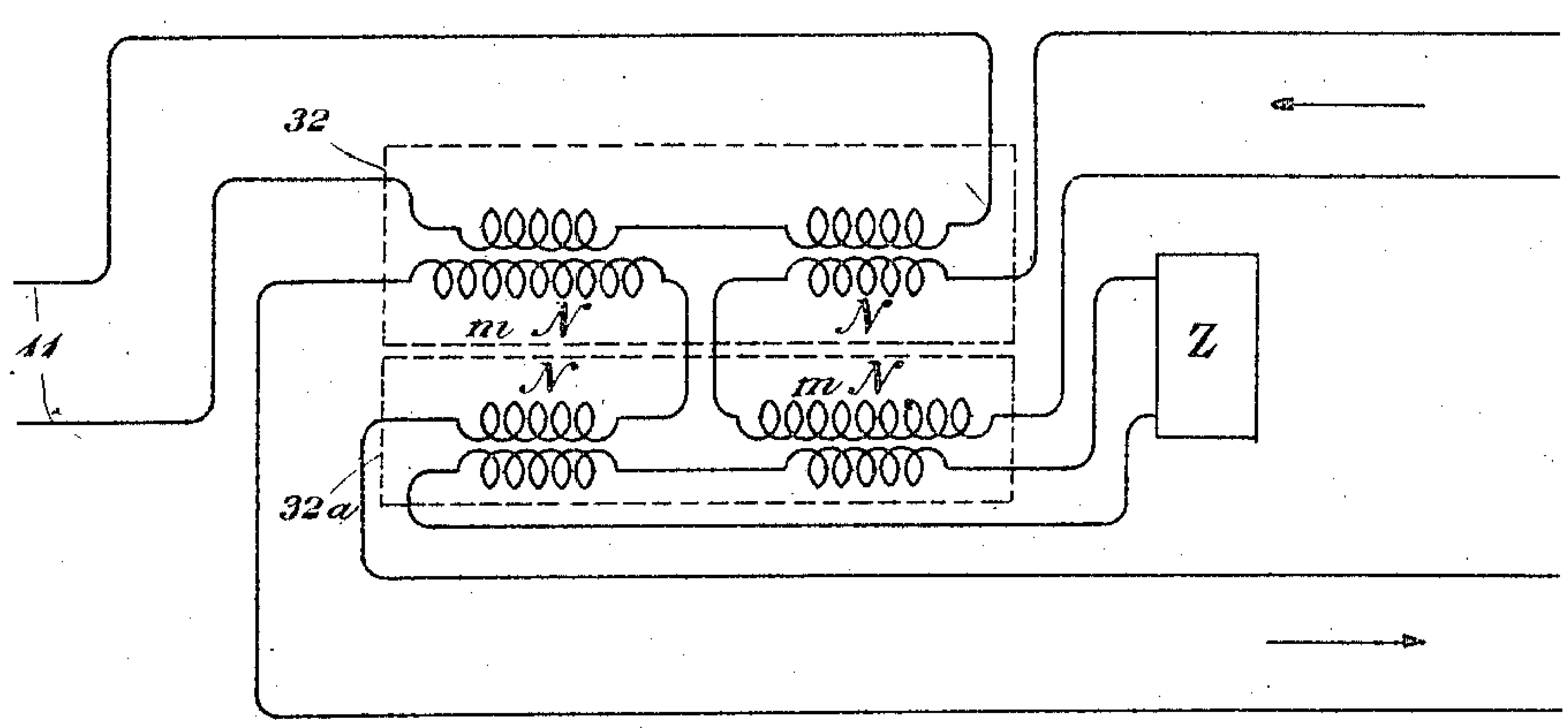

Fig. 5

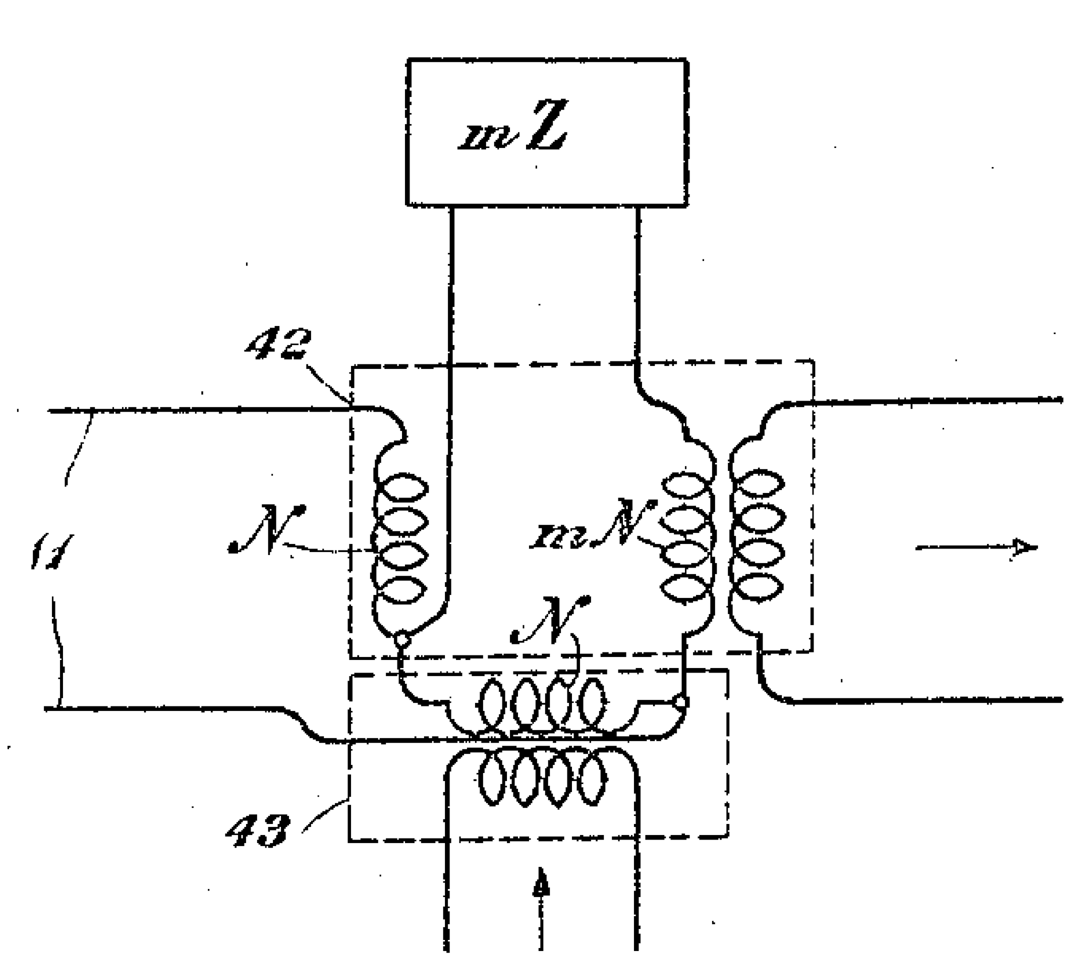

Fig. 6

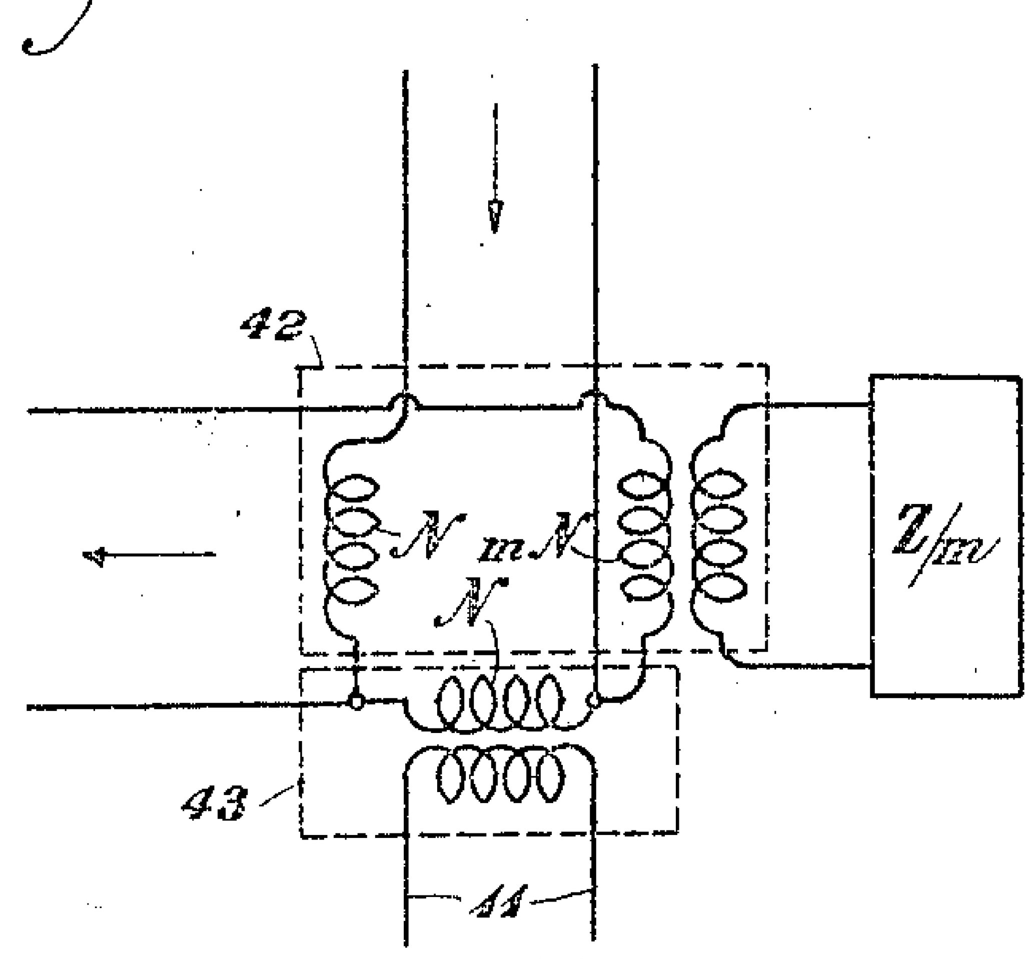

Fig. 7

INVENTOR
H. Nyquist
BY
G E Folk
ATTORNEY

Patented Aug. 5, 1924. 1,504,135

UNITED STATES PATENT OFFICE.

HARRY NYQUIST, OF ELMHURST, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

TELEPHONE REPEATER CIRCUITS.

Application filed September 2, 1921. Serial No. 497,842.

To all whom it may concern:

Be it known that I, HARRY NYQUIST, residing at Elmhurst, in the county of Queens and State of New York, have invented certain Improvements in Telephone Repeater Circuits, of which the following is a specification.

This invention relates to telephone repeater circuits and in particular to the type commonly known as the 22 type repeater, in which two repeater elements are used for the transmission of speaking currents in the two directions. The object of the invention is to increase the energy carrying capacity or the effective output of a repeater circuit. A second object is to accomplish this result without increasing the capacity of the individual amplifier elements used, that is, without resorting to the expedient of using larger amplifying tubes. Still a further object of the invention is to accomplish this increased effective output without overloading or crowding the repeater element. All of these objects are accomplished by diminishing the energy losses ordinarily occurring in repeater circuits. More specifically I accomplish these various objects by the suitable use of asymmetrical hybrid coil arrangements, designed to give increased transmission efficiency between the output of the repeating element and the line at the expense of the transmission efficiency between the input of the repeating element and the line.

The invention will be better understood by reference to the accompanying drawing in which Figure 1 shows a circuit arrangement as adapted to the usual 22 type repeater circuit. Fig. 2 shows a modification of the circuit in Fig. 1, for use in such cases where it may be desirable to terminate the telegraph circuits at the repeater station or to have the telegraph signals shunted around said repeater without the use of composite sets. Fig. 3 shows an adaption of the invention to a four-wire circuit. Figs. 4 to 7 show the invention as applied to other types of repeating coils.

Referring more particularly to Fig. 1, 11 and 12 represent transmission lines which are to be associated with each other at repeater station by the so-called 22 type circuit. This circuit contains a hybrid coil 14, comprising the windings 24 and 25 in series and connecting the line 11 to a balancing network 15 and the windings 26 and 27 inductively connected to 24 and 25. A similar hybrid coil 16, comprising series windings 34 and 35, and the line 12 to the balancing network 17 and includes the induction windings 36 and 37. For conversation in one direction there is connected across the intermediate points of the windings 24 and 25 the input of the repeater 21, the output of which contains the windings 36 and 37 inductively connected with windings 34 and 35 in the usual way. Similarly for conversation in the opposite direction, there is connected across the intermediate points of the wndings 34 and 35 of the coil 16, the input of the repeater 23, the output of which is associated with the coil 14. The connection as thus described is put in this standard arrangement, the balancing networks 15 and 17 are made to have the same impedance as their corresponding lines 11 and 12, and under these conditions, a portion of the incoming energy from the line 11 is dissipated in the network 15, and a half only of the potential is available for the input of the repeater element 21. Of the amplified energy from the output circuit of 23, half is transmitted to the line 11 and the other half is dissipated in the network 15.

In order to increase the effective capacity of the repeater element, I propose to decrease the portion of the output energy from the repeater element which is dissipated in the balancing network and I accomplish this by making the hybrid coils asymmetric. For example, as shown in Fig. 1, I make the number of turns of the winding 25 a fractional part only of those in the winding 24. Thus, if there are N turns in the portion of the coil 24 associated with the line, I would then make the number of turns in the portion 25 associated with the balancing network equal to $\frac{N}{m}$. At the same time I make the impedance of the balancing network equal to $\frac{Z}{m}$ where Z is the impedance of the line as seen from the hybrid coil. A similar arrangement is provided in connection with the line 12 and its hybrid coil.

Under these circumstances it is seen that a current in the winding 26, 27 will induce in the winding 25 an E. M. F. which is only $\frac{1}{m}$ of that in winding 24 although the current flowing in 15 and in 11, in series, will be the same and that therefore the energy dissipated in 15 will be only $\frac{1}{m}$ of that sent to the line 11. As a result for a given energy supplied by element 23 a larger quantity is sent to line 11. It is also true that the effective voltage impressed on the input of element 21 is reduced by the factor m, but this can very readily be made up, in whole or in part, by means of the potentiometer 28 which is always associated with repeaters as used in practice. It will in general still be desirable to arrange the number of turns in the respective parts of the hybrid coil 14 so that the impedance as seen from the output terminals of the repeater element will be the same as formerly, which will be the internal impedance of the repeater element itself. This will necessitate a change in the number of turns in the windings 26 and 27, the change being in accordance with the change in the windings 24 and 25. A similar line of reasoning applies to line 12, network 17 and coil 16. From the above it is apparent that the circuit arrangement described will either make it possible to carry a given amount of power with a repeater element of similar capacity or to increase the effective capacity of a tube of given size.

Fig. 2 shows a modification in which the number of turns of the winding 25 associated with the balancing network is increased by the factor m, and the impedance of the balancing networks is increased by the same factor. In this case in order to accomplish the desired results it will be necessary to face the repeater element in the reverse direction so that the input is inductively associated with the line by the windings 26, 27 and the output is conductively associated with the windings 24 and 25 at their intermediate points.

By a similar line of reasoning it may be shown that a similar gain is obtained. For example, incoming energy on the line 11 will now produce in the windings 26, 27 a voltage less than normal, due to the fact that there is no longer a unit ratio between the primary and the secondary of the transformer. On the other hand, output energy from the element 21 will be divided between the line 11 and the balancing network 15 in such a way that the portion dissipated in the network is smaller than that in the line, by the factor m. As a result, for a given effective output to the line 11, a smaller amount of energy must be supplied by the element 21 or for a given amount of energy from the element 21 a larger quantity will be delivered to the line 11. The new proportion of the number of turns in the hybrid coil and the new impedance of the balancing network will still leave the system as a whole balanced in the manner required for a repeater circuit of the 22 type.

It sometimes occurs in telephone practice that it is desirable to use a given transmission line for both telephone and telegraph purposes simultaneously. In general the strength of the telegraph impulses is much greater than that of a telephone current. Usually it is not desirable to have this telegraph current pass through the amplifier or it may be desirable to terminate the telegraph circuit at or near the repeater station. In this event the arrangement of circuit of Fig. 2 is especially useful for the reason that the telegraph impulses, being of a low frequency, are not transmitted efficiently by the transformer constituting the hybrid coils, and therefore substantially no effect is produced by it on the input circuit of the repeaters. On the other hand, the impression of the full telegraph voltage in the output circuit of the repeater elements, does not produce any appreciable reaction on the line as a whole through the repeater. Therefore, as indicated in Fig. 2, the output circuit of the repeater element 21 is conductively connected at the intermediate points of the hybrid coil and the telegraph circuit is taken off in parallel with said output circuit. The branch circuits for this purpose are shown at 31 and 32 and while I have shown no apparatus associated therewith, it is to be understood that these branches may go directly or indirectly to suitable telegraph terminal apparatus, or may be connected together by suitable relays to permit the telegraph message to continue through the lines 11 and 12, being shunted around the repeater circuit.

In Fig. 3 I have shown the application of my invention to a four-wire circuit in which the direction of transmission and the direction in which the repeater elements operate is shown by the arrows. For the particular direction of operation shown, it is necessary that the balancing network shall have a larger impedance than the line by the factor m and that the turns of the hybrid coil directly connected to said network shall have a larger number of turns than the portion directly connected to the line by the same factor m, as shown in Fig. 2. Under these circumstances the energy absorbed by the balancing network will be diminished without a corresponding diminution in the amount of energy supplied to the line but that a corresponding diminution in the amount of energy which the repeater element must supply. I have shown but one end of this four-wire circuit arrangement for the reason that the other end is identical thereto and the circuit as a whole virtually amounts to an unlimited extension of the conductors leading to the repeater elements 21 and 23 of Figs. 1 and 2, as is well understood in the art.

While thus far I have described the invention in connection with one type of repeater circuit, it should be understood that it can be applied equally well to others. In Fig. 4 for example there is shown a repeater circuit comprising two coils, 32 and 32^a, each coil containing three windings 33, 34 and 35. By making the windings asymmetrical to the extent of having m times as many terms in the winding 34 as in 35, the same asymmetry in distribution of power absorption is produced as described in connection with the previous figures. For this particular connection the balancing network should have the same impedance Z as the line. The wires 36 and 37 may constitute the four wires of a four-wire circuit such as shown in Fig. 3 or may constitute the wires leading to repeater elements such as 21 and 23 of Figs. 1 and 2, the circuit then leading to a similar set of coils associated with the transmission line from the other direction. In either case these lines 36 and 37 may be spoken of as the four-wire circuit. The arrows indicate the direction of transmission of talking current.

Fig. 5 shows the conjugate connection for the same set of repeating coils. Here again the balancing network has the same impedance Z as the incoming line 11 and the power consumed in this balancing network will be a fractional part only of that which is sent to the transmission line.

Fig. 6 shows the invention applied to still another type of repeating coil. In this type of repeater one coil comprises the three windings which are shown in the figure as vertical and a second coil comprises the two windings shown as horizontal. Asymmetry is introduced by placing in one of the vertical coils m times as many turns as in the other windings of that coil. In order to maintain balance for this circuit it is necessary that the balancing network shall have an impedance mZ where Z is the line impedance. Under these circumstances the power consumed in the balancing network will be a fraction only of that given to the line 11.

Fig. 7 shows the conjugate connection for the same type of repeating coils. For this connection it is necessary that the balancing network shall have an impedance of $\frac{Z}{m}$, and under this condition the repeater will remain balanced and at the same time the power dissipated in the balancing network will be a fraction only of that sent to the line 11.

I wish it to be understood that I have shown the application of my invention to a limited number of typical circuits only but that with various modifications it may be applied to other repeater circuits. Also I do not wish to be limited to any particular value for the factor m, it being possible to vary this over a considerable range.

What is claimed is:

1. In a repeater circuit comprising transmission lines interconnected by one-way repeater paths including amplifiers and having balancing networks associated with the lines for rendering the outgoing side of one repeater path conjugate with respect to the incoming side of the opposite repeater path, the method of increasing the effective capacity of the amplifiers, which consists in decreasing the absorption of output energy in the balancing network and increasing the ratio of amplification of each amplifier to compensate for the consequent decrease in the absorption by each amplifier of input energy from the line.

2. In a repeater circuit comprising transmission lines interconnected by one-way repeater paths including amplifiers and having balancing networks associated with the lines for rendering the outgoing side of one repeater path conjugate with respect to the incoming side of the opposite repeater path, the method of increasing the effective capacity of the amplifiers, which consists in associating each transmission line with its corresponding balancing network by a coil having asymmetrical windings and increasing the amplifying ratio of each amplifier to compensate for the consequent decrease in the absorption by each amplifier of input energy from the line.

3. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, said hybrid coils having asymmetrical windings, and means for increasing the amplifying ratio of the amplifiers in the repeater paths to compensate for the decrease in the energy to the amplifier due to the asymmetric arrangement of the coils.

4. A repeater circuit comprising transmission lines, one-way repeater paths inter-

connecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, the windings of said hybrid coils being designed to transfer less output energy from the amplifiers to the networks than to the lines, and means to increase the amplifying ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

5. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, said balancing networks being of different impedance from the corresponding lines, whereby the absorption in said networks of energy from said amplifiers is diminished, and means for increasing the amplification ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

6. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, said hybrid coils comprising windings conductively connected to the lines and networks, conductive connections from intermediate points of said windings to the corresponding repeater elements, said windings being thereby divided into portions having a ratio other than unity, and means to increase the amplification ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

7. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, the connection from each repeater element to the corresponding hybrid coil being such that the ratio of turns directly connected to the transmission line and directly connected to the balancing network is other than unity, and means for increasing the amplification ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

8. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, the connection from each amplifying element and corresponding hybrid coil being such that the ratio of turns directly connected to the transmission line and directly connected to the balancing network is greater than unity, and means for increasing the amplification ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

9. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, conductive connections from the intermediate points of the windings of the hybrid coils to the corresponding repeater elements, said connections dividing said winding into portions having a ratio of turns other than unity, and means for increasing the amplification ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

10. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing networks, conductive connections from intermediate points of the windings of the hybrid coils to the corresponding repeater elements, said connections dividing said winding into portions having a ratio of turns other than unity, each balancing network having an impedence bearing the same ratio to the impedence of its line, and means for increasing the amplification ratio of the amplifiers to compensate for the corresponding decrease in input enegry from the line.

11. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater paths and balancing net works, conductive connections from intermediate points of the series windings of said hybrid coils to the input of the amplifying elements, said connections dividing said windings into network portions and line portions in which the ratio of turns of the network portions and of the line portions is less than unity, and means for increasing the amplification ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

12. A repeater circuit comprising transmission lines, one-way repeater paths interconnecting said lines, amplifiers in each of said paths, a balancing network for each transmission line, hybrid coils for interconnecting the transmission lines, repeater

paths and balancing networks, conductive connections from intermediate points of the series windings of said hybrid coils to the inputs of the corresponding amplifiers, said connections dividing said windings into network portions and line portions in which the ratio of the turns in the network portions and in the line portions is less than unity, each network having an impedance bearing the same ratio to the impedance of its corresponding line, and means for increasing the amplification ratio of the amplifiers to compensate for the corresponding decrease in input energy from the line.

In testimony whereof, I have signed my name to this specification this 29th day of August, 1921.

HARRY NYQUIST.