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H. A. BARTON ET AL

REPEATER FOR TRANSMISSION LINES

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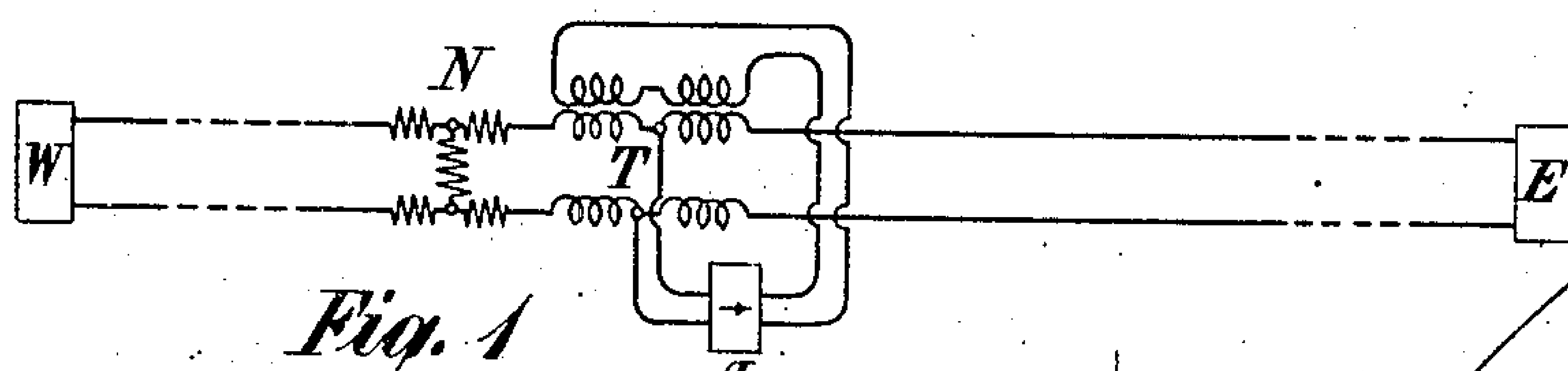

Fig. 1

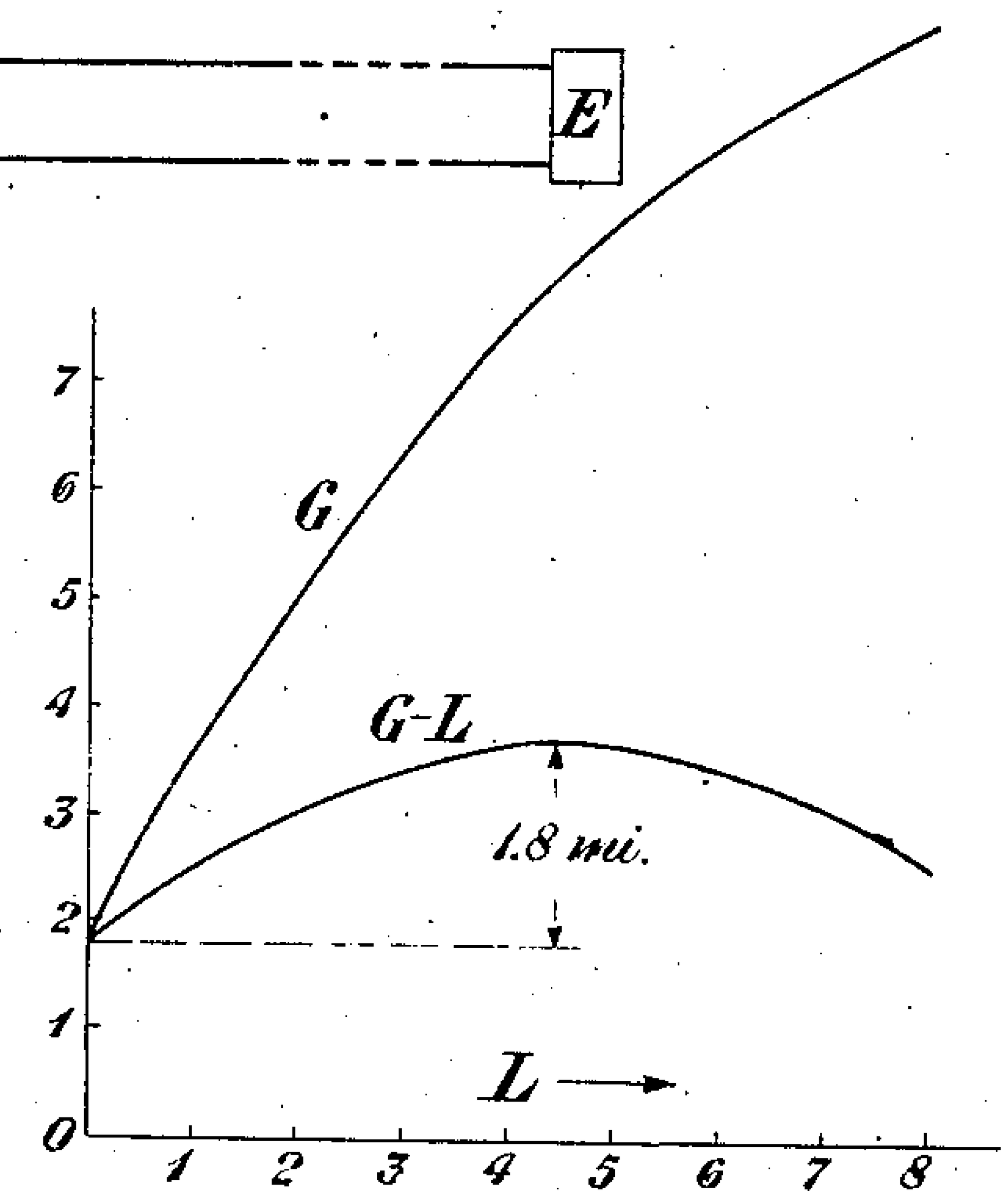

Fig. 2

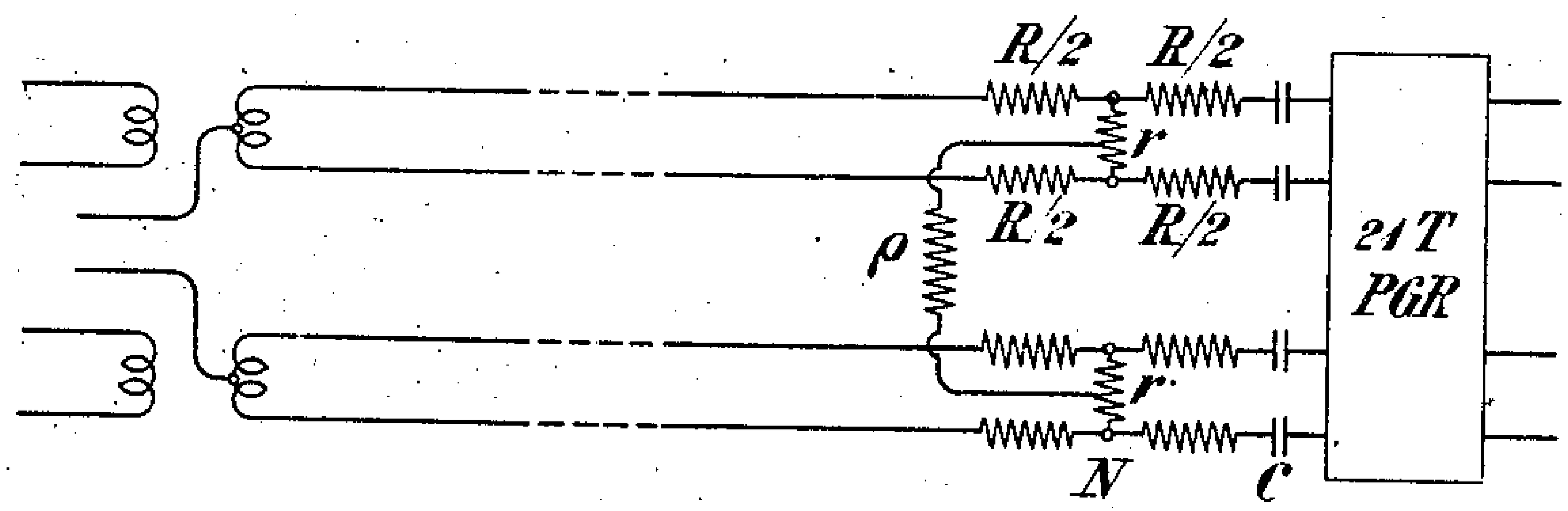

Fig. 3

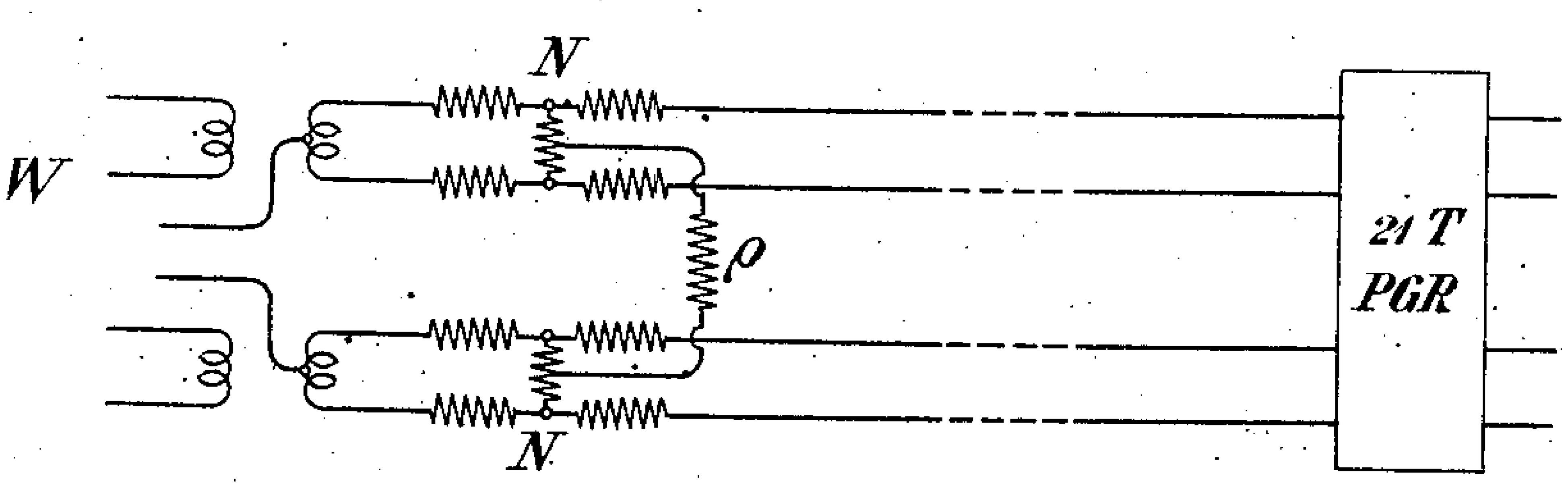

Fig. 4

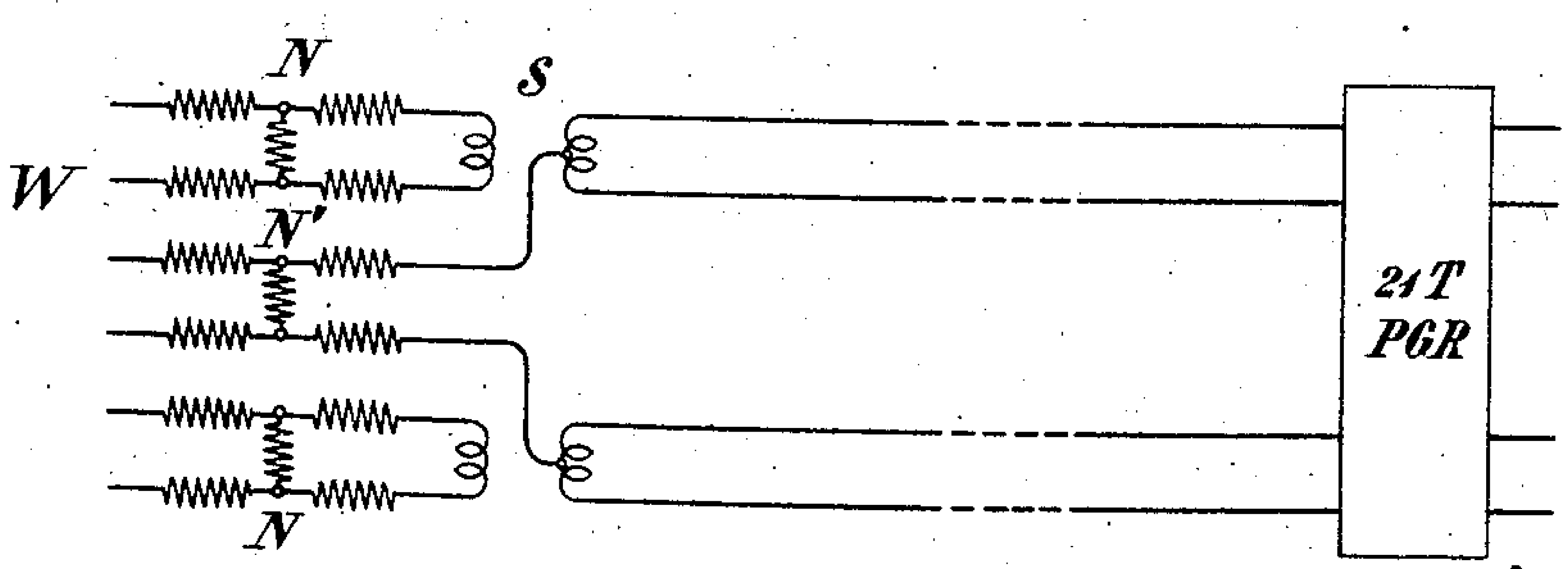

Fig. 5

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UNITED STATES PATENT OFFICE.

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REPEATER FOR TRANSMISSION LINES.

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It is an object of our invention to improve the construction and operation of a transmission line in which there is employed a repeater of a certain type. Another object of our invention is to remedy the unbalance effect on a repeater interposed between two lines of unequal length. Still another object is to equalize the effect of lines of different length on a repeater of the type which repeats both ways with a single amplifying element. These and other objects of our invention will become apparent on consideration of a limited number of specific examples of practice in accordance with the invention, which are disclosed in the following specification taken with the accompanying drawings. It will be understood that the following description applies to these examples of the invention and that the scope of the invention is pointed out in the appended claims.

Referring to the drawings, Figure 1 is a diagram of a transmission line embodying our invention. Fig. 2 is a curve diagram that will be referred to in explaining the principle of the invention, and Figs. 3, 4 and 5 illustrate respectively different ways of realizing the invention in connection with lines over which both side and phantom circuits are operated.

Fig. 1 represents a telephone transmission line intended for simultaneous two-way operation and comprising an interposed repeater of the so-called 21-type. This means that the repeater operates both ways but uses only a single amplifying element A for this purpose. The usual three-winding hybrid transformer T is designed so that if the lines extending each way therefrom are equal in all respects, then an incoming wave on either line will go in part to the input side of the amplifier A. The amplified output will then go equally to the line both ways from the transformer and none of this output will get back to the input of the amplifier A, because of the absence of any potential drop across the input terminals due to the balanced output.

The impulses put upon the line from the repeater output will be reflected back in some degree from the terminal stations E and W and if these are both far distant, any reflection is highly attenuated before it returns to the repeater. If either or both terminals are not far distant the reflected waves may have considerable magnitude and will enter the input of the amplifier A.

In the case where one station W is near and the other station E is distant it is possible to improve the circuit by means which will be described.

It might appear that to lengthen the line to station W by interposing artificial line would do more harm than good because such interposed artificial line must attenuate the transmission either way between the two stations E and W. But in accordance with the principle of our invention, as we shall show, there may be a positive advantage gained by interposing a properly designed artificial line between the repeater and the nearer station W.

The network or artificial line N is interposed, as shown in Fig. 1. Let its equivalent in "standard miles" be represented by the character L. Since a wave going out from the repeater to the station W and reflected back therefrom must traverse the network N twice, the attenuating effect on that wave due to interposing the network N will be represented by 2L. But so far as transmission is concerned from E to W or from W to E, the attenuating effect of the network N is only L.

If sufficient gain is given by the amplifying element to overcome the attenuation of the reflected wave, "singing" or sustained oscillations are set up. The element A will be adjusted to give a gain which is less than the singing gain by a specific margin, e. g. 5 standard miles which must be allowed between singing and operating gain in order to secure good quality. By the interposition of the network N the attenuation of the reflected waves has been increased by 2L so that the gain in the amplifier A can also be increased by 2L and the margin of 5 miles between singing and operating gain is still maintained. It should be noted that the foregoing statement is true, whatever numerical value this margin may have. The insertion of the net has increased the transmission loss between E and W either way by L. However, it has made it possible to increase the gain of the repeater 2L which results in a net gain of L.

A practical method for determining the proper magnitude of the network N as measured in "standard miles" L will now be explained in connection with Fig. 2. By "standard miles" we refer to units of attenuation of any apparatus interposed between a transmitting point and a receiving point, whose number L is given by the formula $Z=21.13 \log_{10} R$ where R is the ratio of received current when the apparatus is not interposed to received current when it is interposed. Various values of L are tried and the utmost repeater gain without singing is also determined for each value of L. These values of L are laid off as abscissæ in Fig. 2 and the corresponding values of gain for the repeater A are set up as ordinates, thus giving the curve G in Fig. 2.

But since the gain in the repeater, as indicated by the curve G, is offset to some extent by the loss L in the network N, a new curve marked G—L is constructed by diminishing each ordinate of the curve G by the corresponding value for L. This curve G—L will have a distinct maximum value, as appears in Fig. 2, and the value of L at this maximum is the appropriate value to be given to the network N. Fig. 2 is drawn for an actual example of a 19 gauge medium heavy loaded circuit containing a 21-type repeater with 35 miles of line on one side and 10 miles on the other side. It will be seen that there is a net improvement of 1.8 "standard miles" by interposing 4.5 "standard miles" for the value of L in the network N.

The network N must have the same characteristic impedance as the circuit in which it is interposed; this may be accomplished by design according to well understood principles.

Figs. 3, 4 and 5 show alternative ways in which the invention may be practiced in connection with lines comprising side and phantom circuits. The 21-type phantom group repeater is indicated diagrammatically by the rectangle with the legend "21T—PGR". In Fig. 3, a network N is provided for each pair having in each conductor the two resistances in series, each R/2. Bridged across between them is the shunt resistance r. R and r are given appropriate values in accordance with well known principles of design so that the network shall have the same characteristic impedance as the line and shall give the loss found by the method previously described. Then the mid-points of the two shunt resistances, each having the value r, are connected by a resistance ρ such that

$$\rho=\frac{9}{64}(R+2r)$$

Subject to this condition, the loss inserted in the phantom circuit and the characteristic impedance presented to it will be approximately correct.

It may be necessary for the purpose of securing proper balance to use condensers as shown in Fig. 3 by the character C to make the characteristic impedance of the inserted network more accurately equal to that of the line.

The networks N and the resistance ρ may be put at the distant end of the line close to the station W, as shown in Fig. 4. Still another modification is shown in Fig. 5, where the networks N are put in the local circuits determined by the repeating coils S, which are interposed in accordance with the principle of phantom design. In this case, a complete independent network N′ of proper design will be interposed in the taps that go to complete the phantom circuit, as is shown in Fig. 5. An advantage of the arrangement in Fig. 5 is that it will give less danger of cross-talk between the side circuits and the phantom circuit.

We claim:

1. In combination, a 21-type repeater, two lines of different length extending therefrom and a network interposed in the line of shorter length, said network having the same characteristic impedance as the lines, and an attenuation value such that the increase in the gain in the repeater made possible by the interposed network will be more than the one-way transmission loss in the network.

2. The method of increasing the gain at which a 21-type repeater between two lines of different length may be operated, which consists in causing the unbalance waves on the side of the shorter line to traverse an interposed network twice of the same characteristic impedance as the line while the effective transmission will traverse it but once.

3. The method of determining the optimum attenuation to be introduced in the shorter side of a transmission line with an interposed 21-type repeater, which consists in plotting against said attenuation the maximum repeater gain diminished by said attenuation thus giving the desired attenuation corresponding to the maximum on the plot.

4. In combination, a transmission system comprising two sides and a phantom with an interposed 21-type phantom group repeater, networks in each side making it possible to improve transmission on each side and an impedance element in conjunction

with these networks constituting means further to improve transmission on the phantom circuit.

5. In combination, a transmission system comprising two sides and a phantom with an interposed 21-type phantom group repeater, and appropriate networks to make it possible to improve transmission on each side and on the phantom.

In testimony whereof, we have signed our names to this specification this 25th day of January, 1923.

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