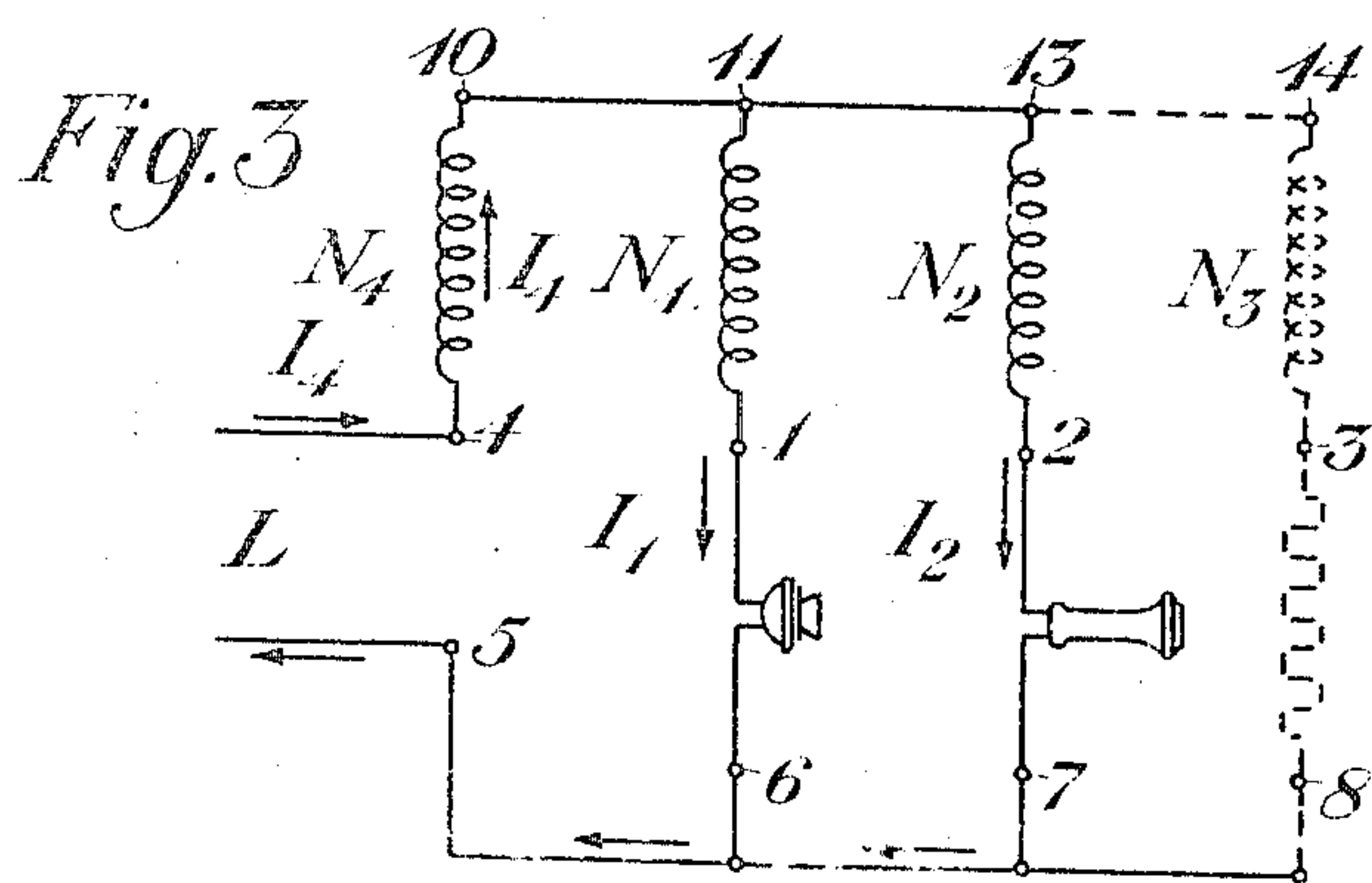
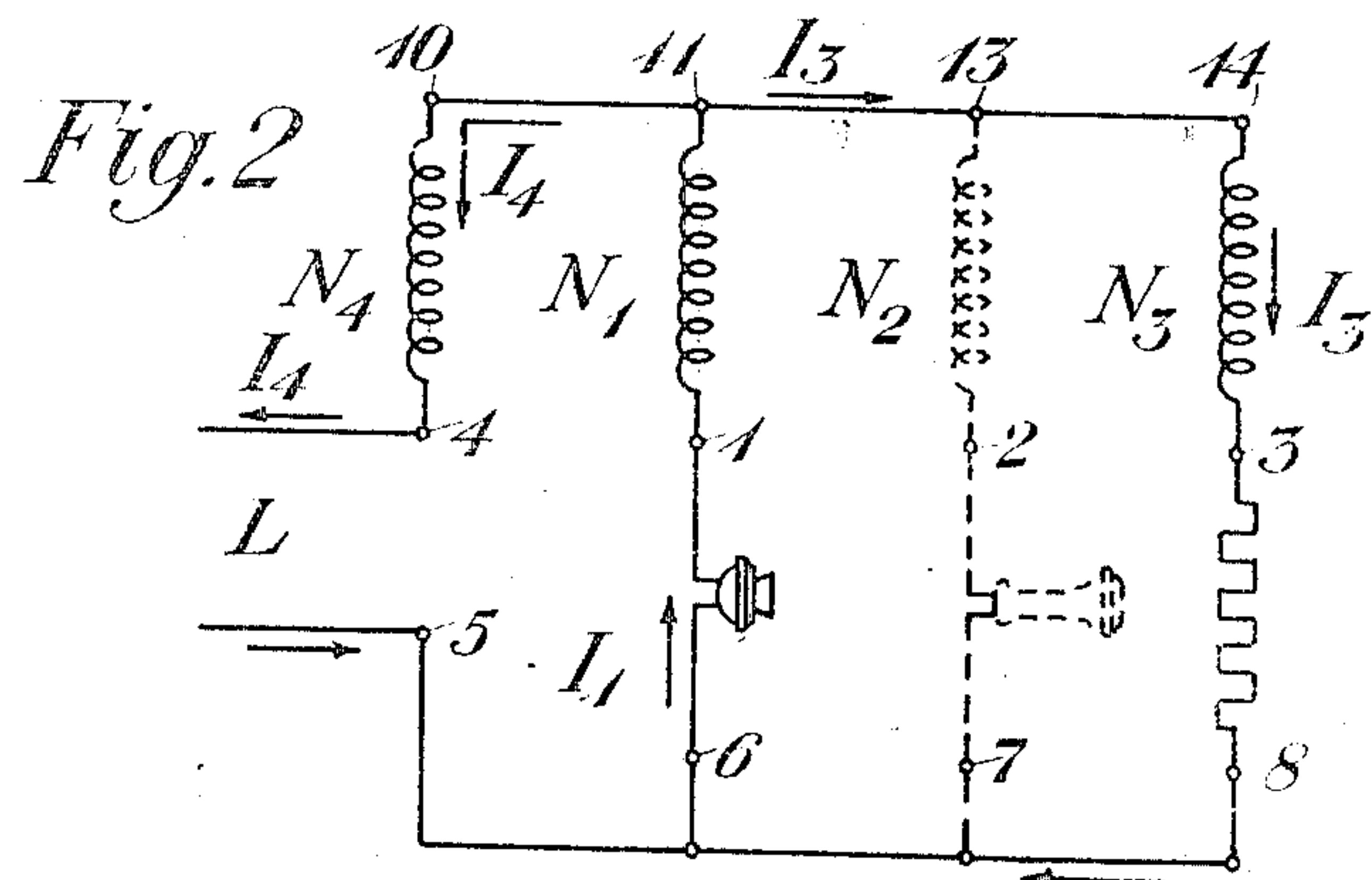
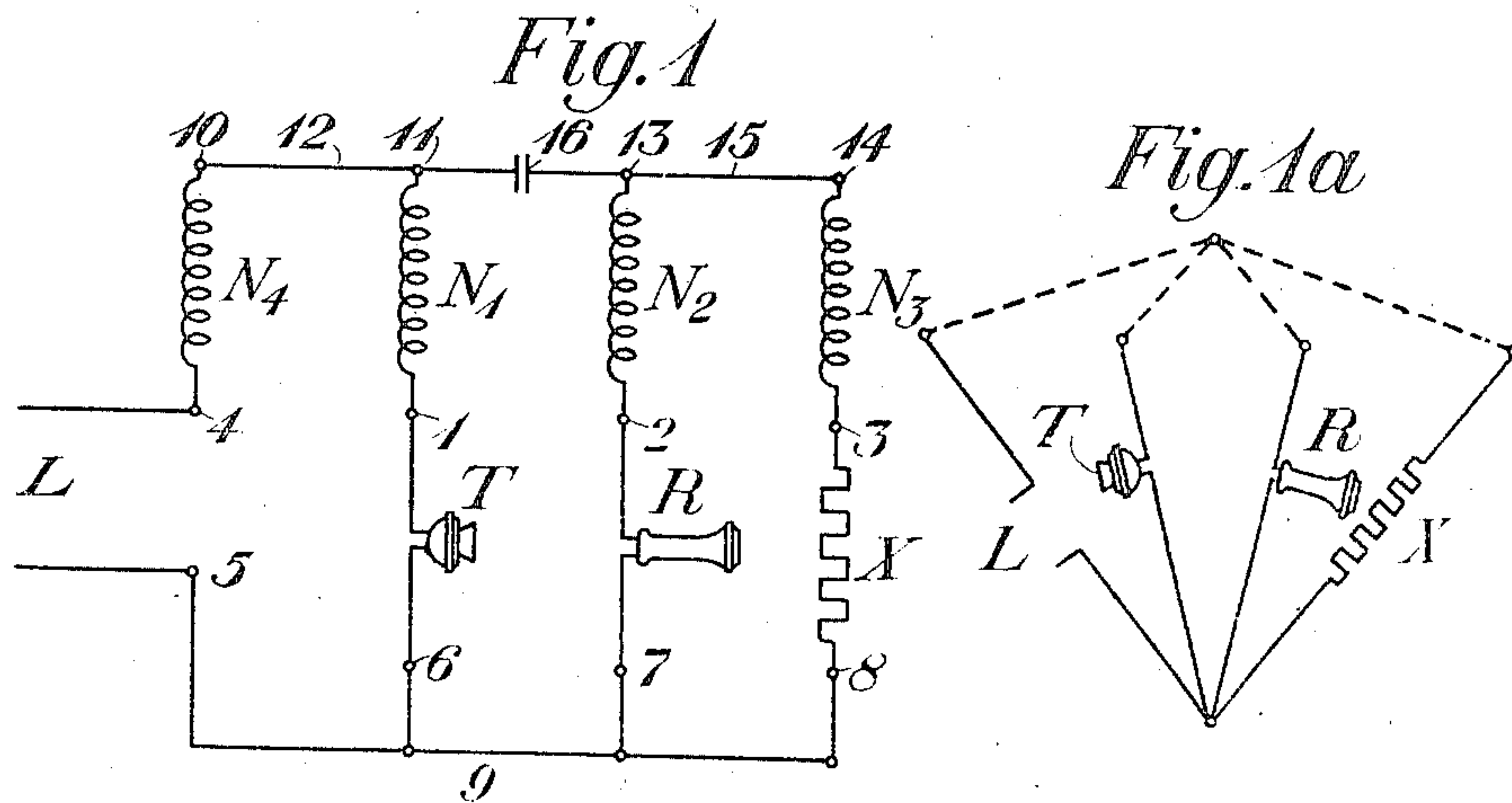


G. A. CAMPBELL.
SIGNALING CIRCUIT.
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1,254,475.

Patented Jan. 22, 1918.



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SIGNALING-CIRCUIT.

1,254,475.

Specification of Letters Patent.

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To all whom it may concern:

Be it known that I, GEORGE A. CAMPBELL, residing at Upper Montclair, in the county of Essex and State of New Jersey, have invented certain Improvements in Signaling-Circuits, of which the following is a specification.

This invention relates to circuit arrangements for signaling systems wherein signals may be either transmitted from or received at the same station. In its more specific aspects this invention is embodied in a subscriber's telephone station, hereinafter termed, in accordance with common usage, a substation, and more particularly in the combination of a substation and a telephone line. Its object is to provide a signaling circuit arrangement which in coöperative combination with a similar and equal communicating arrangement or station shall deliver the maximum amount of energy to the receiving apparatus of said communicating station or arrangement. A further object is to provide an arrangement such that the receiving apparatus is protected from interference by the transmission energy originating at the same station. In other words its object is to provide signaling means characterized by the maximum possible ratio of received and transmitted energy and further characterized by the absence of side tone.

The object of the invention is attained, in its specific aspect, by providing a substation consisting of transmitter, receiver, auxiliary resistance, and a transformer having a plurality of windings which, in combination with a telephone line, shall satisfy the following fundamental requirement: Given two identical substations designed for invariable two-way communication, and connected by a line of given impedance and length, the amount of energy absorbed by the receiver at the receiving station shall be the maximum part of the total telephonic energy developed by the transmitter at the transmitting station consistent with invariable two-way communication, and, as hereinafter explained, consistent with a desirable amount of discrimination against disturbing line noise. This fundamental re-

quirement may be stated in terms of the following subordinate requirements which are necessary for its satisfaction: (1) The transmitter and receiver shall be conjugate, that is there shall be negligible side tone in the receiver in consequence of the actuation of the transmitter by sound waves; (2) the line and auxiliary resistance shall be conjugate in order that none of the energy absorbed by the substation from the line shall be wasted in said auxiliary resistance; (3) for a given line having a definite impedance the telephonic energy delivered by the transmitter shall be a maximum; (4) the amount of energy delivered by the line to the substation shall be a maximum, in other words the impedance of the substation as seen from the line shall be equal to the impedance of the line; (5) at a small sacrifice of efficiency it shall be possible to discriminate effectively against disturbing line noise as distinguished from the telephonic signals from the communicating station.

A substation satisfying the above-mentioned requirements is ideal in that its overall efficiency from transmitter of one substation to receiver of the communicating substation is a theoretical maximum which cannot be exceeded by any invariable substations whether satisfying the requirement of transmitter and receiver conjugacy or not. It is further ideal in the sense that a minimum number of elements is employed since at least one auxiliary element is necessary to secure freedom from side tone.

It might be inferred that the addition of an auxiliary resistance element, necessary as it is to secure freedom from side tone, would at the same time necessarily reduce the efficiency of the substation since energy is unavoidably wasted in said auxiliary resistance. That this is not the case and that the efficiency of the substation of my invention is a theoretical maximum which cannot be exceeded by any two-way substation whether with or without side tone, the following considerations will show. The simplest form of substation for invariable two-way communication is that in which the receiver and transmitter are connected in series with each

other across the line. In such an arrangement the over-all efficiency is a maximum when the resistance of the receiver is equal to that of the transmitter. When this condition is satisfied obviously fifty per cent. of the energy delivered by the line to the substation is wasted in the transmitter and fifty per cent. of the energy delivered by the transmitter is wasted in the receiver. Further such an arrangement labors under the disadvantage of full side tone. In the substation of my invention fifty per cent. of the energy delivered by the line to the substation is wasted in the transmitter but none in the auxiliary resistance if said auxiliary resistance and said line are conjugate; hence the efficiency of receiving is as great as that of the simple series substation. When transmitting no energy is wasted in the receiver but fifty per cent. of the energy delivered by the transmitter is wasted in the auxiliary resistance. The transmitting efficiency is therefore also a theoretical maximum and neither transmitting nor receiving efficiency is reduced by the addition of the auxiliary resistance which is necessary to secure freedom from side tone. The foregoing consideration will serve to explain the desirability of having the line and auxiliary resistance conjugate as well as the transmitter and receiver.

In my present invention I provide a substation comprising transmitter, receiver, auxiliary resistance and transformer, and so proportion said component elements and so relate them to a telephone line and to each other that, in combination with said telephone line, said substation satisfies all of the foregoing requirements.

I have discovered that the above-mentioned requirements may be satisfied by a large number of arrangements employing the minimum number of elements and all equally efficient and without side tone. While theoretically all these arrangements are equally good, practical considerations make certain arrangements preferable.

This application is a division of application Serial Number 119,282, filed September 9, 1916. The invention is best understood by reference to the accompanying drawings in which:

Figure 1 is a diagram illustrating one form of substation embodying the invention of this application.

Figs. 2 and 3 are diagrams illustrating the current flow in the substation of Fig. 1 during transmission and reception respectively.

Fig. 1^a is a schematic diagram of the substation illustrated in Figs. 1, 2 and 3.

In order to illustrate the scope of my invention and elucidate the principles on which all specific embodiments rest, a general theoretical discussion will now be given which

applies to all substations satisfying the requirements heretofore stated in this specification. In this discussion and the equations and formulae included in this specification the subscripts 1, 2, 3 and 4 will refer to transmitter, receiver, auxiliary resistance and line respectively. Thus I_1 , I_2 , I_3 , I_4 will denote the currents flowing in transmitter, receiver, auxiliary resistance and line respectively, while R_1 will denote the resistance of the transmitter, R_2 the resistance of the receiver, etc.

Consider a substation consisting of transmitter, receiver, auxiliary resistance and appropriate transformer windings, connected to a line of given impedance. In practice the line connects two similar and equal substations between which communication is established. It is a well known principle that if a terminal impedance is connected to a source of electromotive force through a line of impedance

$$Z = R_4 + iR'_4,$$

where R_4 is the resistance and R'_4 the reactance component of the impedance, the terminal impedance must be $R_4 - iR'_4$ for maximum absorption of energy. In particular if the line impedance has no reactance component the impedance of the terminal arrangement as seen from the line should be equal to the resistance component of the impedance of the line. The condition, then, that the substation shall have maximum energy absorption from the line is that its impedance, as seen from the line, shall be equal to the line impedance. The significance of the foregoing statement may be explained by reference to Fig. 1 as follows: Let the substation be disconnected from the line and let the impedance of the substation be measured across terminals 4 and 5. Then the impedance so measured shall be equal to the impedance of the line. With the line terminated at each end by a substation satisfying this condition, the line may be replaced, as regards transmission from either substation, by an impedance element of resistance equal to the impedance of the line. Any reactance effect, which is in practice small, may be eliminated by neutralizing reactance and, therefore, need not be considered. The condition, then, that the substation have maximum energy absorption from the line is that its impedance as seen from the line be a pure resistance of value equal to the impedance of the line. This condition is evidently equivalent to the following requirement; let an electromotive force be impressed on the substation terminals through a resistance equal to the impedance of the line; then the energy consumed in the substation shall be equal to the energy consumed in said resistance.

Further, line and auxiliary resistance are conjugate by requirement (2), as hereinbefore stated, or in other words, the auxiliary resistance is connected to points of equal potential with respect to an electromotive force applied to the line terminals. Moreover, the impedance of the substations as seen from the line should be equal to that of the line. Let, then an electromotive force E_4 be impressed through a resistance R_4 on a substation where transmitter and receiver resistances are R_1 and R_2 respectively, and the resultant currents in line, transmitter and receiver be I_4 , I_1 and I_2 respectively. Then, the impedance across the substation terminals must be R_4 as seen from the line and the total resistance in series with E_4 is $2R_4$, and since the current in the line is I_4 , it follows that

$$\frac{E_4}{2R_4} = I_4$$

The total energy consumed may then be expressed by the formula,

$$I_4^2 R_4 + I_1^2 R_1 + I_2^2 R_2 = I_4 E_4 = \frac{E_4^2}{2R_4}$$

Since the energy consumed by the substation is equal to that consumed by the resistance R_4 and is therefore one-half of the total energy consumed, it follows that requirement 4 may be formulated by the following equation:

$$R_4 I_4^2 = I_2^2 R_2 + I_1^2 R_1 = \frac{E_4^2}{4R_4} \quad (1)$$

This equation states that the energy consumption in the resistance R_4 is equal to that in the substation, and that the substation is equivalent, as seen from the line, to a resistance of value R_4 .

Similarly, if transmitter and receiver are conjugate the condition that the transmitter shall have its maximum output to line and auxiliary resistance may be formulated as follows: Let an electromotive force E_1 in the transmitter produce currents I_1 , I_4 and I_3 in transmitter, line and auxiliary resistance. Then, for maximum output, it follows that:

$$I_1^2 R_1 = I_4^2 R_4 + I_3^2 R_3 = \frac{E_1^2}{4R_1} \quad (2)$$

Equation (2) is the analogue of equation (1) and may be interpreted as follows by reference to Fig. 1: Let the transmitter be disconnected from terminals 1 and 6 and let the impedance be measured across said terminal. Then if equation (2) is satisfied the impedance so measured is equal to the impedance of the transmitter itself. In other words, the impedance of the combination, as seen from the transmitter is equal to that of the transmitter itself.

As hereinafter shown for the particular

embodiments of my invention, equation (2) follows as a consequence of the conditions of double conjugacy and equation (1). Therefore the foregoing four requirements impose but three restrictions on the substation.

To complete the general discussion it remains to consider the energy division between receiver and transmitter when receiving, and between line and auxiliary resistance when transmitting. Let W_0 be the total amount of telephonic energy developed by the transmitter at the transmitting substation; then, by equation (2), $1/2 W_0$ is the amount of energy delivered to line and auxiliary resistance. Let the amount of energy taken by the auxiliary resistance be x times that taken by the line, then the amount of energy taken by the line is

$$\frac{1/2 W_0}{(1+x)}$$

so that the transmitting efficiency is measured by

$$\frac{1}{(1+x)} \quad (3)$$

Of the total energy delivered to the receiving substation, let the transmitter absorb y times that absorbed by receiver; then the receiving efficiency is measured by

$$\frac{1}{(1+y)} \quad (4)$$

The over-all efficiency from transmitter of one station to receiver of communicating station is clearly proportional to the product of the transmission efficiency and receiving efficiency; therefore the over-all efficiency is by formulæ (3) and (4):

$$\left(\frac{1}{1+x} \right) \left(\frac{1}{1+y} \right)$$

If x and y were independent, clearly the over-all efficiency would be a maximum for $x=y=0$. For all substations embodying the principles of my invention it may be readily shown, however, that x and y are connected by the relation $xy=1$. Eliminating x from the above formula by means of this relation, the expression for the over-all efficiency becomes

$$\frac{y}{(1+y)^2} \quad (5)$$

In order to demonstrate the above statement, namely that $xy=1$, designate the elements or branches T, R, X and L by 1, 2, 3 and 4, respectively, and let 1 and 2 be conjugate and also 3 and 4 be conjugate. Further it will be assumed for an electromotive force in branch 4, equation (1) is satisfied while for an electromotive force in branch (1), equation (2) is satisfied. Let S_{11} denote the current produced in branch or ele-

ment 1 by a unit electromotive force in branch 1, S_{12} the current produced in branch 2 by a unit electromotive force in branch 1, etc. Then by the conjugacy of branches 1 and 2 and branches 3 and 4, it follows that

$$S_{12}=S_{34}=0.$$

Also by equation (1)

$$S_{44}^2 R_4 = S_{42}^2 R_2 + S_{41}^2 R_1 = \frac{1}{4R_4} \quad (1')$$

and by equation (2)

$$S_{11}^2 R_1 = S_{13}^2 R_3 + S_{14}^2 R_4 = \frac{1}{4R_1} \quad (2')$$

Now it is a fundamental principle which is deducible from elementary algebra, that $S_{41}=S_{14}$. That is, the current set up in branch 1 by a unit electromotive force in branch 4 is equal to the current set up in branch 4 by a unit electromotive force in branch 1. Multiplying equation (1') by R_4 and equation (2') by R_1 and subtracting it follows that:

$$S_{42}^2 R_2 R_4 = S_{13}^2 R_1 R_3 \quad (a)$$

Now in accordance with the notation adopted in this specification, the energy consumed in branch 3 is x times that consumed in branch 4 when an electromotive force acts in branch 1; therefore

$$S_{13}^2 R_3 = x S_{14}^2 R_4 \quad (b)$$

Also the energy consumed in branch 1 is y times that consumed in branch 2 when an electromotive force acts in branch 4; whence

$$S_{41}^2 R_1 = y S_{42}^2 R_2 \quad (c)$$

Multiplying (b) and (c)

$$S_{13}^2 R_1 R_3 = xy S_{24}^2 R_2 R_4 \quad (d)$$

From (a) and (d) it follows at once that $xy=1$.

Obviously the expression given by formula (5) is a maximum when $y=1$. This means that for a given amount of telephonic energy developed in the transmitter at the transmitting substation a maximum amount is usefully delivered to the receiver at the receiving substation connected by the line, when $y=1$. Since the maximum amount of energy in the receiver is the prime desideratum of telephony, it would appear that the substation should be designed to make $y=1$. Another consideration, however, modifies this conclusion somewhat, namely, the effect of line noise. Since the line noise originates in the line the amount delivered to the receiver is proportional to

$$\frac{1}{1+y}$$

(see equation 4) while the amount of energy

delivered from the transmitter of the communicating station is proportional to

$$\frac{y}{(1+y)^2}$$

(see equation 5). The ratio of the latter to the former is

$$\frac{y}{1+y}$$

and this increases as y increases beyond unity. It will be clear, then, that if y is made greater than unity the substation discriminates against line noise as compared with the signals it is desired to receive. The amount of discrimination desired depends of course on the amount of line noise present. For conditions occurring in practice I have found by experiment that a desirable value for y is 1.4. With this value of y the over-all efficiency is reduced 2.8% below the maximum for $y=1$, while the receiving efficiency alone is reduced 16.6%. It is thus seen that a good degree of discrimination against line noise is obtained with a small loss in over-all efficiency.

The above consideration as to over-all efficiency and discrimination against line noise may be formulated as

$$R_1 I_1^2 = y R_2 I_2^2 \quad (6)$$

for an electromotive force inserted in the line. In this equation y is to have a value lying between 1 and 1.5 preferably.

Proceeding now to a description of the specific circuits, in Fig. 1 a telephone line L is shown as connected to a substation comprising a transmitter T, a receiver R, an auxiliary resistance X, and a transformer having four windings N_1 , N_2 , N_3 and N_4 . Said windings are on the same magnetic circuit and the transformer is preferably designed to have very small leakage. The individual windings should for the best operation have high self impedances and low resistances. Terminals 5, 6, 7 and 8 of line, transmitter, receiver and auxiliary resistance are connected together by conductor 9 so that said elements have in effect a common terminal. Windings N_4 , N_1 , N_2 and N_3 are connected in series with line, transmitter, receiver and auxiliary resistance respectively. Terminals 10 and 11 of windings N_4 and N_1 , respectively, are connected together by conductor 12 while terminals 13 and 14 of windings N_2 and N_3 are connected together by conductor 15. Conductors 12 and 15 are connected by condenser 16. The function of condenser 16 is to confine the direct-current battery supply current, transmitted to the substation over line 1, to the transmitter and to exclude it from the receiver and auxiliary resistance. Said condenser should therefore

be of relatively large capacity so as to have negligible impedance at telephonic frequency. What impedance it presents at telephonic frequencies is largely neutralized by the unavoidable magnetic leakage of the transformer so that the effect of said condenser will be ignored as regards the true telephonic currents as distinguished from the direct battery supply current.

Referring to Fig. 2 which is a diagram illustrating the operation of transmitting in which condenser 16 is omitted for simplicity, arrows indicate the relative direction of telephonic current flow through the various branches and circuits. The direct battery supply current is not indicated, said current merely serving to energize the transmitter so that actuations of said transmitter cause it to function as a source of telephonic energy. In said figure elements in which there is no flow of current corresponding to actuation of the transmitter are indicated in dotted lines. Referring to Fig. 2, the operation of transmitting will now be described. Actuation of the transmitter T sets up a flow of alternating current in said transmitter. The current flowing in the transmitter, denoted by I_1 , divides at terminal 11, a part I_4 flowing out over the line, said current being the usefully transmitted current, while a part I_3 flows through the auxiliary resistance and is wasted therein. Since when the substation is proportioned in accordance with the rules of design hereinafter set forth, the substation is free from side tone, no telephonic current flows in receiver R during transmission, and said element is indicated therefore in dotted lines. This condition is only attained when the relative number of turns of windings N_1 , N_2 , N_3 and N_4 are properly proportioned with reference to the impedances of line L and auxiliary resistance X. When they are so properly proportioned the induced voltage in winding N_2 just balances the potential difference between terminals 7 and 13 and no current flows in said branch.

The proportioning of the component elements of the substation of Fig. 1 in order to satisfy the requirement that the transmitter and receiver shall be conjugate, will now be deduced.

In the derivation of the succeeding formulae certain simplifying assumptions will be made. It will be assumed that the resistances of the transformer windings and the reactance of the condenser are negligibly small, that there is no magnetic leakage between the transformer windings and that the self-inductances of said windings are very large compared with the impedances of any of the other component elements of the substation and the line impedance. Ex-

perience has shown that these simplifying assumptions are justified and that the assumed conditions may be closely realized in practice by careful design. The impedances of line, transmitter, receiver and auxiliary resistance will be denoted by R_4 , R_1 , R_2 and R_3 respectively and the currents flowing in said elements by I_4 , I_1 , I_2 and I_3 respectively. The number of turns in coils N_1 , N_2 , N_3 and N_4 will be denoted by n_1 , n_2 , n_3 and n_4 respectively. Referring now to Fig. 2, it will be clear that $I_2=0$ and $I_1=I_3+I_4$. Further if the transformer coils have very high self impedance, the magnetizing current is negligibly small and consequently

$$n_1 I_1 = n_3 I_3 + n_4 I_4. \quad 80$$

Consequently, as regards transmission

$$(n_1 - n_3) I_3 = (n_4 - n_1) I_4$$

and

$$I_3 = I_1 \left(\frac{n_1 - n_4}{n_3 - n_4} \right) \quad (7) \quad 85$$

$$I_4 = I_1 \left(\frac{n_1 - n_3}{n_4 - n_3} \right) \quad 90$$

Now letting V denote the potential difference between terminals 11 and 6, it is clear that the same potential difference exists between terminals 10 and 5, 13 and 7, and 14 and 8. The voltages induced in the four coils are clearly proportional to the relative number of turns of the coils; thus if K denotes the voltage induced per turn the voltages induced in coils N_1 , N_2 , N_3 and N_4 are clearly Kn_1 , Kn_2 , Kn_3 and Kn_4 respectively. It will then be evident that, since the voltage impressed between two terminals is equal to the impedance drop between said terminals,

$$\begin{aligned} V &= Kn_4 + R_4 I_4 \\ V &= Kn_3 + R_3 I_3 \\ V &= Kn_2 \end{aligned} \quad 105$$

Eliminating V

$$\begin{aligned} K(n_2 - n_4) &= R_4 I_4 \\ K(n_2 - n_3) &= R_3 I_3 \end{aligned} \quad 110$$

Eliminating K

$$\frac{R_3}{R_4} = \left(\frac{n_2 - n_3}{n_2 - n_4} \right) \frac{I_4}{I_3} \quad 115$$

But as shown above

$$\frac{I_4}{I_3} = \frac{n_1 - n_3}{n_4 - n_1} \quad 120$$

whence

$$\begin{aligned} \frac{R_3}{R_4} &= \frac{(n_2 - n_3)(n_1 - n_3)}{(n_2 - n_4)(n_4 - n_1)} \\ &= - \frac{(n_3 - n_2)(n_3 - n_1)}{(n_4 - n_2)(n_4 - n_1)} \quad (8) \end{aligned} \quad 125$$

Equation (8) expresses the relations which must obtain among the component elements in order that no current shall flow through the receiver in consequence of the
5 actuation of the transmitter.

Referring now to Fig. 3 which is a diagram illustrating the operation of reception of signals over line L from a distant station, current I_4 flowing over line L enters
10 the substation through winding N_4 . This current divides at terminal 11, a part I_1 , flowing through transmitter T, and the remainder I_2 flowing through receiver R. It is the latter current which constitutes the
15 usefully received current. No current flows in auxiliary resistance X when the component elements are properly proportioned as hereinafter set forth. This is due to the fact that the voltage induced in winding N_3
20 just balances the voltage impressed between terminals 5 and 10.

The proper proportioning for conjugacy of line and auxiliary resistance will now be deduced. Referring to Fig. 3 and employing the same notation as that used in deriving equation (8), it will be clear that
25 $I_4 = I_1 + I_2$ and that when the magnetizing current is negligible,

$$30 \quad n_4 I_4 = n_1 I_1 + n_2 I_2$$

It therefore follows that, as regards reception,

$$(n_1 - n_4) I_1 + (n_2 - n_4) I_2 = 0$$

and
35

$$\begin{aligned} I_1 &= I_4 \left(\frac{n_2 - n_4}{n_2 - n_1} \right) \\ I_2 &= I_4 \left(\frac{n_1 - n_4}{n_1 - n_2} \right) \end{aligned} \quad (9)$$

40 Further if V denotes the potential difference between terminals 10 and 5 and K the induced voltage drops per turn of each

$$\begin{aligned} 45 \quad V &= K n_1 + I_1 R_1 \\ V &= K n_2 + I_2 R_2 \\ V &= K n_3 \end{aligned}$$

Solving the last three equations and eliminating V and K

$$50 \quad \frac{R_2}{R_1} = \frac{I_1 (n_3 - n_2)}{I_2 (n_3 - n_1)}$$

Eliminating $\frac{I_1}{I_2}$ by equation (9) it follows
55 that

$$\frac{R_2}{R_1} = - \frac{(n_2 - n_4)(n_2 - n_3)}{(n_1 - n_4)(n_1 - n_3)} \quad (10)$$

This is the formulation of the relations
60 which must obtain among the component elements in order that line and auxiliary resistance shall be conjugate.

The conditions necessary to the satisfaction of the remaining fundamental requirements of the ideal substation, will now be
65 formulated for the substation of Fig. 1. Considering requirement (4) which is formulated in equation (1), it is evident that this requirement may be written as:

$$70 \quad R_4 = R_1 \left(\frac{I_1}{I_4} \right)^2 + R_2 \left(\frac{I_2}{I_4} \right)^2$$

whence by equation (9)

$$75 \quad R_4 = R_1 \left(\frac{n_2 - n_4}{n_2 - n_1} \right)^2 + R_2 \left(\frac{n_1 - n_4}{n_1 - n_2} \right)^2 \quad (11)$$

Considering next requirement (4) as formulated by equation (2) and eliminating the currents therefrom by aid of equations (7),
80

$$R_1 = R_3 \left(\frac{n_1 - n_4}{n_3 - n_4} \right)^2 + R_4 \left(\frac{n_1 - n_3}{n_4 - n_3} \right)^2 \quad (12)$$

Finally by aid of equations (7) the fifth
85 fundamental requirement as formulated in equation (6) is expressible as:

$$90 \quad R_1 = y R_2 \left(\frac{n_1 - n_4}{n_2 - n_4} \right)^2 \quad (13)$$

Equations 8, 10, 11, 12 and 13 formulate all the conditions necessary to the satisfaction of the fundamental substation requirements. It remains to put these equations
95 in more convenient form for use as design formulæ. In particular it is desirable to express the constants of the substation in terms of R_1 , R_4 and y since these quantities are generally specified in practice. The combination of equations (10) and (11) gives by
100 the elimination of R_2 ,

$$\frac{R_1}{R_4} = \frac{(n_1 - n_2)(n_1 - n_3)}{(n_4 - n_2)(n_4 - n_3)} \quad (14)$$

The same result follows from the elimination of R_3 from equations (8) and (12).
105

Equations (10), (13) and (14) reduce to

$$\begin{aligned} \frac{n_4 - n_3}{n_1 - n_3} &= \pm \sqrt{\frac{R_4}{R_1} \left(\frac{1+y}{y} \right)} \\ \frac{n_3 - n_4}{n_2 - n_1} &= \pm \sqrt{\frac{R_4}{R_1} \left(\frac{y}{1+y} \right)} \end{aligned} \quad (15)$$

In these last two equations the right hand
115 side is double valued indicating that there are two substations corresponding to two modes of winding the transformer coils. Practical considerations render preferable that mode of winding corresponding to the
120 solution with negative signs. If the

$$\sqrt{\frac{R_4}{R_1}}$$

is denoted by A and

$$\sqrt{\frac{1+y}{y}}$$

by h , the results of equations 8, 10, 11, 12, 15 are expressed in the following design formulæ:

$$\begin{aligned} \frac{n_3 - n_4}{n_3 - n_1} &= -Ah \\ \frac{n_2 - n_4}{n_2 - n_1} &= -A/h \\ \frac{n_1 - n_4}{n_3 - n_1} &= -(Ah + 1) \\ \frac{n_1 - n_4}{n_2 - n_1} &= -(A/h + 1) \\ R_3 &= R_4 \frac{1}{y(Ah + 1)^2} \\ R_2 &= R_4 \frac{1}{(1 + y)(A/h + 1)^2} \end{aligned} \quad (A)$$

The type of substation disclosed above and illustrated in the accompanying drawing is but one of a large number employing only one transformer and one auxiliary resistance and all of these are ideal in the sense that they satisfy the fundamental requirements for an ideal substation, as stated heretofore in this specification. It will be understood therefore, that my invention is not limited to the specific embodiments herein illustrated, but is broadly directed to providing a substation comprising a single transformer and only one auxiliary element, which is so proportioned with reference to the line with which it is to be coöperatively combined, that it is ideally efficient and substantially without side tone. Furthermore, I do not desire to limit the design of the substations herein disclosed and illustrated to the accompanying design formulæ. These formulæ are derived on the assumption that ideal transformers are employed and that the component elements have no reactance, assumptions which are only approximately justified in practice. When particularly high precision is desired I may, therefore, proportion the substation more precisely by taking into account the fact that the transformer impedances are finite, and that the line and the various substation elements may have in general some reactance. The accompanying formulæ, however, give quite satisfactory results, and the methods by which they are derived will enable one skilled in the art, to compute more precisely the substation constants when desired.

It will be understood that in the appended claims, where certain elements are said to

be conjugate, or certain impedance relations are said to exist, since in practice these conditions can, in general, only be approximated, these expressions will be satisfied by structures substantially conforming thereto, especially where some compromise with regard to the rigid requirements is necessary in order to discriminate against line noise. It will be further understood that while I have specifically illustrated and described my invention as embodied in a telephone substation it is capable of many and varied embodiments which render it applicable in other kinds of signaling and consequently my invention is not to be limited to the particular form and use herein disclosed.

What is claimed is:

1. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver and an auxiliary resistance, a terminal common to said line and three substation elements, a four coil transformer, each coil being individually in series with one of said four elements and a terminal common to said four coils.

2. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver and an auxiliary resistance, a terminal common to said line and three substation elements, a four coil transformer, each coil being individually in series with one of said four elements and a terminal common to said four coils, the component elements of said substation being so proportioned that said transmitter and receiver are conjugate.

3. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver and an auxiliary resistance, a terminal common to said line and three substation elements, a four coil transformer, each coil being individually in series with one of said four elements and a terminal common to said four coils, the component elements of said substation being so proportioned that said line and auxiliary resistance are conjugate.

4. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver and an auxiliary resistance, a terminal common to said line and three substation elements, a four coil transformer, each coil being individually in series with one of said four elements and a terminal common to said four coils, the component elements of said substation being so proportioned that the impedance of the substation, as seen from the line is equal to that of the line.

5. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver and an auxiliary

resistance, a terminal common to said line and three substation elements, a four coil transformer, each coil being individually in series with one of said four elements and
 5 a terminal common to said four coils, the component elements of said substation being so proportioned that the impedance of the combination consisting of line, receiver and
 10 auxiliary resistance, as seen from the transmitter, is equal to that of the transmitter.

6. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver and an auxiliary resistance, a terminal common to said line
 15 and three substation elements, a four coil transformer, each coil being individually in series with one of said four elements and a terminal common to said four coils, the component elements of said substation being so
 20 proportioned that said transmitter and receiver are conjugate, said line and auxiliary resistance are conjugate, the impedance of the substation, as seen from the line is equal to that of the line, the impedance of the
 25 combination consisting of line, receiver and auxiliary resistance, as seen from the transmitter, is equal to that of the transmitter.

7. In a two-way signaling system, an induction coil having four windings, a circuit for the transmission and reception of
 30 signals including one winding of said induction coil, a transmitting circuit proper comprising a transmitting apparatus and a second winding of said induction coil, a receiving circuit proper comprising a receiving apparatus and a third winding of
 35 said induction coil, and a balancing circuit including the fourth winding of said induction coil, all of said circuits having a common terminal, and said elements being so proportioned and related that the impedance of the combination comprising said
 40 first named circuit, said receiving circuit proper, said balancing circuit and said transformer, as seen from said transmitting circuit proper, is equal to the impedance of said transmitting circuit proper.

8. In a two-way signaling system, an induction coil having four windings, a circuit for the transmission and reception of
 50 signals including one winding of said induction coil, a transmitting circuit proper comprising a transmitting apparatus and a second winding of said induction coil, a receiving circuit proper comprising a receiving apparatus and a third winding of
 5 said induction coil, and a balancing circuit including the fourth winding of said induction coil, all of said circuits having a common terminal, and said elements being so
 60 proportioned and related that said receiving

circuit and said transmitting circuit proper are conjugate.

9. In a two-way signaling system, an induction coil having four windings, a circuit for the transmission and reception of
 65 signals including one winding of said induction coil, a transmitting circuit proper comprising a transmitting apparatus and a second winding of said induction coil, a receiving circuit proper comprising a receiving apparatus and a third winding of said
 70 induction coil, and a balancing circuit including the fourth winding of said induction coil, all of said circuits having a common terminal, and said elements being so proportioned and related that said balancing circuit and said first named circuit are conjugate.
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10. In a two-way signaling system, an induction coil having four windings, a circuit for the transmission and reception of
 80 signals including one winding of said induction coil, a transmitting circuit proper comprising a transmitting apparatus and a second winding of said induction coil, a receiving circuit proper comprising a receiving apparatus and a third winding of said
 85 induction coil, and a balancing circuit including the fourth winding of said induction coil, all of said circuits having a common terminal, and said elements being so proportioned and related that the impedance of the combination, comprising said transmitting circuit proper, said receiving circuit
 90 proper, said balancing circuit and said transformer, as seen from said first named circuit, is equal to the impedance of said first named circuit.
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11. In a two-way signaling system, an induction coil having four windings, a circuit for the transmission and reception of
 100 signals including one winding of said induction coil, a transmitting circuit proper comprising a transmitting apparatus and a second winding of said induction coil, a receiving circuit proper comprising a receiving apparatus and a third winding of said
 105 induction coil, and a balancing circuit including the fourth winding of said induction coil, all of said circuits having a common terminal, and said elements being so proportioned and related that said transmitting circuit and said receiving circuit are conjugate; said first named circuit and said
 110 balancing circuit are conjugate; the impedance of the combination, comprising said first named circuit, said receiving circuit proper, said balancing circuit and said transformer, as seen from said transmitting
 115 circuit is equal to the impedance of said transmitting circuit; and the impedance of
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the combination, comprising said transmitting circuit proper, said receiving circuit proper, said balancing circuit and said transformer, as seen from said first named circuit is equal to the impedance of said first named circuit.

In testimony whereof, I have signed my

name to this specification in the presence of two subscribing witnesses, this 10th day of March 1917.

GEORGE A. CAMPBELL.

Witnesses:

KENNETH L. WILKINSON,
ALFRED KAUFMANN.