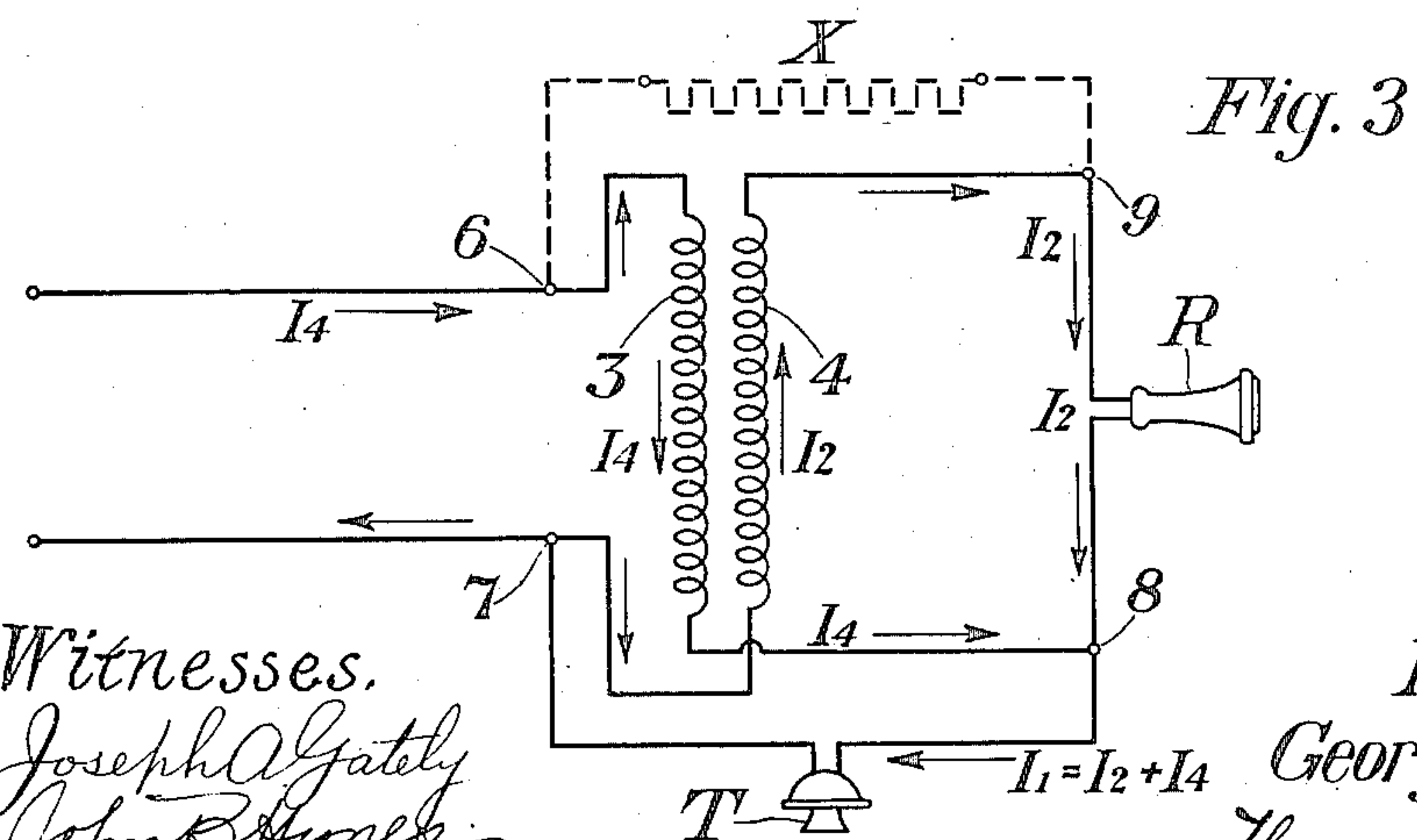
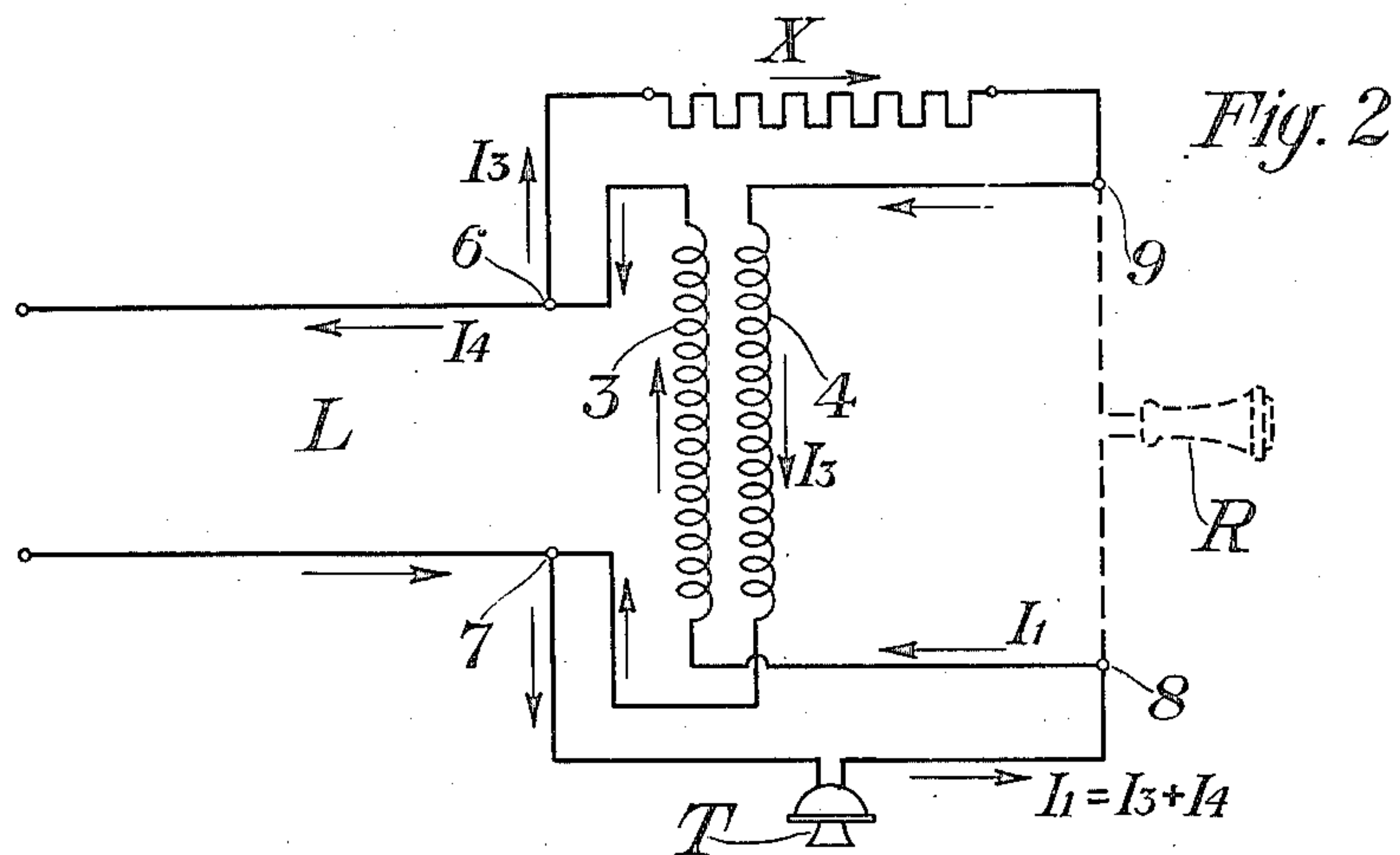
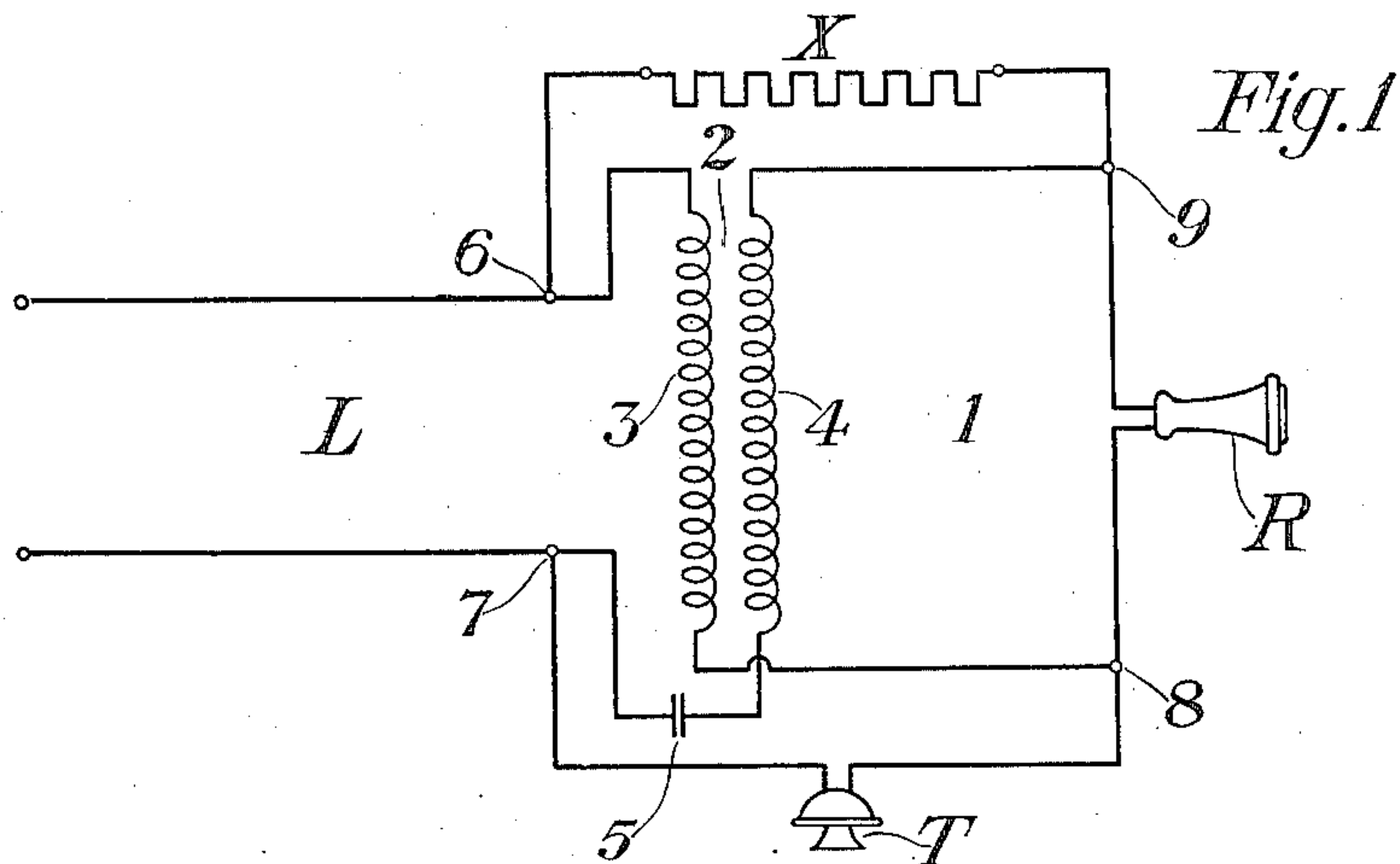


G. A. CAMPBELL.
 SIGNALING CIRCUIT.
 APPLICATION FILED SEPT. 9, 1916.

1,254,474.

Patented Jan. 22, 1918.



Witnesses.

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UNITED STATES PATENT OFFICE.

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SIGNALING-CIRCUIT.

1,254,474.

Specification of Letters Patent.

Patented Jan. 22, 1918.

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To all whom it may concern:

Be it known that I, GEORGE A. CAMPBELL, residing at 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 requirement 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.

My invention is best understood by reference to the accompanying drawings in which Figure 1 is a diagram illustrating the specific embodiment of my invention; Fig. 2 is a simplified diagram illustrating the operation of the substation of Fig. 1 when transmitting telephonic signals, and Fig. 3 is a simplified diagram illustrating the operation of the substation of Fig. 1 when receiving telephonic signals.

Referring to Fig. 1, a telephone line L terminates in a substation 1, said substation comprising a transmitter T, a receiver R, an auxiliary resistance X, preferably non-inductive, and a transformer 2 having two windings 3 and 4. Said transformer is preferably of very high impedance and very closely coupled, conditions, it is well known, which may be very approximately satisfied in telephone transformers. It is also desirable that the resistances of said windings be negligibly small. When direct current is supplied to transmitter T from line L, a condenser 5 is preferably inserted in series with winding 4 in order to confine the direct current to the transmitter. Said condenser may be so large as to offer very small reactance to currents of telephonic frequency, or its capacity reactance may be substantially neutralized by the inductive reactance of trans-

former winding 4. In either case the capacity effect may be rendered negligible as regards telephonic currents.

As shown in the drawing, line L, transmitter T, receiver R and auxiliary resistance X are in serial connection. One terminal of auxiliary resistance X is directly connected to terminal 6 of line L, the other terminal of resistance X being connected to terminal 7 of line L, through winding 4. One terminal of transmitter T is directly connected to terminal 7 of line L while the other terminal of transmitter T is connected to terminal 6 through winding 3.

The operation of the substation illustrated in Fig. 1 will now be described. Fig. 2 is a simplified diagram of the operation when transmitting while Fig. 3 is a similar diagram illustrating the operation of receiving. In said diagrams the arrows indicate the relative direction of flow of telephonic current in the several elements. Elements in which no telephonic current flows are drawn in broken line. In said diagrams, as well as in the equations and formulæ hereinafter given, the subscripts 1, 2, 3 and 4 refer to transmitter, receiver, auxiliary resistance and line, respectively: thus I_1 , I_2 , I_3 and I_4 denote the currents flowing in the transmitter, receiver, auxiliary resistance and line, respectively. In interpreting said diagrams it should be understood that the direct battery supply current which is preferably supplied over the line from a central source of energy is not indicated since said current merely serves to energize the transmitter. Further it will be understood that the flow of telephonic current as indicated by the arrows is conditioned by the proper proportioning of the component elements of the substation in accordance with the design formulæ hereinafter derived and set forth.

Referring to Fig. 2 actuation of the transmitter T sets up variations in the resistance thereof which are equivalent in their action to an alternating electromotive force in said transmitter. An alternating current of telephonic frequency is therefore superposed on the direct current (not indicated), the path and relative direction of said alternating current being indicated by arrows. Since the substation is without side tone the total alternating current in the transmitter, denoted by I_1 , flows from terminal 8 through winding 3 to line terminal 6. Here the current divides, a portion I_4 flowing out over the line, and a portion I_3 , flowing to terminal 9 through resistance X. From terminal 9 the current I_3 flows down through winding 4 to terminal 7 where it adds to the returning line current I_4 and thence flows back through the transmitter. It will be clear that the transmitter current I_1 is equal to the sum of the line current I_4 and the current I_3 which flows through the

resistance X. Said current I_3 is wasted in the resistance X, but, as herein shown, such waste is unavoidable in two-way communication. If the auxiliary resistance were omitted, an equivalent waste of energy would be necessitated in the receiver with the further disadvantage of side tone. It will be observed that no current flows through receiver R and consequently terminals 8 and 9 must be at the same potential as regards the transmission current. This is made possible by a proper proportioning of the relative impedances of line and auxiliary resistance with reference to the relative number of turns on windings 3 and 4. Since a greater current flows through winding 3 than through winding 4 the number of turns in winding 4 must be greater than that of winding 3. In fact, if the transformer is highly efficient the currents in windings 3 and 4 must be inversely proportional to their respective number of turns. If therefore a current is required in winding 4 equal to the current flowing through resistance X, no current flows in receiver R and the terminals 8 and 9 are necessarily at the same potential.

Referring to Fig. 3, which is a simplified diagram illustrating the operation of receiving and relative directions of flow of telephonic current, current flows in over line L to terminal 6 and thence through 3 to terminal 8. Said current will be denoted by I_4 . This current flowing through winding 3 induces a current I_2 in the opposite direction in winding 4, the relative values of currents I_4 and I_2 being inversely proportional to the relative number of turns on windings 3 and 4. Current I_2 flows down through receiver R to terminal 8 where it unites with I_4 and thence the combined currents I_2 and I_4 , that is current I_1 flows through transmitter T to terminal 7. At terminal 7 the current divides, the portion I_4 flowing back over the line while the portion I_2 flows through winding 4. No current flows through auxiliary resistance X when the elements of the substation are properly proportioned; that is when the relative resistances of transmitter and receiver are properly proportioned with reference to the transformer ratio.

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 formulæ included in this specification the subscripts 1, 2, 3 and 4 will as hereinbefore stated, 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 6 and 7. 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 substation 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 sub-

station whose transmitter and receiver resistances are R_1 and R_2 respectively, and let 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

$$\frac{E_4}{2R_4} = I_4 \quad (10)$$

The total energy consumed may then be expressed by the formula

$$I_4^2 R_4 + I_1^2 R_1 + I_2^2 R_2 = I_4 E_4 = \frac{E_4^2}{2R_4} \quad (15)$$

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:

$$R_4(I_4)^2 = (I_2)^2 R_2 + (I_1)^2 R_1 = \frac{(E_4)^2}{4R_4} \quad (1) \quad (25)$$

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:

$$(I_1)^2 R_1 = (I_4)^2 R_4 + (I_3)^2 R_3 = \frac{(E_1)^2}{4R_1} \quad (2) \quad (40)$$

Equation (2) is the analogue of equation (1), and may be interpreted as follows by reference to Fig. 1. Let the conductor which connects transmitter T to terminal 7 be opened and let the impedance be measured across terminals 7 and 8. 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), $1/2W_0$ 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

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

so that the transmitting efficiency is measured by

$$\frac{1}{(1+x)} \quad (3) \quad (75)$$

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

$$\frac{1}{(1+y)} \quad (4) \quad (85)$$

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 formulae (3) and (4):

$$\left(\frac{1}{1+x}\right) \left(\frac{1}{1+y}\right) \quad (95)$$

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

$$\frac{y}{(1+y)^2} \quad (5) \quad (105)$$

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 element 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)

$$(S_{44})^2 R_4 = (S_{42})^2 R_2 + (S_{41})^2 R_1 = \frac{1}{4R_4} \quad (1') \quad (125)$$

and by equation (2)

$$(S_{11})^2 R_1 = (S_{13})^2 R_3 + (S_{14})^2 R_4 = \frac{1}{4R_1} \quad (2') \quad (130)$$

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

$$(S_{14})^2 R_1 = y (S_{24})^2 R_2 \quad (c)$$

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%. However, under certain conditions it may be desirable to substantially increase the value of y beyond unity. It will be therefore understood that, when the value of y is referred to as approximately unity, its actual value may considerably exceed the theoretical optimum.

The above considerations 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.

The proportioning of the arrangement of Fig. 1, in order to satisfy the fundamental requirements, will now be given. The condition that receiver R shall be conjugate with respect to transmitter T is satisfied if no current flows in said receiver in consequence of an electromotive force of telephonic frequency inserted in series with said transmitter between points 7 and 8. If receiver R is to be conjugate to said transmitter then points 8 and 9 must be at the same potential as regards the effect of said electromotive force. Further, if windings 3 and 4 have very high self impedances, the currents flowing in said windings must be inversely proportional to their number of turns, n_1 and n_2 respectively. Bearing these considerations in mind, the condition of conjugacy of transmitter and receiver is derivable as follows:

Assume an electromotive force in the transmitter branch, and let I_1 , I_2 , I_3 and I_4 denote the currents flowing in transmitter, receiver, auxiliary resistance and line respectively. Then if transmitter and receiver are conjugate

$$I_2 = 0$$

and

$$I_1 = I_4 + I_3$$

Also if the self impedance of the transmitter is very high

$$n_1 I_1 = n_2 I_3$$

whence

$$I_3 = \frac{n_1}{n_2} I_1$$

$$I_4 = \frac{n_2 - n_1}{n_2} I_1$$

If K denotes the voltage drop per turn in the transformer windings, V the potential difference across the terminals of the transmitter, and R_1 , R_2 , R_3 and R_4 the resistances of transmitter, receiver, auxiliary

resistance and line respectively, it follows that:

$$Kn_1 + I_3 R_3 = 0$$

$$-Kn_2 = V$$

$$Kn_1 + I_4 R_4 = V$$

These equations at once reduce to the following relation which must be satisfied for conjugacy of transmitter and receiver:

$$R_3 = \frac{n_2 - n_1}{n_2 + n_1} R_4 \quad (7)$$

where R_3 and R_4 are the resistances of auxiliary resistance and telephone line respectively.

Similarly it may be shown that the requirement of conjugacy of auxiliary resistance with respect to line is that

$$R_2 = R_1 \frac{(n_2 + n_1)}{n_2 - n_1} \quad (8)$$

where R_2 and R_1 are the resistances of receiver and transmitter respectively.

Since, when transmitting, no telephonic current exists in the receiver in consequence of the relation expressed by equation (7), it follows that the currents I_1 , I_4 , I_3 flowing in transmitter, line and auxiliary resistance respectively, are proportional to n_2 , $n_2 - n_1$ and n_1 . Hence the condition of maximum output of transmitter, as formulated by equation (2), is satisfied by the arrangement of Fig. 1, if

$$R_1 (n_2)^2 = R_3 (n_1)^2 + R_4 (n_2 - n_1)^2$$

or

$$R_1 = R_3 \left(\frac{n_1}{n_2} \right)^2 + R_4 \left(\frac{n_2 - n_1}{n_2} \right)^2 \quad (9)$$

Similarly the condition as formulated by equation (1) is satisfied if

$$R_4 = \left(\frac{n_1}{n_2} \right)^2 R_2 + \left(\frac{n_2 + n_1}{n_2} \right)^2 R_1 \quad (10)$$

Equation (10) follows from equations (7), (8) and (9) and does not therefore constitute an independent requirement.

Finally the general relation as formulated by equation (6) is satisfied if

$$R_2 = \frac{1}{y} \left(\frac{n_2 + n_1}{n_1} \right)^2 R_1 \quad (11)$$

Denoting the transformer ratio $\frac{n_2}{n_1}$ by r ,

equations (8) and (11) give

$$y = (r + 1)(r - 1)$$

$$r = \sqrt{1 + y} \quad (12)$$

If the line impedance R_4 and the energy division y are given, then in consequence of equations 7—12, the substation satisfies all the fundamental requirements if the con-

stants thereof are determined by the following design formulæ:

$$\left. \begin{aligned} r &= \sqrt{y + 1} \\ R_2 &= R_4 \\ R_3 &= \frac{\sqrt{y + 1} - 1}{\sqrt{y + 1} + 1} R_4 \\ R_1 &= \frac{\sqrt{y + 1} - 1}{\sqrt{y + 1} + 1} R_4 \end{aligned} \right\} (A)$$

As a concrete example of the use of formulæ (A) let it be required to design the substation of Fig. 1 for maximum over-all efficiency, the line impedance being 600 ohms. Then $y = 1$ and $R_4 = 600$, and by design formulæ (A) we have $r = 1.414$; $R_2 = 600$ ohms; $R_3 = 103$ ohms; $R_1 = 103$ ohms.

If, instead of maximum over-all efficiency discrimination against line noise is specified, y should be taken as greater than unity, say, for example, 1.5. Then by formulæ (A) the values of the various quantities are: $r = 1.581$; $R_2 = 600$ ohms; $R_3 = 135$ ohms; $R_1 = 135$ ohms.

It will be evident from formulæ (A) that if the values of R_4 and y are specified, the remaining four values are uniquely determined. In general, the line impedance R_4 and energy division factor y are specified and the design formulæ are therefore written in the form most convenient in general.

The 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 react-

ance. 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 systems and consequently my invention is not to be limited to the particular form and use herein disclosed.

What is claimed is:

1. In combination with a telephone line, a substation, said substation comprising a transmitter, a receiver, an auxiliary resistance, and a transformer, and circuit connections therefor, said elements being so proportioned and connected that the transmitter and receiver are conjugate, the impedance of the substation, as seen from the line, is equal to the impedance of the line, and the impedance of the combination, comprising the line, receiver, auxiliary resistance and transformer, as seen from the transmitter, is equal to the impedance of the transmitter.

2. In combination with a telephone line, a substation, said substation comprising a transmitter, a receiver, an auxiliary resistance, and a transformer, the component elements of said substation being so proportioned and connected that the impedance of the substation, as seen from the line, is equal to that of the line.

3. In combination with a telephone line, a substation, said substation comprising a transmitter, a receiver, an auxiliary resistance, and a transformer, the component elements of said substation being so proportioned and connected that the impedance of the substation, as seen from the line, is equal to that of the line, and the transmitter and receiver are conjugate.

4. In combination with a telephone line, a substation, said substation comprising a transmitter, a receiver, an auxiliary resistance, and a transformer, the component elements of said substation being so proportioned and connected that the impedance of the combination, comprising the line, receiver, auxiliary resistance and transformer,

as seen from the transmitter, is equal to that of the transmitter.

5. In combination with a telephone line, a substation, said substation comprising a transmitter, a receiver, an auxiliary resistance, and a transformer, the component elements of said substation being so proportioned and connected that the impedance of the combination, comprising the line, receiver, auxiliary resistance and transformer, as seen from the transmitter, is equal to that of the transmitter and the transmitter and receiver are conjugate.

6. In combination with a telephone line, a substation, said substation comprising a transmitter, a receiver, an auxiliary resistance, and a transformer, the component elements of said substation being so proportioned and connected that the impedance of the substation, as seen from the line, is equal to that of the line, and that of the combination, comprising the line, receiver, auxiliary resistance and transformer, as seen from the transmitter, is equal to that of the transmitter.

7. In combination with a telephone line, a substation, said substation comprising a transmitter, a receiver, an auxiliary resistance, and a transformer, the component elements of said substation being so proportioned and connected that the impedance of the substation, as seen from the line, is equal to that of the line, and that of the combination, comprising the line, receiver, auxiliary resistance and transformer, as seen from the transmitter, is equal to that of the transmitter and the line and auxiliary resistance are conjugate.

8. A substation circuit comprising a transmitter, a receiver and a resistance, connected in series, a transformer winding in shunt with said transmitter and receiver, and a second transformer winding in shunt with said receiver and resistance.

9. In a telephone system a line, and a common battery substation, said substation comprising a transmitter, a receiver, a resistance, and a transformer, and such circuit connections that the transmitter and receiver are conjugate.

10. In a telephone system a line, and a common battery substation, said substation comprising a transmitter, a receiver, a resistance, and a transformer and such circuit connections that the transmitter will deliver maximum telephonic energy without the absorption of transmission energy by the receiver.

11. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver, an auxiliary resistance and a transformer having a plurality of windings, the component elements of said substation being so proportioned with refer-

ence to the electrical characteristics of said line and being so related that said transmitter delivers the maximum amount of energy when transmitting, and said substation absorbs the maximum amount of energy when receiving, and is without side tone.

12. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver, an auxiliary resistance and a transformer having a plurality of windings, the component elements of said substation being so proportioned with reference to the electrical characteristics of said line and being so related that the impedance of said substation, as seen from said line, is equal to the impedance of said line, and the impedance of the combination, comprising the line, receiver, auxiliary resistance and transformer, as seen from said transmitter, is equal to the impedance of said transmitter, said transmitter and receiver are conjugate and said line and auxiliary resistance are conjugate.

13. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver, an auxiliary resistance and a transformer having a plurality of windings, said component elements of said substation being so proportioned with reference to the characteristic impedance of said line and so related to each other and to said line that said auxiliary resistance is conjugate with respect to said line, said receiver is conjugate to said transmitter, the impedance of said substation, as seen from said line, is equal to the characteristic impedance of said line, and the impedance of the combination, comprising the line, receiver, auxiliary resistance and transformer, as seen from the terminals of said transmitter, is equal to the impedance of said transmitter.

14. The combination of a substation and a telephone line, said substation comprising a transmitter, a receiver, an auxiliary resistance and a transformer having two windings, said line, transmitter receiver and auxiliary resistance being serially connected, and said transformer windings connecting the terminals of said receiver to the terminals of said line, the impedances of said transmitter, receiver and auxiliary resistance and the relative number of turns of said windings of said transformer being so proportioned with reference to the characteristic impedance of said telephone line that said auxiliary resistance is conjugate with respect to said line, said receiver is conjugate with respect to said transmitter, the impedance of said substation as seen from said line, is equal to the impedance of said line, and the impedance of the combination, comprising the line, receiver, auxiliary resistance and transformer, as seen from said transmitter is equal to the impedance of said transmitter.

15. The combination of substation and a telephone line, said substation comprising a transmitter, a receiver, an auxiliary resistance and a two-winding transformer, said transmitter connecting one terminal of said line to one terminal of said receiver, said auxiliary resistance connecting the other terminal of said line to the other terminal of said receiver, one of said transformer windings being connected between the common terminal of said line and auxiliary resistance and the common terminal of said transmitter and receiver, and the other of said transformer windings being connected between the common terminals of line and transmitter and of receiver and auxiliary resistance.

16. In a two-way signaling system, a circuit for the transmission and reception of signals, a transmitting circuit proper, a receiving circuit proper, a balancing circuit, and a transformer with a plurality of windings, said elements being so proportioned and related that 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 circuit proper, is equal to the impedance of said transmitting circuit proper.

17. In a two-way signaling system, a circuit for the transmission and reception of signals, a transmitting circuit proper, a receiving circuit proper, a balancing circuit, and a transformer with a plurality of windings, said elements being so proportioned and related that said receiving circuit and said transmitting circuit proper are conjugate.

18. In a two-way signaling system, a circuit for the transmission and reception of signals, a transmitting circuit proper, a receiving circuit proper, a balancing circuit, and a transformer with a plurality of windings, said elements being so proportioned and related that said balancing circuit and said first named circuit are conjugate.

19. In a two-way signaling system, a circuit for the transmission and reception of signals, a transmitting circuit proper, a receiving circuit proper, a balancing circuit, and a transformer with a plurality of windings, said elements being so proportioned and related that the impedance of 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.

20. In a two-way signaling system, a circuit for the transmission and reception of signals, a transmitting circuit proper, a receiving circuit proper, a balancing circuit, and a transformer with a plurality of windings, said elements being so proportioned and re-

lated that said transmitting circuit and said receiving circuit are conjugate; said first named circuit and said 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 circuit is equal to the impedance of said transmitting circuit; and the impedance of 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.

21. In a signaling system, a circuit for the transmission and reception of energy, a transmitting apparatus, a receiving apparatus, an auxiliary circuit provided with an auxiliary resistance, and a transformer comprising a plurality of windings, the transmitting apparatus, receiving apparatus, said first named circuit and auxiliary circuit, being interconnected by the transformer windings, and so proportioned that said receiving apparatus and said transmitting apparatus are conjugate.

22. The combination of substation and a telephone line, said substation comprising a transmitter, a receiver, an auxiliary resistance and a two-winding transformer, said transmitter connecting one terminal of said line to one terminal of said receiver, said auxiliary resistance connecting the other terminal of said line to the other terminal of

said receiver, one of said transformer windings being connected between the common terminal of said line and auxiliary resistance and the common terminal of said transmitter and receiver, and the other of said transformer windings being connected between the common terminals of line and transmitter and of receiver and auxiliary resistance, the component elements of said substation having approximately the following values,

$$r = \sqrt{y+1}$$

$$R_2 = R_4$$

$$R_3 = \frac{\sqrt{y+1}-1}{\sqrt{y+1}+1} R_4$$

$$R_1 = \frac{\sqrt{y+1}-1}{\sqrt{y+1}+1} R_4$$

where R_1 , R_2 , R_3 and R_4 are the impedances of transmitter, receiver, auxiliary resistance and telephone line respectively, y is a factor having a value approximately unity and r is the ratio between the transformer windings.

In testimony whereof, I have signed my name to this specification in the presence of two subscribing witnesses, this first day of September 1916.

GEORGE A. CAMPBELL.

Witnesses:

JOHN R. CARSON,
C. C. ROSE.