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SIGNALING CIRCUIT.

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SIGNALING-CIRCUIT.

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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 cooperative 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 to 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 com-

munication 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 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 will now be fully understood by reference to the accompanying drawing in which:

Figures 1, 5 and 9 are schematic diagrams of three forms of substations in accordance with this invention, said diagrams being so arranged as to clearly indicate the equivalence of the different circuits. Figs. 2, 6 and 10 are circuit diagrams showing the arrangement of the several forms of substations in greater detail. Figs. 3, 7 and 11 are circuit diagrams indicating the relative direction of current flow in the several circuits shown in Figs. 2, 6 and 10, respectively, during transmission, the dotted lines indicating elements through which no current flows. Figs. 4, 8 and 12 are similar diagrams indicating the relative direction of current flow during reception.

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 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. 2, as follows: Let the substation be disconnected from the line and let the impedance of the substation be measured across terminals *a* and *d*. 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 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; 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

$$I_4^2R_4+I_1^2R_1+I_2^2R_2=I_4E_4=\frac{E_4^2}{2R_4}$$

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:

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

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

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

Equation (2) is the analogue of equation (1) and may be interpreted as follows by reference to Fig. 2: Let the transmitter be disconnected from the terminals b and c and let the impedance be measured across said terminals. 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

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

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 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)

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

and by equation (2)

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

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:

$$(S_{42})^2R_2R_4=(S_{13})^2R_1R_3 \quad (a)$$

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

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

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

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

Multiplying (b) and (c)

$$(S_{13})^2R_1R_3=xy(S_{24})^2R_2R_4 \quad (d)$$

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

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

(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 considerations as to over-all efficiency and discrimination against line noise may be formulated as

$$R_1(I_1)^2=yR_2(I_2)^2 \quad (6)$$

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, one form of my invention is illustrated in Fig. 2 in which L represents a telephone line terminating in a substation comprising a transmitter T, a receiver R, an auxiliary resistance X and a two winding induction coil, the windings of which are designated N_1 and N_2. The line L, resistance X and receiver R are connected to a common terminal d, the remaining terminals b and c of the resistance and receiver being inter-connected by the windings N_1 and N_2 of the induction coil, with the transmitter T connected in parallel therewith. The remaining terminal of the line is connected to the junction point a of the two windings of the induction coil. A condenser may be provided in series with the winding N_2, if desired, so that direct current from a distant source will flow over the line to terminal a and thence through the winding N_1 to terminal b. At terminal b the current divides, part flowing through the transmitter and re-

ceiver in series to terminal d, and part flowing in parallel therewith through the auxiliary resistance X to terminal d. From terminal d the current flows back over the line.

The operation during transmission is indicated in Fig. 3 in which the arrows represent the direction of current flow at any given instant. When the transmitter T is operated, variations in the current flow are produced, the effect being equivalent to applying a variable electromotive force to the transmitter. At a given instant a current I_1 flows from terminal b, through the transmitter and winding N_2, to terminal a, where the current divides and a current I_4 equal to I_3 flows over the line and through the auxiliary resistance X, to the terminal b, while a current I_1-I_4 flows in parallel therewith, through the winding N_1. Potentials are induced in the windings of the transformer of such value and direction that terminals c and d are brought to the same potential, so that no current flows through the receiver during transmission and consequently the substation is anti-sidetone.

The action during reception is indicated in Fig. 4 and is as follows: Upon the application of a receiving potential to the line terminals, since no current flows through the auxiliary resistance, the line and receiver are in a series circuit and a current I_2 equal to I_4 flows from terminal c, through the receiver and over the line L, to terminal a. A current I_1 flows in parallel therewith from terminal c, through the transmitter and the winding N_1, to terminal a, where the two currents merge and a current I_4+I_1 flows from terminal a, through the winding N_2 to terminal c. Potentials are induced in the transformer windings of such value and direction that terminals b and d are brought to the same potential, so that no current is wasted in the auxiliary resistance during reception.

The proportioning of the arrangement of Fig. 2, to satisfy the fundamental requirements of the substation of my invention, will now be given. In deriving the design formulæ, the resistances of the transformer windings will be ignored. It will be assumed further that there is no magnetic leakage between the transformer windings and that the self-impedances are very large compared with the impedances of any of the component elements of the substation or the impedance of the line. Experience has shown that these simplifying assumptions are justified and that the assumed conditions may be closely realized in practice by careful design.

To formulate the condition for conjugacy of transmitter T and receiver R, assume an electromotive force in the transmitter circuit and assume that the required condition of conjugacy is satisfied. In other words, assume that the terminals of the receiver are at points of equal potential with respect to an electromotive force applied to the transmitter. Let I_1, I_2, I_3 and I_4 denote the currents flowing in the transmitter, the receiver, auxiliary resistance and line, respectively, and R_1, R_2, R_3 and R_4 denote the resistances of the corresponding elements. The condition of conjugacy of the receiver, with respect to the transmitter, requires that no current flow through the receiver during transmission and hence $I_2=0$. It is also clear from Fig. 3 that $I_3=I_4$. Assuming that a potential is applied across terminals b and c, the potential drop through winding N_1 must equal the IR drop through the line and auxiliary resistance. Consequently, if n_1 denote the number of winding turns in coil N_1

$$Kn_1=(R_3+R_4)I_4$$

where K represents the drop per turn of the transformer windings. Furthermore, since terminals c and d are at the same potential, the algebraic sum of the drop through windings N_1 and N_2 and the IR drop of the auxiliary resistance X must equal zero. Hence, if n_2 denote the number of winding turns in coil N_2

$$Kn_2=Kn_1-R_3I_3$$

Also since the algebraic sum of the ampere turns of the transformer windings must equal zero, it follows that

$$n_2I_1=n_1(I_1-I_4)$$

From the above formulæ we get

$$(R_3+R_4)I_4=Kn_1$$
$$R_3I_4=K(n_1-n_2)$$
$$(n_1-n_2)I_4=n_1I_4$$

whence

$$1+\frac{R_4}{R_3}=\frac{n_1}{n_1-n_2}$$
$$\frac{R_4}{R_3}=\frac{n_1-n_1+n_2}{n_1-n_2}=\frac{n_2}{n_1-n_2}$$

Therefore,

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

$$\frac{I_1}{I_4}=\frac{n_1}{n_1-n_2}=\frac{I_1}{I_3} \quad (8)$$

Referring now to Fig. 4 which shows the condition when receiving, since the transmitter and the two transformer windings are in a series closed circuit, the algebraic sum of the drops through windings N_1 and N_2 and the IR drop through the transmitter must equal zero. Consequently

$$K(n_1-n_2)=R_1I_1$$

Furthermore, since points b and d are at the same potential, the IR drop through the

transmitter must equal the IR drop through the receiver and hence

$$R_1 I_1 = R_2 I_2$$

Furthermore, the algebraic sum of the ampere turns of the transformer windings must be zero, so that

$$n_1 I_1 = n_2 (I_1 + I_4)$$

Also

$$I_2 = I_4$$

Therefore

$$\frac{R_2}{R_1} = \frac{I_1}{I_2} = \frac{I_1}{I_4}$$

$$(n_1 - n_2) I_1 = n_2 I_4$$

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

whence

$$\frac{R_2}{R_1} = \frac{n_2}{n_1 - n_2} \quad (9)$$

$$\frac{I_1}{I_4} = \frac{I_1}{I_2} = \frac{n_2}{n_1 - n_2} \quad (10)$$

Substituting equation 8 in equation 2 and remembering that during transmission $I_3 = I_4$, we get

$$\left(\frac{n_1}{n_1 - n_2}\right)^2 R_1 = R_3 + R_4 \quad (11)$$

Substituting equation 10 in equation 6 we get

$$\frac{R_2}{R_1} = \frac{1}{y}\left(\frac{n_2}{n_1 - n_2}\right)^2 \quad (12)$$

Collecting formulæ 7, 9, 11 and 12, we have

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

$$R_2 = R_1 \frac{n_2}{n_1 - n_2} \quad (9)$$

$$R_3 + R_4 = R_1 \left(\frac{n_1}{n_1 - n_2}\right)^2 \quad (11)$$

$$R_2 = \frac{1}{y} R_1 \left(\frac{n_2}{n_1 - n_2}\right)^2 \quad (12)$$

If now we represent the ratio of the transformer windings $\frac{n_1}{n_2}$ by r, we get the following:

$$R_3 = R_4 (r - 1) \quad (a)$$

$$R_2 = R_1 \frac{1}{r - 1} \quad (b)$$

$$R_3 + R_4 = R_1 \left(\frac{r}{r - 1}\right)^2 \quad (c)$$

$$R_2 = \frac{1}{y} R_1 \left(\frac{1}{r - 1}\right)^2 \quad (d)$$

Solving equations (b) and (d) we get

$$\frac{1}{r-1} = \frac{1}{y}\left(\frac{1}{r-1}\right)^2$$

Simplifying we have

$$r - 1 = \frac{1}{y}$$

whence

$$r = \frac{y+1}{y} \quad (13)$$

From equations 13 and (a)

$$R_3 = \frac{1}{y} R_4 \quad (14)$$

From equations 13 and (b) we have

$$R_2 = y R_1 \quad (15)$$

From equations 13 and (c) we have

$$R_3 + R_4 = R_1 (1 + y)^2$$

Substituting equation 14 in the preceding, we get

$$R_1 = \left(\frac{1}{1+y}\right)^2 \frac{1+y}{y} R_4 = \frac{1}{y(1+y)} R_4 \quad (16)$$

Comparing equations 15 and 16, we have

$$R_2 = \frac{1}{1+y} R_4 \quad (17)$$

Collecting, we have as the design formulæ for the substation of Fig. 2, the following:

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

It will be noted that in the above formulæ the impedances of the transmitter, receiver and auxiliary resistance are given in terms of the impedance of the line and the ratio y, while the ratio of the transformer windings is given in terms of the ratio y. Consequently, having given the impedance of the line and having selected a suitable value for y, the remaining elements of the substation may be readily computed.

A modified form of substation is illustrated in Fig. 6, which differs from that of Fig. 2, in that the transmitter is shunted only by the winding N_2, while the line is connected to the terminal of the winding N_2 through the winding N_1, instead of being connected to the common terminal of the two windings as in Fig. 2. A condenser may be inserted in series with winding N_2, so that direct current will flow from the line

through winding N_1 to terminal b, and thence in parallel through auxiliary resistance X, and through the transmitter T and receiver R to terminal d, from which point it flows back over the line.

The operation during transmission will be clear from Fig. 7. A variable potential applied to the transmitter causes a current I_1 to flow in a local series circuit, including the transmitter T and the winding N_2. An induced current I_4 equal to I_3 then flows from the line through the winding N_1 to terminal b, through the auxiliary resistance X, to terminal d, from which point it flows back over the line. Potentials are induced in the windings of the transformer of such value and direction that terminals c and d are brought to the same potential so that no current flows through the transmitter.

During reception, as indicated in Fig. 8, since no current flows through the auxiliary resistance, the receiver and line are in a series circuit and a potential applied to the line causes a current I_4 equal to I_2 to flow from terminal c, through the receiver R and over the line L to terminal a, and thence through the winding N_1 to terminal b. A current I_1 flows in parallel therewith from terminal c, through the transmitter to terminal b, where the two currents combine and a current I_1+I_4 flows from terminal b through the winding N_2 to terminal c. Potentials are induced in the transformer windings of such value and direction that terminals b and d are brought to the same potential, so that no current flows through the auxiliary resistance.

A comparison of Figs. 1, 5 and 9 shows that the several substations herein disclosed differ from each other only in the connections of the transformer windings. Referring to design formulæ A for the substation of Fig. 1, it will be seen that the expressions for the impedance of the transmitter, receiver and auxiliary resistance as given in the last three formulæ of the group are independent of the ratios of the transformer windings so that these expressions will hold true for all of the substations herein disclosed. Writing

$$r=\frac{n_1}{n_2}=\frac{N_{ab}}{N_{ac}}$$

the first equation of design formulæ A may be written

$$\frac{N_{ab}}{N_{ac}}=\frac{1+y}{y} \quad (18)$$

Comparing Fig. 6 with Fig. 2, the number of turns of the transformer winding connecting terminals a and b and a and c, respectively, may be expressed as follows:

$$N_{ab}=n_1$$
$$N_{ac}=n_1-n_2$$

Substituting these values in equation 18, we get as the corresponding equation for the substation of Fig. 6

$$\frac{N_{ab}}{N_{ac}}=\frac{n_1}{n_1-n_2}=\frac{r}{r-1}=\frac{1+y}{y} \quad (19)$$

The design formulæ for the substation of Fig. 6 then become

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

A third form of substation is illustrated in Fig. 10 which differs from that of Fig. 6 in that the transmitter is shunted by winding N_1, while the line L is connected to the terminal of winding N_1, through the winding N_2. A condenser may be inserted between the terminal c and the junction point of the two windings, so that direct current from the line flows through the windings N_2 and N_1 and thence in parallel through the auxiliary resistance X and through the transmitter T and receiver R to terminal d, from which point the current flows back over the line.

During transmission, as indicated in Fig. 11, a variable potential applied to the transmitter causes a current I_1 to flow from terminal c, through the transmitter to terminal b, where the current divides and a current I_3 equal to I_4 flows through the auxiliary resistance X, over the line L, and through the winding N_2 to terminal c. A current I_1-I_4 flows in parallel therewith from terminal b, through the winding N_1 to terminal c. Potentials are induced in the transformer windings of such value and direction that terminals c and d are brought to the same potential, so that no current flows through the receiver.

During reception, as indicated in Fig. 12, since no current flows through the auxiliary resistance, the receiver and line are in a series circuit and a potential applied to the line causes a current I_4 equal to I_2 to flow from terminal c, through the receiver R, over the line L and through the winding N_2 back to terminal c. An induced current I_1 flows in a local closed circuit, including the transmitter T and the winding N_1. Potentials are induced in the transformer windings of such value and direction that points b and d are brought to the same potential so that no current is wasted in the auxiliary resistance.

Comparing Fig. 10 with Fig. 2, it will be seen that the number of turns of the wind-

ings of the transformer, connecting terminals a and b and a and c, respectively, may be written as follows:

$$N_{ab}=n_2+n_1$$

$$N_{ac}=n_2$$

Substituting these values in equation 18, we have as the corresponding equation for the substation of Fig. 10 the following:

$$\frac{n_2+n_1}{n_2}=1+r=\frac{1+y}{y} \quad (20)$$

The design formulæ for the substation of Fig. 10 may then be written

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

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 cooperatively 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 respect to the rigid requirements is necessary in order to discriminate against line noise. It will also be 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. It will be further understood that in this specification the word substation is employed in its generic sense and that consequently its significance is not limited to a subscriber's telephone station but embraces broadly a telephone station including a repeater station for relaying telephonic signals.

What is claimed is:

1. In a two way signaling system, the combination of a transformer having a plurality of windings, and four component elements consisting, respectively, of a path for the transmission and reception of signals, a path including transmitting apparatus, a path including receiving apparatus, and a path including a balancing resistance, said last three mentioned paths being connected in a closed circuit, a series circuit including said first mentioned path and one winding of said transformer connected to the junction point of said third and fourth mentioned paths and one of the remaining junction points of said closed circuit, and another winding joining the third junction point of said closed circuit with said series circuit.

2. In a two way signaling system, the combination of a transformer having a plurality of windings, and four component elements consisting, respectively, of a path for the transmission and reception of signals, a path including transmitting apparatus, a path including receiving apparatus, and a path including a balancing resistance, said last three mentioned paths being connected in a closed circuit, a series circuit including said first mentioned path and one winding of said transformer connected to the junction point of said third and fourth mentioned paths and one of the remaining junction points of said closed circuit, and another winding joining the third junction point of said closed circuit with said series circuit, said elements being so proportioned and related that the impedance of the combination comprising said transformer, and said first, third and fourth mentioned paths, as seen from said second mentioned path, is equal

to the impedance of said second mentioned path.

3. In a two way signaling system, the combination of a transformer having a plurality of windings, and four component elements consisting, respectively, of a path for the transmission and reception of signals, a path including transmitting apparatus, a path including receiving apparatus, and a path including a balancing resistance, said last three mentioned paths being connected in a closed circuit, a series circuit including said first mentioned path and one winding of said transformer connected to the junction point of said third and fourth mentioned paths and one of the remaining junction points of said closed circuit, and another winding joining the third junction point of said closed circuit with said series circuit, said elements being so proportioned and related that the impedance of the combination comprising said transformer and said second, third and fourth mentioned paths, as seen from said first mentioned path, is equal to the impedance of said first mentioned path.

4. In a two way signaling system, the combination of a transformer having a plurality of windings, and four component elements consisting, respectively, of a path for the transmission and reception of signals, a path including transmitting apparatus, a path including receiving apparatus, and a path including a balancing resistance, said last three mentioned paths being connected in a closed circuit, a series circuit including said first mentioned path and one winding of said transformer connected to the junction point of said third and fourth mentioned paths and one of the remaining junction points of said closed circuit, and another winding joining the third junction point of said closed circuit with said series circuit, said elements being so proportioned and related that said third and second mentioned paths are conjugate.

5. In a two way signaling system, the combination of a transformer having a plurality of windings, and four component elements consisting, respectively, of a path for the transmission and reception of signals, a path including transmitting apparatus, a path including receiving apparatus, and a path including a balancing resistance, said last three mentioned paths being connected in a closed circuit, a series circuit including said first mentioned path and one winding of said transformer connected to the junction point of said third and fourth mentioned paths and one of the remaining junction points of said closed circuit, and another winding joining the third junction point of said closed circuit with said series circuit, said elements being so proportioned and related that said fourth and first mentioned paths are conjugate.

6. In a two way signaling system, the combination of a transformer having a plurality of windings, and four component elements consisting, respectively, of a path for the transmission and reception of signals, a path including transmitting apparatus, a path including receiving apparatus, and a path including a balancing resistance, said last three mentioned paths being connected in a closed circuit, a series circuit including said first mentioned path and one winding of said transformer connected to the junction point of said third and fourth mentioned paths and one of the remaining junction points of said closed circuit, and another winding joining the third junction point of said closed circuit with said series circuit, said elements being so proportioned and related that the impedance of the combination comprising said transformer, and said first, third and fourth mentioned paths, as seen from said second mentioned path, is equal to the impedance of said second mentioned path, the impedance of the combination comprising said transformer and said second, third and fourth mentioned paths, as seen from said first mentioned path, is equal to the impedance of said first mentioned path, said third and second mentioned paths are conjugate and said fourth and first mentioned paths are conjugate.

In testimony whereof I have signed my name to this specification this 9th day of August, 1917.

GEORGE A. CAMPBELL.