April 12, 1927. F. W. McKOWN ET AL 1,624,057

TELEPHONE SUBSTATION CIRCUITS

Filed June 1, 1925

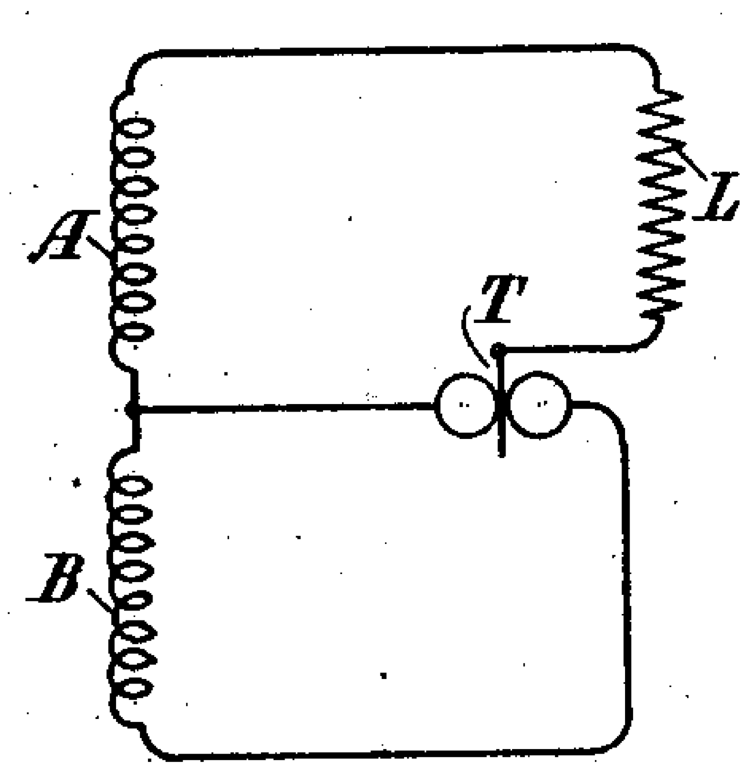

Fig. 1

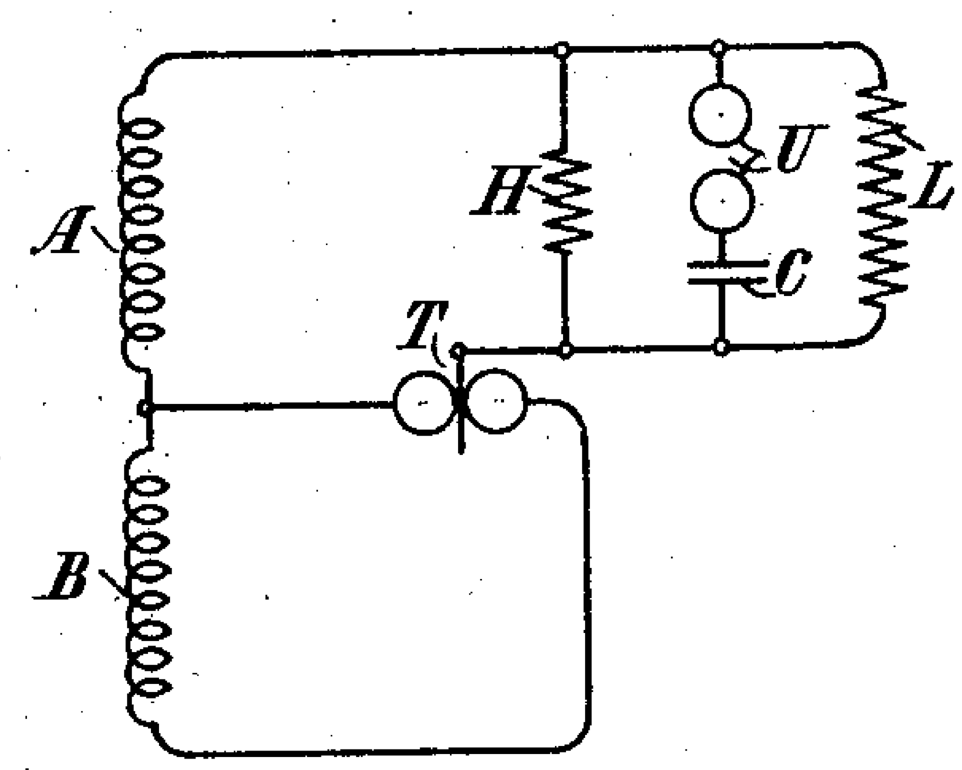

Fig. 2

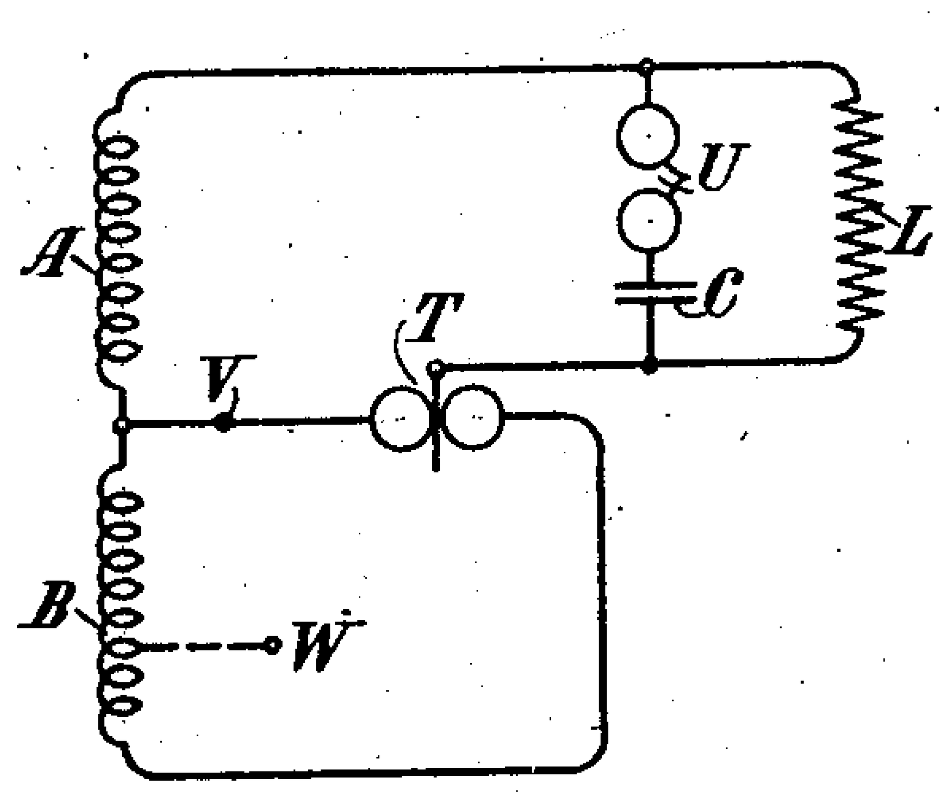

Fig. 3

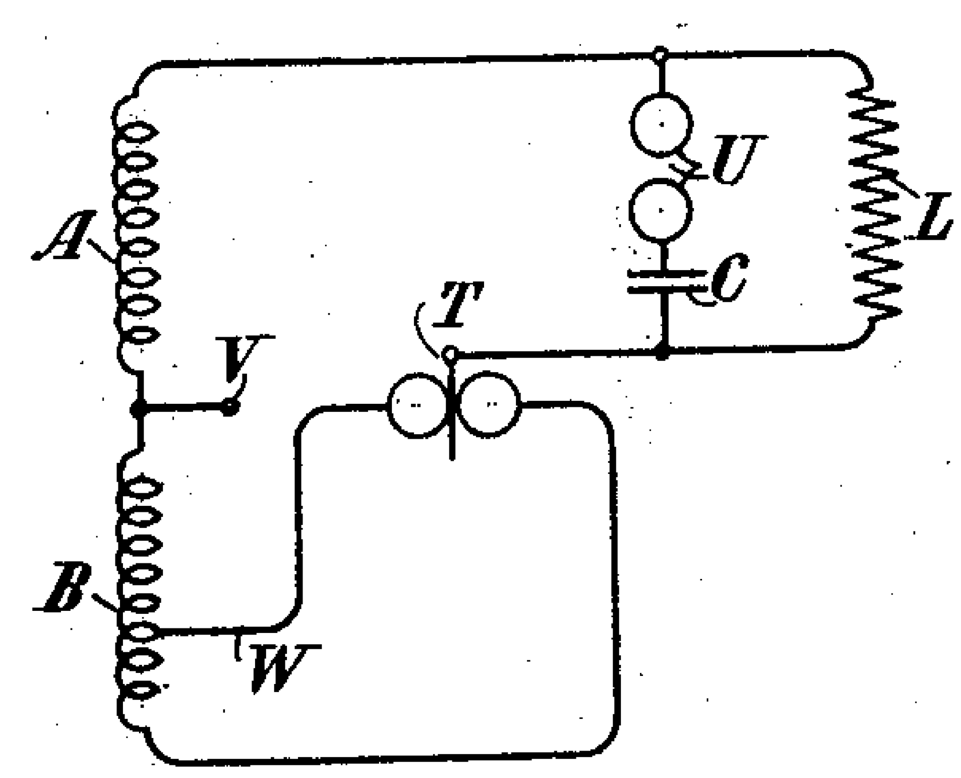

Fig. 4

INVENTORS

F. W. McKown and E. Dietze

BY

ATTORNEY

Patented Apr. 12, 1927. **1,624,057**

UNITED STATES PATENT OFFICE.

FREDERICK W. McKOWN, OF ENGLEWOOD, AND EGINHARD DIETZE, OF WESTFIELD, NEW JERSEY, ASSIGNORS TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

TELEPHONE SUBSTATION CIRCUITS.

Application filed June 1, 1925. Serial No. 34,164.

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 aspect 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 set.

The object of this invention is to provide an economical signaling circuit arrangement which in co-operative combination with a similar and equal signaling circuit arrangement at the distant end of a telephone line, shall deliver a large proportion of energy to the receiving apparatus of said signaling circuit arrangement at the distant end of the line.

A further object is to provide a substation consisting of a transmitter and a receiver of the electromagnetic type, having a plurality of windings and arranged for invariable two-way communication over a line having given impedance and length. In other words, the object of the invention is to provid signaling means characterized by a minimum number of elements.

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 a telephone line, the transmitter and receiver each having a resistance which is equal to one-half of the line impedance. In such an arrangement the over-all efficiency is a maximum for an invariable set, even though 50 per cent of the energy delivered by the line to the substation is wasted in the transmitter and only 50 per cent of the energy available at the transmitter reaches the line. Further, such an arrangement labors under the disadvantage of full side tone.

In the types of substation circuits now in use, the transmitter has a resistance which is about one-twelfth of the line impedance. Such a transmitter cannot be employed in the simple series circuit if the conditions for maximum energy transfer are to be satisfied. To improve the efficiency of the substation it has been customary to employ a transformer or induction coil in the substation circuit in order to step up the transmitter resistance. In the arrangements of the present invention, however, the induction coil has been eliminated and its function has been relegated to the receiver.

The invention will be more fully understood by reference to the accompanying drawing, in which Figure 1 is a substation having a minimum number of elements, Fig. 2 shows a substation in which an equalizing resistance is connected across the line for the purpose of reducing side tone on short loops. Fig. 3 is a modification of Fig. 1, and Fig. 4 shows a substation in which the windings of the receiver are proportioned so as to reduce side tone.

In order to illustrate the scope of the invention and elucidate the principles on which the embodiments rest, a general theoretical discussion will now be given which applies to the substations shown in the drawing of this specification. In this discussion and the equations and formulæ included in the specification, the subscripts "T," "L" and "R" will refer to transmitter, line and receiver respectively. Thus, I_T, I_L and I_R will denote the currents flowing in the transmitter, line and receiver, respectively, while Z_T will denote the impedance of the transmitter, Z_L the impedance of the line, etc.

Consider the substation illustrated in Fig. 1 consisting of a two-element transmitter and receiver connected to a line of given impedance. In practice, the line connects two similar and equal substations between which communication is established. For transmitting, consider the transmitter as having a voltage E in series with each transmitter button, the two transmitter buttons having equal impedances. By Kirchoff's laws,

$$I_L(Z_A+Z_L+Z_T)+I_B(Z_M-Z_T)=E$$

and

$$I_L(Z_M-Z_T)+I_B(Z_B+2Z_T)=-2E$$

In the foregoing expressions A and B

refer to the two windings of the electromagnetic receiver used in the substation, Z_A and Z_B refer to the self-impedances of said windings, and Z_M refers to the mutual impedance of said windings. Solving these equations simultaneously, (bearing in mind that the impedance of a receiver having two windings, A and B, which are series aiding, is

$$Z_A+Z_B+2Z_M)$$

the current in the line, I_L, is

$$\frac{E(Z_B+2Z_M)}{(Z_A+Z_L+Z_T)(Z_B+2Z_T)-(Z_M-Z_T)^2}$$

and the current in winding B, I_B, is

$$\frac{-E(2Z_A+2Z_L+Z_M+Z_T)}{(Z_A+Z_L+Z_T)(Z_B+2Z_T)-(Z_M-Z_T)^2}$$

In deriving the values of the currents in the respective branches when signals are being received at the substation, consider a voltage e to be in series with the line L, then

$$I_L(Z_A+Z_L+Z_T)+I_B(Z_M-Z_T)=e$$

and

$$I_L(Z_M-Z_T)+I_B(Z_B+2Z_T)=o$$

The expression for the value of the current in the line L, I_L, when signals are being received at the substation is

$$\frac{e(Z_B+2Z_T)}{(Z_A+Z_L+Z_T)(Z_B+2Z_T)-(Z_M-Z_T)^2}$$

The current I_B in the lower branch, which includes the winding B of the receiver of the substation is

$$\frac{e(Z_T-Z_M)}{(Z_A+Z_L+Z_T)(Z_B+2Z_T)-(Z_M-Z_T)^2}$$

The transmitting efficiency of the substation may be expressed as the square root of the ratio of the power actually sent into the line by the transmitter of the substation to the maximum power that could be sent into the line by the transmitter of the ideal invariable substation. The transmitting efficiency may be determined from the expression

$$\sqrt{\frac{P_A}{P_i}},$$

in which P_A is the power actually delivered to the line, or

$$\sqrt{P_A}=I_L\sqrt{R_L};$$

and P_i, the power in the ideal invariable substation circuit, is determined from the expression

$$\sqrt{P_i}=\frac{1}{\sqrt{2}}\cdot\frac{E}{\sqrt{2Z_T}}\cdot$$

Substituting the value of the current in the line, I_L, derived hereinbefore, and bearing in mind that

$$Z_M=\sqrt{Z_AZ_B}$$

approximately, the transmitting efficiency becomes

$$\frac{2\sqrt{Z_TR_L}\cdot(Z_B+2\sqrt{Z_AZ_B})}{(Z_A+Z_L+Z_T)(Z_B+2Z_T)-(Z_M-Z_T)^2}$$

The receiving efficiency of the substation may be expressed as the square root of the ratio of the power actually sent into the receiver of the substation from the line to the maximum power that could be sent into the receiver of the ideal invariable substation from the line. The receiving efficiency of the substation may be written as

$$\sqrt{\frac{P_A}{P_i}},$$

in which P_A is the energy actually delivered to the receiver, or

$$\sqrt{P_A}=I_R\sqrt{R_R},$$

and

$$\sqrt{P_i}\ \text{is}\ \frac{1}{\sqrt{2}}\cdot\frac{e}{2\sqrt{R_L}}\cdot$$

Defining the effective current in the receiver as the quotient of the ampere turns and the turns of the receiver, the receiving efficiency may then be determined from the expression

$$\frac{2Z_T\sqrt{2R_LR_R}}{(Z_A+Z_L+Z_T)(Z_B+2Z_T)-(Z_M-Z_T)^2}\cdot\frac{2\sqrt{Z_A}+\sqrt{Z_B}}{\sqrt{Z_A}+\sqrt{Z_B}}$$

The power in the receiver of an invariable substation circuit when a voltage is acting in series with the transmitter at the same substation is known as side tone. The side tone efficiency is

$$\sqrt{\frac{P_A}{P_i}},$$

in which P_A is the power actually delivered to the receiver at the same substation, and P_i is the value obtained from the expression

$$\sqrt{P_i}=1/2\cdot\frac{E}{2\sqrt{2Z_T}},$$

the impedance of the transmitter, Z_T, being merely a resistance at normal telephonic frequencies. The value of the current in the receiver, I_R, having been determined hereinbefore, the side tone efficiency will then be found to be

$$\frac{2(2Z_L+Z_T)\sqrt{2Z_TR_R}}{(Z_A+Z_L+Z_T)\,(Z_B+2Z_T)-(Z_M-Z_T)^2}\cdot\frac{\sqrt{Z_B}}{\sqrt{Z_A}+\sqrt{Z_B}}$$

The transmitter may be considered a generator having a fixed internal resistance which sends current through the receiver at the same substation and through the line in series therewith. While transmitting, the energy in the receiver is wasted so far as transmission to the substation at the distant end of the line is concerned. Also, while receiving, the power delivered to the transmitter is wasted. In order to have the maximum energy transfer between the line and the substation the generator element should be equal to the element to which power is being delivered. Therefore, in order to obtain the maximum energy transfer between the line and the substation while transmitting, the line should have the same impedance as the transmitter, and while receiving, the receiver should have the same impedance as the line. From the equations given hereinbefore the maximum energy transfer between the line and the substation may be obtained when the impedance of the substation, Z_S has the magnitude

$$\frac{Z_T(2Z_A+Z_B+2Z_M+Z_T)}{Z_B+2Z_T}$$

The energy ratio Y_R is known in the art as

$$\left(\frac{\text{transmitting efficiency}}{\text{receiving efficiency}}\right)^2$$

Substituting the values for the transmitting and receiving efficiencies, respectively, the energy ratio Y_R will be found to equal

$$\frac{Z_B}{2Z_T\cos\theta}$$

in which θ is the receiver angle, the tangent of θ being the ratio of the reactance component to the resistance component of a single winding of the electromagnetic receiver, θ being of substantially equal magnitude for both of the windings.

The embodiments of this invention disclose arrangements in which the transmitter, receiver and line are effectively in parallel. Side tone may become objectionable on short loops because noises at the substation, which excite the transmitter, will produce sounds in the receiver. Furthermore, the operator talks in his own ear, and if he talks very loudly the effect of side tone may make it very uncomfortable for him. It is therefore important that on short loops the side tone be kept very low.

On inspection of the formula for the side tone efficiency it will be noted that the side tone efficiency varies in accordance with the impedance of the line, the side tone increasing as the impedance of the line increases. In arrangements of the parallel type, the side tone may be reduced by making the impedance of the substation set higher than the impedance of the line.

Fig. 2 shows an arrangement of the parallel type in which an equalizing resistance H is connected in shunt with the circuit. Thus the current in the line is lowered, the side tone being reduced to an even greater extent than the efficiency. A condenser C is serially connected to the ringer U for ringing purposes. Figs. 3 and 4 are similar to Fig. 1, the ringing circuit, consisting of the ringer U and condenser C, being shown connected across line L. In Fig. 3 the transmitter is connected to terminal V and the windings of the receiver are proportioned for maximum efficiency. In Fig. 4 the transmitter is connected to terminal W. Point W may be chosen to proportion the windings of the receiver so as to considerably reduce side tone, thus involving some loss in efficiency also. It will therefore be desirable to connect the transmitter to terminal V on long loops and to terminal W on short loops.

The accompanying formulæ give satisfactory results and the methods by which they are derived enable one skilled in the art to compute the substation constants when desired.

It will be understood that while certain embodiments have been specifically illustrated and described as embodied in a telephone substation, it is capable of many and varied embodiments which render it applicable to other kinds of signaling systems. Consequently, the invention is not to be limited to the particular form and use herein disclosed but is to be limited only by the appended claims. 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 staton including a repeater station for relaying telephonic signals.

What is claimed is:

1. A circuit comprising two branches, devices for converting sound waves into electric waves, means for simultaneously actuating said devices, and means for converting electric waves into sound waves, said latter means consisting of two closely coupled windings each of substantially low resistance, one of which is arranged in each of said branches, said windings being employed to step-up the resistance of said devices to any desired value.

2. A substation circuit comprising two branches, a receiver having two windings

between which there is a high mutual impedance, one winding being arranged in each branch, a device consisting of a diaphragm and two buttons for converting sound waves into electric waves, and means simultaneously actuating the buttons of said device.

3. A substation circuit comprising upper and lower branches, a device consisting of a diaphragm and two buttons on either side thereof, means for simultaneously actuating said diaphragm and said buttons, and a receiver having a pair of closely coupled windings, one winding being arranged in each of said branches.

4. A telephone circuit comprising upper and lower branches, a line connected to said upper branch, a two-element transmitter having one element in said upper branch and both elements in said lower branch, and a receiver having two closely coupled windings arranged on a single core, one winding being associated with each of said branches.

5. A telephone circuit having two branches comprising a line, a receiver having two closely coupled windings, one winding being associated with the first branch and the other winding being associated with the second branch, a two-element transmitter arranged so that one element is in said first branch, and so that both elements are in said second branch, the windings of said receiver functioning to step-up the transmitter resistances and being proportioned so that said receiver may be made substantially anti-side tone.

6. In combination, a line, a two-element transmitter, and a receiver having two windings, one winding of said receiver, the line, and one element of said transmitter being included in one branch, the other winding of said receiver and both elements of said transmitter being included in another branch, the windings of said receiver having a high mutual impedance and being proportioned so that the side tone may be lowered to a predetermined value.

7. In a telephone circuit, in combination, two devices for converting sound waves into electric waves, and a receiver having two windings, said windings being so proportioned that when said devices are simultaneously actuated by a sound wave only current below a predetermined amount will flow in said receiver, the windings of said receiver having a high mutual impedance.

8. In a telephone circuit, in combination, two devices for converting sound waves into electric waves, and a two-winding, electromagnetic receiver connected thereto, the windings of said receiver being closely coupled and being so proportioned that the current flowing through said receiver will be limited to a predetermined value when sound waves actuate said devices.

In testimony whereof, we have signed our names to this specification this 27th day of May, 1925.

FREDERICK W. McKOWN.
EGINHARD DIETZE.