Oct. 23, 1945. K. S. JOHNSON 2,387,269

TELEPHONE SYSTEM

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FIG. 1

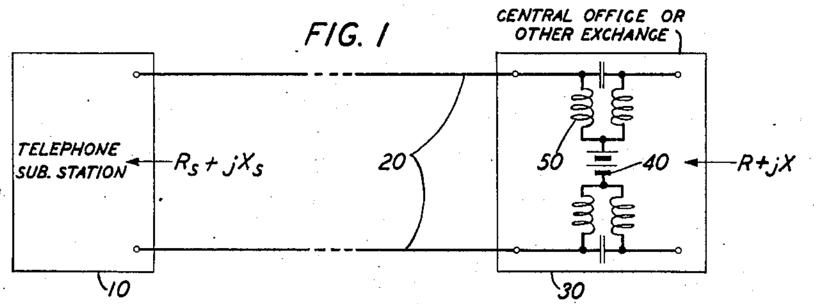

FIG. 2

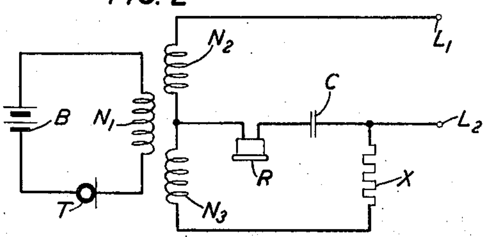

FIG. 3

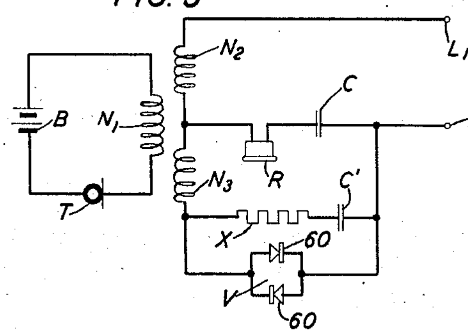

FIG. 4

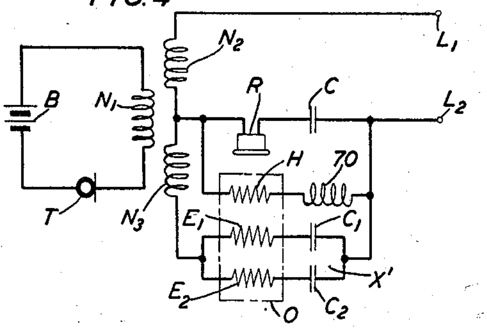

FIG. 5

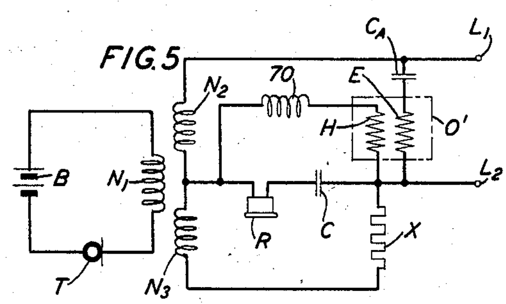

FIG. 6

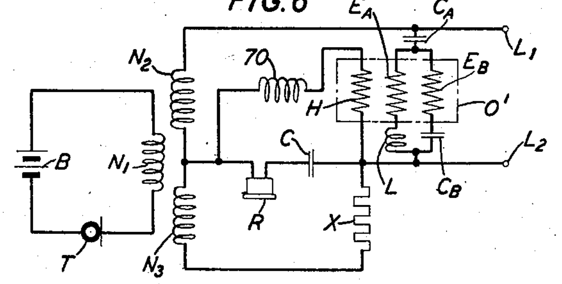

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FIG. 7

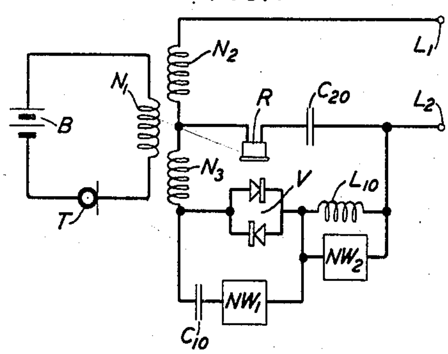

FIG. 8

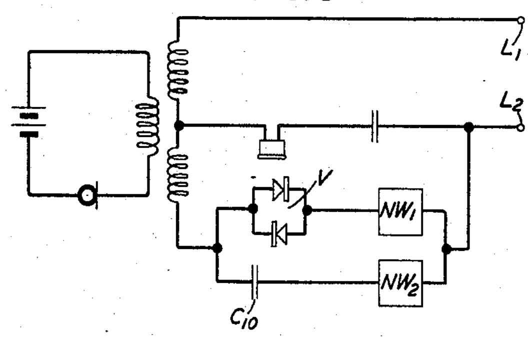

FIG. 9

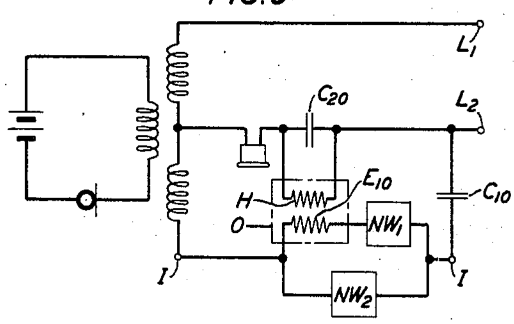

FIG. 9A

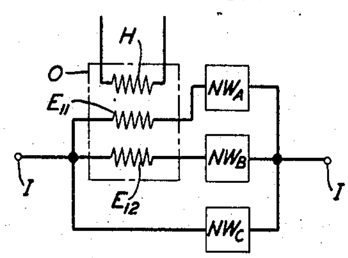

FIG. 9B

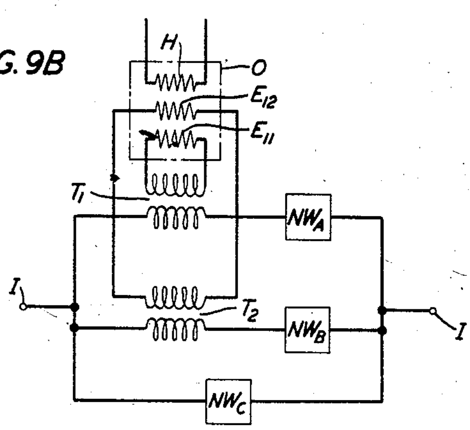

FIG. 9C

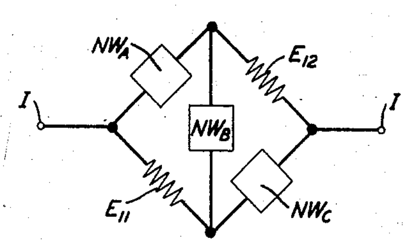

FIG. 10

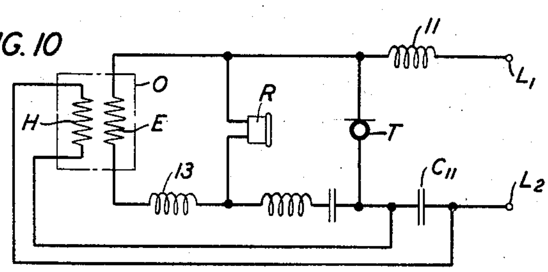

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FIG. 11

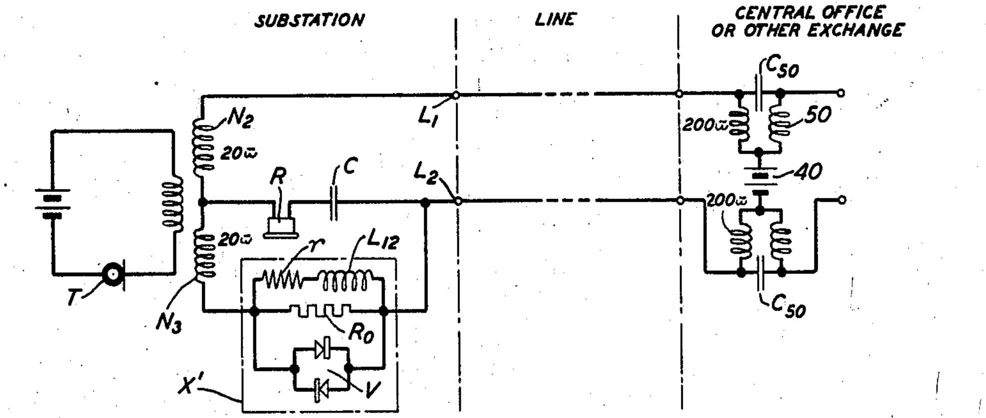

FIG. 12

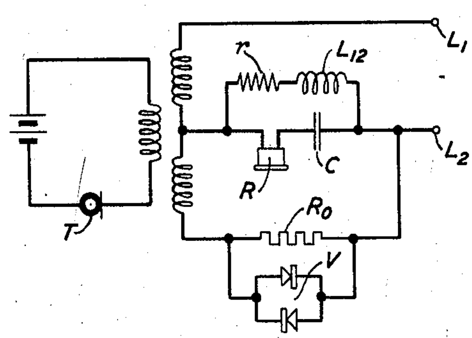

FIG. 16

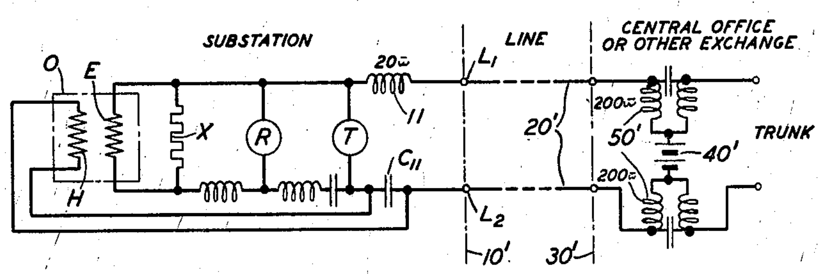

FIG. 13

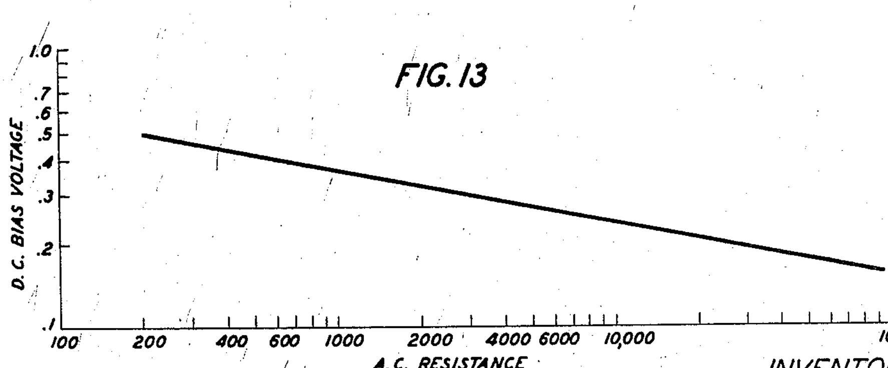

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FIG. 14

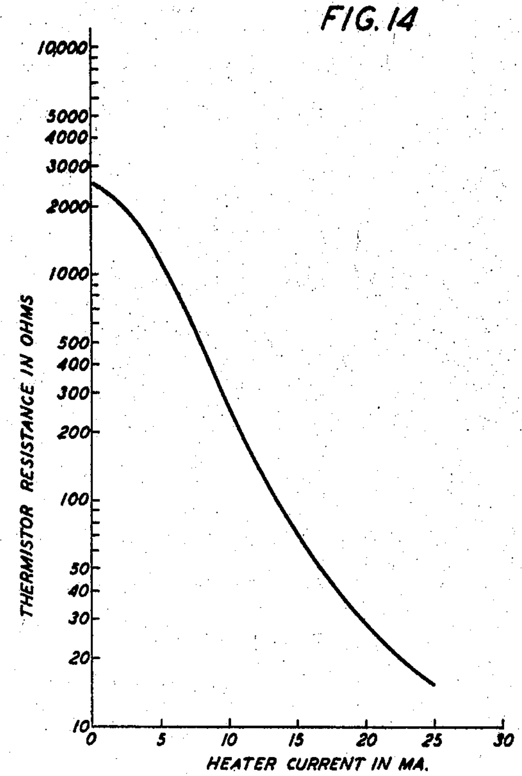
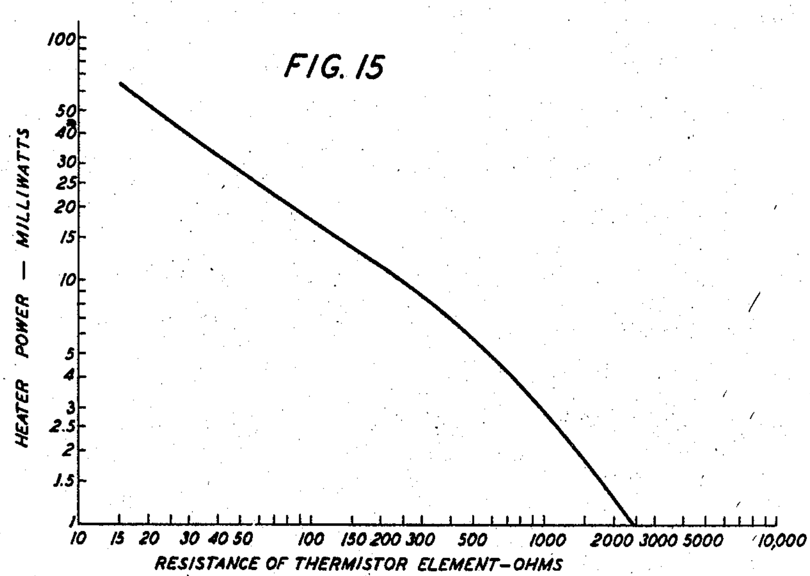


FIG. 15



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Patented Oct. 23, 1945

2,387,269

UNITED STATES PATENT OFFICE

2,387,269

TELEPHONE SYSTEM

Kenneth S. Johnson, South Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application October 24, 1942, Serial No. 463,184

26 Claims. (Cl. 179—81)

This invention relates to circuit arrangements for telephone signaling systems wherein signals may be transmitted from or received at the same telephone station.

More specifically the invention relates to or may be embodied in a subscriber's telephone station or substation as it is more commonly called, and more particularly to the combination of a substation and a telephone line.

The particular substations herein illustrated and described are of the so-called Campbell anti-sidetone circuit type, the invention being disclosed with reference to substations of that type as shown and described with reference to Figs. 1 and 4 in G. A. Campbell Patent 1,254,472, issued January 22, 1918, and Figs. 1 and 1A in J. W. Gooderham Patent 1,901,958, issued March 21, 1933.

As developed at length in the Campbell patent mentioned hereinabove, telephone substations of the type disclosed therein comprise a transmitter, a receiver, a balancing network consisting in its simplest form of an auxiliary resistance, and a transformer having a plurality of windings which, in combination with a telephone line, are so designed that: (1) the transmitter and the receiver shall be conjugate, that is, there shall be negligible sidetone in the receiver in consequence of the actuation of the transmitter by sound wave; (2) the line and the auxiliary resistance may be conjugate in order that a negligible amount of the energy absorbed by the substation from the line shall be wasted in the 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, that is, the impedance of the substation as seen from the line shall be numerically equal to the impedance of the line; and (5) that a small sacrifice of efficiency shall be possible to discriminate effectively against disturbing line noise as distinguished from the telephone signal received from the other or communicating station. Instead of a separate auxiliary resistance, one of the windings of the transformer may be designed so as to include the resistance that would be provided by such a separate resistance.

In the design of a telpehone substation circuit, it is assumed that, in use, it will be associated with a telephone line, loop or path connecting it with a central office or other exchange, for example, a private branch exchange, the line having a particular or average impedance, and the central office or other exchange containing a direct current source of substantially constant potential. In actual practice, a circuit so designed may be used with a subscriber loop or path of considerably different impedance than that assumed. In the latter event, the performance of the subscriber circuit will not be that intended by the designer. If the substation circuit is of the anti-sidetone type already referred to, it is apparent that the sidetone control predicated by the designer will not be realized. Although various proposals have been made to compensate for such a condition, considerable room for improvement still obtains.

In accordance with this invention, it is proposed so to arrange the components of a substation circuit of the anti-sidetone type that the impedance of the balancing network included therein will be automatically adjustable for different lengths of line or different resistance lines between the subscriber's circuit and the exchange, the direct current supplied over the line from the exchange being utilized as a control current to effect the adjustment in the impedance of the balancing network.

In accordance with the invention, also, the automatic adjustment in the impedance of the balancing network may result from the inclusion in the latter of a variable resistance device or element experiencing substantial resistance change with change in the direct current supplied to the station circuit over the line.

In accordance with the invention, furthermore, a substation circuit of otherwise known configuration may have included therein connected across its line terminals, a compensating network arranged to be automatically adjustable in impedance for different lengths of line between the subscriber's circuit and the exchange, the control current being supplied by the direct current flowing over the line from the exchange to the substation.

In a specific arrangement, the balancing network at the substation includes a variable resistance element or device of a material or construction such that the resistance thereof varies appreciably with change in direct current therethrough, or more specifically, such as to have a non-linear current-resistance characteristic. Such a material or device may comprise a metallic body, such as copper, having an intimately adherent layer of oxide, for example, cuprous oxide, thereon. Such a device is known commonly as a copper-oxide rectifier unit or disc. The balancing network may include one or more of such units, together with one or more so-called linear resistances and one or more reactive elements.

that is, inductive and/or capacitive, in order to provide some particular impedance-frequency characteristic to the balancing network.

In another specific arrangement, the balancing network in the substation circuit may include a variable resistance element of a material having a high temperature coefficient of resistance, for example, of either a positive or a negative temperature coefficient of resistance, a heater element being associated with the resistance element. This heater element is connected in the substation circuit in such manner that it is traversed by the direct current or line current. The variable resistance element is proportioned so as to change substantially instantaneously in temperature and therefore in resistance with change in the current flow through the heater element. Variable resistances of this general type are commonly known in the art as "thermistors." By operating along an appropriate portion of the temperature resistance characteristic of the variable resistance element, the changes in the resistance of that element will be such as to compensate for the difference in the impedance of the actual line with which the substation circuit is associated and the line assumed for purposes of design of the substation circuit.

In accordance with the invention, the variable resistance device or element, more generally, may be a varistor. The more common varistors that have already been proposed for use in or actually used heretofore in communications circuits or systems are the copper-oxide varistor, that is, the copper-cuprous oxide rectifier unit or disc; the silicon carbide varistor; and the thermistor. The thermistor is a species of varistor whose nonlinear temperature-resistance characteristic may be availed of by the direct or indirect heating effect thereon of an electric current. Some of the more common thermistors are the silver sulphide thermistor, the uranium oxide thermistor and thermistors involving mixtures of metallic oxides. A further understanding of varistors may be derived from the following articles: "Varistors: Their Characteristics and Uses," J. A. Becker, Bell Laboratories Record, vol. 18, July 1940, pp. 322–327; "Silicon Carbide Varistors," R. O. Grisdale, Bell Laboratories Record, vol. 19, October 1940, pp. 46–51; "Thermistors, Their Characteristics and Uses," G. L. Pearson, Bell Laboratories Record, vol. 19, December 1940, pp. 106–111; "The Copper Oxide Varistor," W. H. Brattain, Bell Laboratories Record, vol. 19, January 1941, pp. 153–159.

In accordance with the invention, the proposed arrangements are not limited to a telephone system in which talking current is supplied from the central office or other exchange. The subscriber circuit may be of the local battery type but utilizing common battery supervision. With either type of circuit, the adjustment in the impedance of the balancing network is related to the direct current supplied over the line to the circuit from a current source, for example, a common battery, at the central office or other exchange.

A more complete understanding of the invention will be derived from the detailed description that follows, taken in conjunction with the appended drawings wherein:

Fig. 1 shows in schematic a telephone system comprising a pair of telephone stations interconnected over a telephone line and embodying the invention;

Fig. 2 shows an anti-sidetone substation circuit of the type described in detail in G. A. Campbell Patent 1,254,472, with particular reference to Figs. 1 to 4 therein;

Fig. 3 shows an anti-sidetone substation circuit including a varistor in the line balancing network thereof;

Fig. 4 shows another modification of the circuit of Fig. 2 in which a pair of thermistors are included in the line balancing network thereof;

Fig. 5 shows another modification of the circuit of Fig. 2 in which a thermistor network is connected across the line terminals of the substation circuit;

Fig. 6 shows a modification of the circuit arrangement of Fig. 5;

Figs. 7 to 9C illustrate how a varistor or, more specifically, a thermistor may be employed to regulate, control or adjust more exactly the overall impedance of the line balancing network of a substation circuit;

Fig. 10 illustrates how the invention of this application may be embodied in an anti-sidetone substation circuit of the general type shown in J. W. Gooderham Patent 1,901,958 of March 21, 1933, with particular reference to Figs. 1 and 1A therein;

Fig. 11 shows a specific circuit along the lines of Figs. 1 and 2 in which the line balancing network X of Fig. 2 is replaced by the composite network X' in accordance with the invention;

Fig. 12 shows a modification of the substation circuit included in Fig. 11;

Fig. 13 shows, for a copper-cuprous oxide unit, the relationship between the alternating current resistance thereof and the direct current biasing voltage therefor;

Fig. 14 shows the relationship between the resistance of and the heating current for a typical thermistor;

Fig. 15 shows the relationship between the resistance of and the heater power supplied to a typical thermistor; and

Fig. 16 shows a circuit arrangement along the lines of Figs. 1 and 10 with the substation circuit having a specific configuration in accordance with this invention.

Fig. 1 shows in schematic a telephone circuit in which the invention may be embodied. A telephone subscriber's station or substation **10** is connected by a telephone line **20** with a central office or other exchange **30**, for example, a private branch exchange, to which, in accordance with well-known telephone practice, other and similar stations may also be connected. For purposes of this disclosure, it is believed necessary only to show at the central office a current source **40**, for example, a battery, and a battery supply coil **50**. Direct current from the source **40** is supplied over the line **20** to the substation, either for talking and supervisory purposes if the substation is of the common battery type, or for supervisory purposes, only, if the substation is of the local battery type. The various substations connected to a given central office may be and usually are at different distances from the central office, that is, the length of telephone line required for the connection will vary from substation to substation and, consequently, there will be variations in the resistance particularly and in the capacitance and the inductance of the subscriber's loop, that is, the path comprising the substation, the line and the central office. If the substation comprises an anti-sidetone circuit including a line balancing network simulating the impedance of the telephone line, the anti-sidetone properties of the circuit will be deleteriously affected if the line impedance is appreciably different from the average impedance assumed in the design of the circuit, unless provision is made for maintaining the optimum relationship between the impedances of the line and the balancing network. A rule-of-thumb procedure would be to measure the impedance of the line as seen at the substation terminals at the time of the installation of a particular subscriber's substation, and to include in the substation circuit a balancing network of optimum impedance with respect to the particular loop. Such a practice would probably require a higher order of technical skill in the installer than is at present the case, increase the cost of installation and make the installer's equipment more complex, as well as obviate the advantages of mass production of substations requiring no additions or changes by the installer before being ready for use.

Fig. 2 shows an anti-sidetone circuit of the type described in detail in the aforementioned Campbell patent with particular reference to Figs. 1 to 4 therein. It is a local battery substation comprising a transmitter T, a receiver R, a multiple-winding induction coil or transformer including windings N_1, N_2, N_3 and a line balancing network X (for example, a resistance, which may be included in the winding N_3). The transmitter winding N_1 and a current source B, for example, a battery, are connected in series in a local circuit; the line winding N_2 and a direct current blocking condenser C are connected across the line terminals L_1, L_2; and the winding N_3 and network X are connected in shunt of the series-connected receiver and condenser. Although not shown, a pair of normally-open contacts could be located in the connection, for example, between battery B and winding N_1, and a second pair of normally-open contacts could be located in the connection, for example, between terminal L_2 and the junction of condenser C and network X. The transmitter and receiver may be included in a hand telephone set or handset, or may be physically separate. As is well known, either the handset or the receiver may be supported on a switchhook or other support when not in use, and be arranged to maintain such contacts in open condition, the removal of the handset or of the receiver from the support causing or enabling the contacts to close or to be engaged. A serially-connected ringer and condenser may be provided across the line terminals L_1, L_2 in accordance with known practice.

In accordance with the Campbell patent, the network X would be proportioned with respect to the particular line with which the circuit was to be used or with respect to a line of some assumed average impedance. If the line with which the set is actually used is not of the assumed impedance, mismatch will reflect itself in increased sidetone. The modified circuit of Fig. 3 illustrates one way of compensating for this condition. The circuit of Fig. 3 is the same as that of Fig. 2 except that a condenser C′ is connected in series with the network X and a variable resistance device or elevent V is connected in parallel with the condenser-resistance, C′—X. The device V may comprise one or more discs of a material having a non-linear resistance current characteristic, for example, a pair of copper-cuprous oxid rectifier discs or units 60 connected in parallel opposition, could be used.

The resistance X should be proportioned with respect to the longest subscriber loop in which it is anticipated that the circuit might be included with the device V offering a very high resistance to the flow of line current therethrough, that is, the device V would be operating at a high resistance point on its current-resistance characteristic. If the actual line should be shorter than the assumed maximum length, or of the same length but of less resistance, the line current will be greater. Since a larger current would then be flowing through the device V, the latter will be operating on its current-resistance characteristic at a point of much lower resistance. Together, then, the resistance X and the device V constitute a line balancing network of lower impedance than for the limiting condition, and obviate the greater unbalance that would exist if the fixed resistance X, only, were present in the substation circuit.

Fig. 4 shows another modification of the circuit of Fig. 2. Instead of comprising the resistance X indicated in Fig. 2, the balancing network may comprise, as illustrated in Fig. 4, a pair of variable resistance devices or elements E_1, E_2, of a material such as silver sulphide, having a high negative temperature coefficient of resistance; or a material such as a mixture of oxides of nickel, manganese and copper, such as is disclosed in E. F. Dearborn and G. L. Pearson Patent 2,282,944 of May 12, 1942, which also has a high negative temperature coefficient of resistance, each element being connected in series with a condenser C_1, C_2. A heater H, to be traversed by the line current, is connected in series with a retard coil 70 around the receiver R and condenser C. The heater and the elements E_1, E_2 may be enclosed in a suitable container or oven O, so that the elements E_1, E_2 are of a temperature determined by the heated condition of the heater as a result of line current flow through the latter. An increase in current flow through the heater will raise the temperature and lower the resistance of the elements E_1, E_2, and a decrease in the current flow through the heater will cause or have an opposite effect on the elements E_1, E_2. The latter are proportioned with respect to a subscriber line of assumed length or resistance, so that, for the line current under such condition, the temperatures and therefore the resistances of the variable resistance elements will be such that the balancing network that they comprise balances such a line. If, in actual use, the subscriber's line is of greater resistance, the line current will be less, the heating effect of the heater will be lower, the temperature of the elements E_1, E_2 will be lower and therefore their resistances will be higher, and the network comprising the elements E_1, E_2 will also be of increased resistance. On the other hand, if the actual subscriber's line is of less resistance, the line current through the heater H will be higher and the heating effect on the elements E_1, E_2 greater, and the latter will be of higher temperatures and lower resistances, whereby the balancing network of such elements E_1, E_2 is also of lower resistance. By appropriate proportions for the condensers C_1, C_2, the phase angle of the balancing network may be given a desired value.

Instead of including variable resistance means in the balancing network to compensate for variations in the length or resistance of the subscriber's loop, the arrangement of Fig. 5 may be employed. This circuit is the same as that of Fig. 2, with the addition of the serially connected heat-sensitive variable resistance element E and condenser C_A. The element E, which may be of a material having a positive temperature coefficient of resistance, is proportioned to adjust in resistance in response to the line direct current so as to compensate for different line resistances and to provide at the substation line terminals, a substantially perfect balance between the balancing resistance X and the total impedance across terminals L_1, L_2. The heater H and retard coil are connected in series with the line, being connected in parallel with the serially-connected receiver R and condenser C. The heater H and the element E may be enclosed or contained in an oven O'. The flow of line direct current through the heater H heats the latter which, in turn, heats the element E, the resistance of the element E at the particular temperature being determined by the resistance-temperature characteristic thereof. If the line resistance is greater than that assumed in the proportioning of the resistance X, the lower line current through the heater H reduces the heating effect of the latter on the element E. The lowering of the temperature of the element E reduces its resistance, and lowers the total effective impedance presented at the line terminals. If, on the other hand, the line resistance of the particular line is less than that assumed, the higher line current through the heater H raises the temperature of the latter and that of the element E, whereby the element E increases in resistance to raise the effective impedance at the substation line terminals. For either departure, therefore, from the optimum line resistance, compensation is introduced so that the substation circuit behaves substantially as if the optimum line condition actually existed.

In the circuit arrangement of Fig. 6, two heat or temperature-sensitive variable resistances or elements E_A, E_B are associated with the heater H within the oven O'. The element E_A may be of a substance or a material having a high positive temperature coefficient of resistance and be connected in series with an inductive reactance L, and the element E_B may comprise a substance or a material having a high negative temperature coefficient of resistance and be connected in series with a capacitive reactance C_B. The condenser C_A may be a blocking condenser. The elements E_A, E_B are proportioned, such that their change in resistance with alteration in line direct current flow through the heater H, resulting from connection of the circuit at line terminals L_1, L_2 to a line of resistance different from that assumed in the proportioning of the balancing resistance X, will maintain at the line terminals L_1, L_2 the total effective impedance for which the balancing network X has its optimum relationship. The reactances due to components L and C_B may be proportioned to compensate for departures in the actual line connected to terminals L_1, L_2 from the impedance of the assumed line.

Figs. 7 to 9C illustrate how a variable resistance element or elements of the type referred to hereinabove may be employed to regulate, control or adjust more exactly the over-all impedance of the line balancing network of a substation circuit, with respect to any two or more different loop lengths or impedances. Fig. 7 is a modification of Fig. 2 in which the balancing resistance X is replaced by a network comprising the variable resistance device V serially connected with the inductive reactor L_{10} and serially connected with a balancing network NW_2. Serially-connected capacitive reactor C_{10} and a balancing network NW_1 are connected in parallel with the device V. The capacitive reactors C_{10}, C_{20} are relatively large-capacity blocking condensers, offering effectively a short circuit from an alternating current standpoint and are for the purpose of directing through the device V all direct current traversing the subscriber's loop through terminals L_1, L_2. The inductance of the reactor L_{10} may be so large that it is effectively an open circuit from an alternating current standpoint, alternating current traversing the subscriber's loop through the terminals L_1, L_2 passing through the networks NW_1, NW_2. For the anticipated long or longest loop, or maximum line or loop resistance, the device V may be arranged so that it presents a very high resistance to the line direct current condition that would exist. For this condition, the device V would exert a minimum or a negligible by-passing action with respect to alternating current, and the networks NW_1, NW_2 together constitute the line balancing network of the substation circuit. For shorter or very short loops, the line direct current will be relatively high, and this relatively greater current traversing the device V will cause the latter to become of sufficiently reduced resistance effectively to short circuit the serially-connected reactor C_{10} and network NW_1. For the short loop condition, therefore, the balancing network of the substation circuit will be constituted essentially by the network NW_2. Each of networks NW_1, NW_2 may comprise a resistance of appropriate magnitude, and may also include inductive and/or capacitive reactance when it is desired that the network embody some particular impedance characteristic. If it is desired to have the two networks NW_1, NW_2 in parallel on the short loop and only one network effectively in the circuit on the long loop, the arrangement of Fig. 8 may be employed. On short loops, because the line direct current is relatively high, the resistance of the device V will be low, and the balancing network for the substation circuit will be constituted by the network NW_1 in parallel with the serially-connected capacitor C_{10} and the network NW_2. For the long loop, however, the resistance of the device V will be very high, because the line direct current will be smaller. Because of the very high resistance of the serially-connected device V and network NW_1, the balancing network for the substation circuit will be constituted effectively by the network NW_2 alone.

Fig. 9 shows a substation circuit in which the variable resistance element E_{10} may be of the heat or temperature-sensitive type, for example, having a high negative temperature coefficient of resistance and having a heater H associated therewith in a suitable container or oven O. The heater H may be connected in parallel with the capacitive reactor C_{20}, and be included in the line direct current path whereby it is traversed by the line direct current. The element E_{10} is serially connected with the network NW_1, the network NW_2 being connected in parallel with such serial connection. For the condition in which the circuit of Fig. 9 is connected at its line terminals L_1, L_2 with the long or the longest loop anticipated, the line direct current flowing through the heater H will be at its lowest and the resultant temperature of the element E_{10} will be such that the latter will be in its, or at a, high resistance condition. The serially-connected element E_{10} and network NW_1 comprise such a high resistance or impedance, therefore, that the balancing network for the substation circuit is comprised effectively of the network NW_2, only. For a short loop to which the substation circuit may be connected through the line terminals L_1, L_2, the line direct current through the heater H will be of relatively high value, and the resultant increase in the temperature of the element E_{10} will cause the latter to reduce in resistance to a low resistance, sufficiently low so that the line balancing network of the substation circuit is comprised effectively of the networks NW_1 and NW_2 in parallel.

It is evident from the foregoing that with a single heater element H and with two or more associated heat or temperature-sensitive variable resistance elements, more complex arrangements of line balancing networks may be obtained than when a single variable resistance element is employed. Using two or more of such variable resistance elements enables a more exact balance to be obtained on three or more different lengths of loop in contrast to the two (short and long) loops previously considered. In this connection, the circuit arrangement shown in Figs. 9A, 9B and 9C could be substituted between the points I—I of Fig. 9, for the heater, variable resistance element, and networks NW_1, NW_2 arrangement of that figure. The heater element H would be connected in shunt of the capacitor C_{20} as in Fig. 9. On very long loops, both of the elements E_{11}, E_{12} might be proportioned so that for the line direct current flowing under the very long loop condition, their resistances would be very high, in which case the line balancing network circuit would be constituted effectively by the network NW_C, only. For very short loops, the relatively higher line direct current will cause the heater H to raise the temperatures of the elements E_{11}, E_{12} sufficiently so that they are reduced to a very low resistance condition in comparison with the impedance of the networks NW_A, NW_B, in which situation the substation circuit line balancing network would be effectively constituted by the three networks NW_A, NW_B, NW_C, in parallel. For lengths of loops intermediate the very long and the very short loops, and which might be denominated medium length loops, the direct line current will cause the heater H to heat the elements E_{11}, E_{12} such that the change in resistance of the element E_{11} is small but the change in resistance of the element E_{12} is sufficient to reduce it to a very low resistance condition in comparison with the impedance of the network NW_C. For this latter condition, the line balancing network of the substation circuit is effectively constituted by the networks NW_B and NW_C in parallel. Each of the networks NW_A, NW_B, NW_C may comprise a resistance of appropriate magnitude and, where some specific impedance or frequency characteristic for the balancing network is desired, may include inductance and/or capacitance components.

The effective values of the resistances of the elements E_{11}, E_{12} may, of course, be raised or lowered by any desired factor by associating an induction coil or transformer T_1, T_2 with the elements E_{11}, E_{12} in the manner indicated by Fig. 9B which, except for the transformers, is the same as the arrangement of Fig. 9A.

Fig. 9C shows still another way of associating a plurality of networks NW_A, NW_B, NW_C with two heat or temperature-sensitive variable resistance elements E_{11}, E_{12} so as to obtain at least three different line balancing conditions for the line balancing network of the substation circuit of Fig. 9. Although not shown, a heater element would be associated with the elements E_{11}, E_{12} in the manner indicated in Figs. 9, 9A and 9B, the heater element being connected in the substation circuit in the manner illustrated in Fig. 9. The elements E_{11}, E_{12} would be proportioned so that when the substation circuit is connected through its line terminals L_1, L_2 in a very short loop, the line direct current flowing through the heater heats the elements sufficiently so that their resistances are very small, whereby the line balancing network of the substation circuit is effectively constituted by the three networks in parallel. For medium length loops, the heating effect of the heater could be such that the resistance of the element E_{11} might still be quite small but the resistance of the element E_{12} might be large in comparison with the impedances of the networks. In this latter situation, the substation circuit line balancing network would be effectively constituted by the network NW_C. For long or very long loops, the heating effect of the heater should be such that the resistances of both elements E_{11} and E_{12} would be very high in comparison with the impedances of the networks, in which case the substation circuit line balancing network would be constituted effectively by the networks NW_A, NW_B, NW_C in series.

Fig. 10 illustrates how this invention may be embodied in an anti-sidetone circuit such as is disclosed in the aforementioned Gooderham patent. The heater element H may be connected, for direct current, in series with the transmitter T and the line winding **11** of the three-winding induction coil between the line terminals L_1, L_2. A variable resistance device or element E, for example, of a material having a negative temperature coefficient of resistance, is connected in series with the winding **13** and is proportioned so that, for the line direct current that would flow in the subscriber's loop of an assumed length and resistance, the heater H maintains the element E at a temperature at which its resistance balances that of the line. If the actual line with which the circuit is connected is of greater resistance than that assumed, thereby resulting in a lower line direct current, the reduced heating effect of the heater H lowers the temperature and, therefore, increases the resistance of the element E. If, on the other hand, the actual line is of lower resistance than that of the assumed line, the higher line direct current increases the heating effect of the heater H, thereby raising the temperature and lowering the resistance of the element E. In this way the line balancing resistance or network in the substation circuit is automatically adjusted for different lengths of line, or for lines of the same length but of different resistances. It will be understood, of course, that some of the line balancing resistance in the substation circuit may be included as a resistive component in the winding **13**, or, if desired, a so-called linear resistance may be connected in series or in parallel with the element E in the shunt circuit around the receiver R that includes the winding **13**. The condenser C_{11} by-passes alternating current around the heater H.

A further understanding of this invention may be obtained from the following illustration of one way in which it may be applied in a specific circuit arrangement. The resistance and the reactance components of the impedance of a plurality of different length communications paths or subscriber loops, comprising a telephone station **10**, a line **20** and an exchange **30**, including a battery supply coil 50, such as is illustrated in Fig. 1 will differ. The central office impedance $R+jX$ at the most important voice frequency in practical design, that is, 1000 cycles per second, for a zero length loop, for an average length loop (4500-foot, No. 26-gauge) encountered in actual practice, and for a very long loop (16000-foot, No. 22-gauge) encountered in actual practice, may be taken as $470+j125$, $905+j10$ and $780-j600$, respectively. In absolute values these would be $486\underline{/14° 53'}$, $905\underline{/0° 38'}$ and $984\underline{/37° 34'}$, respectively. The impedance R_s+jX_s looking into the terminals of the substation 10, which may have impedance characteristics equivalent to those of substation circuits in general use in the telephone plant in this country, may be taken as $457+j255$, or $523\underline{/29° 11'}$. The impedance values assume approximately 40 ohms resistance at the exchange in series with the battery supply coil, representing the exchange wiring and supervisory relay that would be included in a subscriber cord circuit at the exchange.

In an anti-sidetone station circuit of the type shown in Fig. 2, the ratio of the line impedance to the line balancing network impedance is the power distribution ratio, Y. Should a further understanding of this ratio, Y, be required or desired, reference is made to the inventor's book, "Transmission Circuits for Telephonic Communication," published by D. Van Nostrand Company, Inc., New York, New York, particularly Chapter X, "Substation Circuits," and Appendix E, "IX. Local Battery Anti-Side-Tone Substation Circuit." In most commercial telephone substation circuits, the value of Y lies between 1 and 2. In a substation circuit presently extensively incorporated in telephone plant in this country, it is of the order of 1.36.

From the impedance values given above for the three types and lengths of lines, that is, about 486 ohms, 905 ohms and 984 ohms absolute value, it is seen that unless the line balancing network in the case of an anti-side tone set were to have different values in the three typical cases, especially in the first two cases, the amount of sidetone would vary appreciably. For the values already mentioned, the optimum resistance of the balancing network for the circuit of Fig. 2 for zero length loop would be $486 \div Y = 486 \div 1.36$, or approximately 358 ohms, for the average loop $905 \div 1.36 = 665$ ohms, and for the long loop would be $984 \div 1.36$, or approximately 722 ohms.

With these preliminary considerations, the design of a line balancing network including a varistor or a thermistor so that the network impedance will be automatically adjusted to correspond with its optimum value for the resistance or length of loop on which the substation circuit is used, would proceed along the following lines.

Fig. 11 shows a specific circuit along the lines of Figs. 1 and 2 with the balancing network X of Fig. 2 replaced by the composite network X' in accordance with the invention. The windings of the battery supply coil 50 at the exchange may have the indicated resistances, the source of potential 40 for supplying direct current to the subscriber loop may have a voltage of 48 volts. The condensers C_{50} by-pass the voice frequencies. At the substation, the windings N_2, N_3 of the induction coil may have the resistances indicated. The inductive reactor L_{12} is of an inductance so large that at voice frequencies it may be considered as of infinite impedance. For the line direct current condition existing on long loops, the device V is of such high resistance that it may be considered infinitely great. The resistance of the network X, under these conditions (the resistance of resistor r, which may be the resistive component of the reactor L_{12}, being disregarded for the moment), will be determined simply by the magnitude of resistor R_0. With the data assumed, the magnitude of resistor R_0 should then be the resistance desired for the line balancing network when the set is connected to a very long loop, that is, about 722 ohms. For the condition of zero length loop, the resistance of the line balancing network is to be about 358 ohms, to be obtained from the paralleling of the device V and the resistor R_0. In other words, the resistance presented by device V must be equal to $722 \times 358 \div (722-358)$ or 709 ohms approximately.

Fig. 13 shows, for $\frac{1}{8}''$ diameter, copper-cuprous oxide discs arranged in opposed multiple, the relationship between the alternating current resistance thereof and the direct current bias voltage applied to such discs. For a bias voltage of about .41-volt, the alternating current resistance is of the order of 709 ohms. This desired value of voltage may obviously be obtained by choosing resistance r of appropriate magnitude. For example, under a zero length loop condition, the direct current flowing is given by $48 \div (200+200+20+20+r)$ or, if r is 3 or 4 ohms, the current is approximately .108 ampere. If r is made 3.8 ohms, the direct current bias voltage across the device V will be $3.8 \times .108$ or .41-volt, and the alternating current resistance of V will be about 709 ohms.

If an average loop length is considered, for example, one that presents a direct current resistance of 375 ohms, corresponding approximately to a 4500-foot length of No. 26-gauge telephone cable, the line direct current will be given by $48 \div (200+200+20+20+375+3.8)$ or approximately .059 ampere. The direct current bias across the device V is then $.059 \times 3.8$ or approximately .224-volt. From Fig. 13, it is evident that the device V would present a resistance of approximately 15,000 ohms under such condition. Hence, the combined alternating current resistance of the device V and reisance R_0 is approximately $15{,}000 \times 709 \div (15{,}000+709) = 675$ ohms, a close approach to that desired (905/1.36 or 665 ohms) for the average loop condition.

Fig. 12 shows a modification of the substation circuit included in Fig. 11. In Fig. 12, the resistor r and the reactor L_{12} are connected in a series circuit across the series connected receiver R and capacitor C. If the resistor R_0 has a resistance of 722 ohms and that of resistor r is 3.8 ohms, the direct current in the loop is 48 volts $\div (200+200+20+3.8)$ or .113 ampere, and the direct current bias voltage across the device V is, on a zero length loop, $3.8 \times .113$ or .43-volt. The alternating current resistance of the device V is, therefore, about 650 ohms, and the combined alternating current resistance of R_0 and V is about 343 ohms. If, now, a 4500-foot length of No. 26-gauge telephone cable, having a direct current resistance of about 375 ohms, is included in the loop, the direct current flow in the loop is of the order of 48 volts $\div (423+375)$ ohms or .06 ampere. The direct current bias voltage on the resistance r would then be $.06 \times 3.8 = .23$-volt. From Fig. 13, the device V is seen to have an alternating current resistance of about 15,000 ohms; the combined alternating current resistance of R_0 and V is under these conditions $15{,}000 \times 722/(15{,}000+722) = 687$ ohms, a value approaching the 665 ohms existing on the average length of loop. On the very long loops (16,000-foot) the network resistance would be essentially that of R_0 or 722 ohms as desired.

A further understanding of the invention in so far as it involves the use of a temperature-dependent variable resistance or thermistor will be obtained from the following illustration of its application to a specific circuit arrangement.

The material constituting the temperature-dependent variable resistance may comprise a mixture of nickel, manganese and copper oxides such as is disclosed in E. F. Dearborn-G. L. Pearson Patent 2,282,944 of May 12, 1942. The variable resistance device may be constructed in accordance with Figs. 1 and 3 of G. L. Pearson Patent 2,280,257 of April 21, 1942, except that the bead 10 of such Fig. 1 would be of the referred to nickel, manganese and copper oxides mixture, in which the nickel oxide and the manganese oxide are in the ratio of 20 to 80, the copper oxide present being of the order of 5 per cent of the other oxides.

Fig. 14 is a plot of the resistance of such a thermistor versus the current through the heater coil or winding thereof at an ambient temperature of 76° F. The resistance of the heater coil or winding was of the order of 100 ohms. Table I is derived from this curve, the resistance of the thermistor being taken as a function of the power dissipated in the heater coil or winding. Fig. 15 is a plot of the thermistor resistance in ohms versus the power dissipated in the heater coil associated with it.

Table I

Resistance-current characteristics of indirectly heated thermistors

Resistance (ohms)	Direct current with heater resistance (ohms) of—				Power in heater (milliwatts)
	100	10	5	1	
15	.025	.079	.112	.25	62.5
19	.023	.073	.103	.23	52.9
29	.020	.063	.089	.20	40.0
40	.018	.057	.080	.18	32.4
72	.015	.047	.067	.15	22.5
115	.013	.041	.058	.13	16.9
254	.010	.032	.045	.10	10.0
460	.008	.025	.036	.08	6.4
1150	.005	.016	.022	.05	2.5

Consider, now, the circuit arrangement of Fig. 16. It comprises a substation **10'** a telephone line **20'** and an exchange **30'**, the latter including a source **40'** of direct current of substantially constant potential and battery supply coil **50'**. The substation circuit is similar to that of Fig. 10, but the line balancing network included in the branch containing the winding **13** and the thermistor E also includes a resistor X. For purposes of this illustration, the line winding **11** of the substation transformer may have a resistance of approximately 20 ohms, the transmitter T may have a resistance of 40 ohms. The source **40'** at the exchange **30'** may be a 48-volt battery, and each winding of the battery supply coil may have a resistance of about 200 ohms. With a substation circuit of the general type shown, the ratio of the line impedance to the balancing network impedance may be of the order of 13:1. With a line impedance of about 486 ohms, absolute value, for a substantially zero-length loop, the line balancing network resistance would be approximately 486÷13 or approximately 37.4 ohms. The line impedance on a very long loop would be of the order of 984 ohms, for which the line balancing network resistance should be 984÷13 or approximately 75.6 ohms. Assume that the circuit is as shown in Fig. 16; the design should be such that for a very long loop the resistance of the thermistor E is very high so that the line balancing network resistance is substantially that of the resistor X, that is 75.6 ohms. On a very short loop or a substantially zero-length loop, the line direct current flowing will be approximately 48 volts÷(200+200+40+20+R_H), where R_H is the resistance of the heater coil for the element E and will be of very small value. If the resistance of heater H is neglected for the moment, the direct current will be of the order of .104 ampere. If the over-all resistance of the line balancing network for the substantially zero-length loop is to be approximately 37.4 ohms, the resistance of the element E for such condition must be $(75.6\times37.4)\div(75.6-37.4)$ or approximately 74 ohms. To have this resistance, it is to be observed from Table I or from Fig. 15 that the power dissipated in the heater H must be of the order of about 22 milliwatts. Since the line direct current is of the order of .104 ampere, the heater resistance R_H must be of the order of $.022\div(.104)^2$ or about 2.03 ohms.

Assume, now, that the telephone line **20'** comprises a 4500-foot length of No. 26-gauge cable having a resistance of about 375 ohms. The line direct current flowing in the substation **10'** will be $48\div(200+200+20+40+375+2.0)$, or about .0575 ampere. The power dissipated in the heater H will be about $(.0575)^2\times2.03=6.7$ milliwatts. From Table I and Fig. 15, it is observed that the element E will be of about 400 ohms in resistance. Such a resistance in parallel with the 75.6-ohm non-inductive resistance X reduces the over-all line balancing network resistance to a value of $(75.6\times400)\div(75.6+400)$, or about 64 ohms, a value closely approaching that desired for the very long loop.

Although the invention has been disclosed with reference to a number of embodiments, they are believed at this time to be the best mode of applying the principles embodied in the invention, the scope of which, it will be understood, is not limited thereto.

What is claimed is:

1. The combination with a telephone exchange and a telephone line connecting at one end with the exchange, the impedance of which line looking into the other end of the line may be of some value between relatively wide limits, of a subscriber's substation connected to said other end of the line for transmitting and receiving telephone signal currents to and from the line, and a source of substantially constant electromotive force connected to said line for producing in said line a control current distinct from the telephone signal currents and dependent on said line impedance, said substation including a transmitting circuit, a receiving circuit and means comprising a line balancing network adapted to render said circuits conjugate, the line balancing network including impedance means automatically under influence of said control current, adjusting in resistance substantially in accordance with the absolute impedance of the line.

2. The combination with a telephone exchange including a source of current and a telephone line connecting at one end with the exhange, the impedance of which line looking into the other end of the line may be of some value between relatively wide limits, of a subscriber's substation connected to said other end of the line and includ-

ing a transmitting circuit, a receiving circuit and a line balancing network, the line balancing network including impedance means automatically adjusting in resistance substantially in accordance with the absolute impedance of the line in the direction toward a balance between said network and line, and comprising a variable resistance device having a value of resistance dependent upon the current received over said line from said source.

3. The combination of claim 2 in which said variable resistance device comprises a copper-copper oxide variable resistance.

4. The combination of claim 2 in which said variable resistance device includes a resistor adapted to be heated by current from said source, said resistor varying in resistance value in accordance with its change in temperature.

5. The combination of claim 2 in which said variable resistance device comprises silver sulphide connected in circuit to have its temperature controlled by current from said source.

6. The combination of claim 2 in which said variable resistance device comprises a resistor comprising oxides of nickel, manganese and copper connected in circuit to have its temperature controlled by current from said source.

7. The combination with a telephone exchange and a telephone line for transmitting speech currents connecting at one end with the exchange, the impedance of which line looking into the other end of the line may be of some value between relatively wide limits and said exchange containing a source of substantially constant electromotive force connected to said line for transmission over said line of a control current distinct from the speech currents; of a subscriber's substation connected to said other end of the line and including a transmitting circuit, a receiving circuit and means comprising a line balancing network adapted to connect said circuits in energy-transmitting relation to said line in conjugate relation to each other, the line balancing network including impedance means responsive to said control current automatically adjusting in resistance with the magnitude of the control current received at the substation from said exchange over said line toward a condition of balance between said balancing network and said line.

8. The combination with a telephone exchange and a telephone line connecting at one end with the exchange, the impedance of which line looking into the other end of the line may be of some value between relatively wide limits and said exchange containing a source of current for transmission over said line; of a subscriber's substation connected to said other end of the line and including a transmitting circuit, a receiving circuit and a line balancing network, the line balancing network including impedance means automatically adjusting in resistance toward a balance with respect to said line and comprising a device with a non-linear current-resistance characteristic traversed by the current received at said substation from said exchange over said line.

9. The combination with a telephone exchange and a telephone line connecting at one end with the exchange, the impedance of which line looking into the other end of the line may be of some value between relatively wide limits and said exchange containing a source of current for transmission over said line; of a subscriber's substation connected to said other end of the line and including a transmitting circuit, a receiving circuit and a line balancing network, the line balancing network including impedance means automatically adjusting in resistance toward a balance with respect to said line and comprising a device having a non-linear temperature-resistance characteristic indirectly responsive to the current received at said substation from said exchange over said line.

10. The combination with a telephone exchange and a telephone line connecting at one end with the exchange, the impedance of which line looking into the other end of the line may be of some value between relatively wide limits and said exchange containing a source of current for transmission over said line; of a subscriber's substation connected to said other end of the line and including a transmitting circuit, a receiving circuit and a line balancing network, the line balancing network including impedance means automatically adjusting in resistance in the direction of improved balance and comprising a variable resistance device having a high temperature coefficient of resistance, whose resistance varies with the magnitude of the current received at said substation from said exchange over said line.

11. The combination with a telephone exchange and a telephone line connecting at one end with the exchange, the resistance of which line may be of some value between relatively wide limits and said exchange containing a source of current for transmission over said line, of a subscriber's substation connected to the other end of the line and including a transmitting circuit, a receiving circuit and a line balancing network, the line balancing network including resistance means automatically adjusting in resistance with the magnitude of the current received at the substation from said exchange over said line in the direction of improved balance, said resistance means having a steep temperature-resistance characteristic and a heater winding for said resistance means, said resistance means being connected in circuit to be traversed by speech currents but not by current from said source and said heater winding being connected in circuit to be traversed by current received over said line from said source.

12. The combination with a telephone station and a telephone line connecting at one end with the station, the impedance of which line looking into the other end of the line may be of some value between relatively wide limits and said station containing a source of current for transmission over said line; of a second station connected to said other end of the line and including a transmitting circuit, a receiving circuit and a line balancing network, the line balancing network including impedance means automatically adjusting in resistance substantially in accordance with the magnitude of the current received at the second station from said first-mentioned station over said line in such direction as to improve the balance between the circuit of said second station and said line.

13. In combination, an exchange having subscribers' lines of different absolute impedance terminating therein, a subscriber's substation adapted to be connected to any one of said lines, said substation comprising an anti-sidetone speech current receiving and transmitting circuit including a network for balancing the impedance of the connected line, and a source of substantially constant electromotive force for association with the connected line to transmit over the connected line a control current distinct from the

speech currents, said network including an impedance automatically under the influence of said control current variable in magnitude of resistance substantially in accordance with the magnitude of the absolute impedance of the connected line.

14. In combination, a first station, a telephone line connected thereto, a second station adapted to be connected to the opposite end of said line for communication with said first station, said second station comprising an anti-sidetone speech current receiving and transmitting circuit, said circuit including a transmitting branch, a receiving branch, a network for balancing the impedance of the connected line and means for connecting said network to the transmitting branch, the receiving branch and the line with the transmitting branch and the receiving branch conjugate to each other, said network including a resistance automatically variable in magnitude of resistance in dependence upon the magnitude of the resistance of the connected line, toward a condition of balance between said network and the connected line.

15. An anti-sidetone telephone circuit including transmitting circuit, a receiving circuit and means comprising a line balancing network adapted to connect said transmitting circuit and said receiving circuit to the line in conjugate relation to each other, said balancing network including a current-dependent variable resistance.

16. An anti-sidetone telephone circuit including a transmitting circuit, a receiving circuit and means comprising a line balancing network adapted to connect said transmitting circuit and said receiving circuit in energy-transmitting relation to the line to be balanced by the network and in conjugate relation to each other, said balancing network including a thermistor.

17. An anti-sidetone telephone circuit including a transmitting circuit, a receiving circuit and means comprising a line balancing network adapted to connect said transmitting circuit and said receiving circuit in energy-transmitting relation to the line to be balanced by the network and in conjugate relation to each other, said balancing network including a varistor having the non-linear resistance characteristics of a copper-cuprous oxide disc.

18. An anti-sidetone telephone circuit including a transmitting circuit, a receiving circuit and means comprising a line balancing network adapted to connect said transmitting circuit and said receiving circuit in energy-transmitting relation to the line to be balanced by the network and in conjugate relation to each other, said balancing network including a thermistor having the non-linear resistance characteristics of a material such as a mixture of nickel, manganese and copper oxides.

19. The combination of a telephone line, a first telephone station at one end of said line, and a subscriber's substation at the other end of said line and comprising a speech current transmitting circuit, a speech current receiving circuit and a line balancing network, the resistance of said line depending upon the length of the line and said first station including a source of current for supplying direct current to the substation over said line, the magnitude of the direct current being in direct proportion to the resistance of the loop including said first station, the line and the substation, said line balancing network including variable impedance means whose resistance changes in dependence upon the strength of the direct current received over said line from said source in the direction toward a balanced condition between said network and said line.

20. In a telephone system, a telephone exchange, a plurality of telephone lines of different resistances terminating in said exchange and a subscriber substation adapted for connection with any selected one of said lines, said substation comprising an anti-sidetone speech current transmitting and receiving circuit including a network for balancing the impedance of the connected line, said exchange comprising a source of electromotive force for transmitting a control current over the connected line, and said network including a resistance automatically under control of said control current adjustable in magnitude of resistance for telephone lines of different resistances to bring the substation into balance with the connected line.

21. In a telephone system, a telephone exchange, a telephone line, a subscriber substation for connection with said exchange over said telephone line, said exchange including a source of current of substantially constant potential for supplying direct current to said substation over the line, said substation comprising an anti-sidetone speech current transmitting and receiving circuit including a network for balancing the impedance of the line, said network including a resistance automatically adjustable in magnitude of resistance in response to said direct current supplied over said line to improve the balance between said substation and said line.

22. In a telephone system, a telephone exchange, a telephone line, a subscriber substation for connection with said exchange over said telephone line, said exchange including a source of current of substantially constant potential for supplying direct current to said substation over the line, said substation comprising an anti-sidetone speech current transmitting and receiving circuit including a network for balancing the impedance of the line, said network including a resistance having a high temperature coefficient of resistance, said resistance being automatically adjustable in temperature in response to said direct current supplied over said line.

23. In a telephone system, a transmission loop comprising a first station, a telephone line, and a second station including a speech current receiving and transmitting anti-sidetone circuit having a line balancing network, and means for transmitting over the line a control current distinct from the speech currents transmitted from said circuit, said line balancing network including a variable resistance controlled by said control current, automatically adjusting in resistance with the resistance of the transmission loop to improve the balance between said substation and said line.

24. In a two-way signaling system, a line circuit, a transmitting circuit proper including transmitting apparatus, a receiving circuit proper including receiving apparatus, a balancing circuit and a transformer having a plurality of windings, two of said circuits having a winding of said transformer therein and having a terminal in common with one of the other circuits, the remaining circuit being connected with the other circuits inductively only, the transformer ratios and the impedances of two of the four component elements consisting of said line circuit, said balancing circuit, said transmitting apparatus and said receiving apparatus being so proportioned with reference to the impedance of the other two

that said receiving apparatus and transmitting apparatus are conjugate, means comprising a source of substantially constant electromotive force connected to said line circuit for sending a control direct current through substantially the whole length of said line circuit, and a non-linear resistance responsive to said control current included in one of the two component elements consisting of said balancing circuit and said line circuit.

25. In a two-way signaling system, a line circuit, a transmitting circuit proper including transmitting apparatus, a receiving circuit proper including receiving apparatus, a balancing circuit and a transformer having a plurality of windings, two of said circuits having a winding of said transformer therein and having a terminal in common with one of the other circuits, the remaining circuit being connected with the other circuits inductively only, the transformer ratios and the impedances of two of the four component elements consisting of said line circuit, said balancing circuit, said transmitting apparatus and said receiving apparatus being so proportioned with reference to the impedance of the other two that said receiving apparatus and transmitting apparatus are conjugate, means comprising a source of substantially constant electromotive force connected to said line circuit for sending a control direct current through substantially the whole length of said line circuit, a resistance having a high temperature coefficient of resistance located in one of the two component elements consisting of said balancing circuit and said line circuit, and heater means responsive to said control current for controlling the temperature of said resistance.

26. A signaling circuit including in series four components, the first of said components including a line, the second of said components including a winding of a transformer, the third of said components including a receiving instrument in parallel with a series arrangement of a line-balancing impedance means and a second winding of said transformer, and the fourth of said components including a third winding of said transformer, said circuit also comprising a transmitting instrument connected in shunt with a series connection of said first and second components, said three windings being terminated on four terminals and having a common magnetic field, a source of direct current connected to said line at its end remote from said transformer, a resistance having a high temperature coefficient of resistance in said line-balancing impedance means, and heater means for said resistance connected in series with said source, said line and said transmitting instrument, with respect to direct current.

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