July 25, 1933. E. R. WIGAN 1,919,314

TELEPHONE INSTRUMENT CIRCUIT

Filed Jan. 28, 1932 2 Sheets-Sheet 1

Fig. 1.

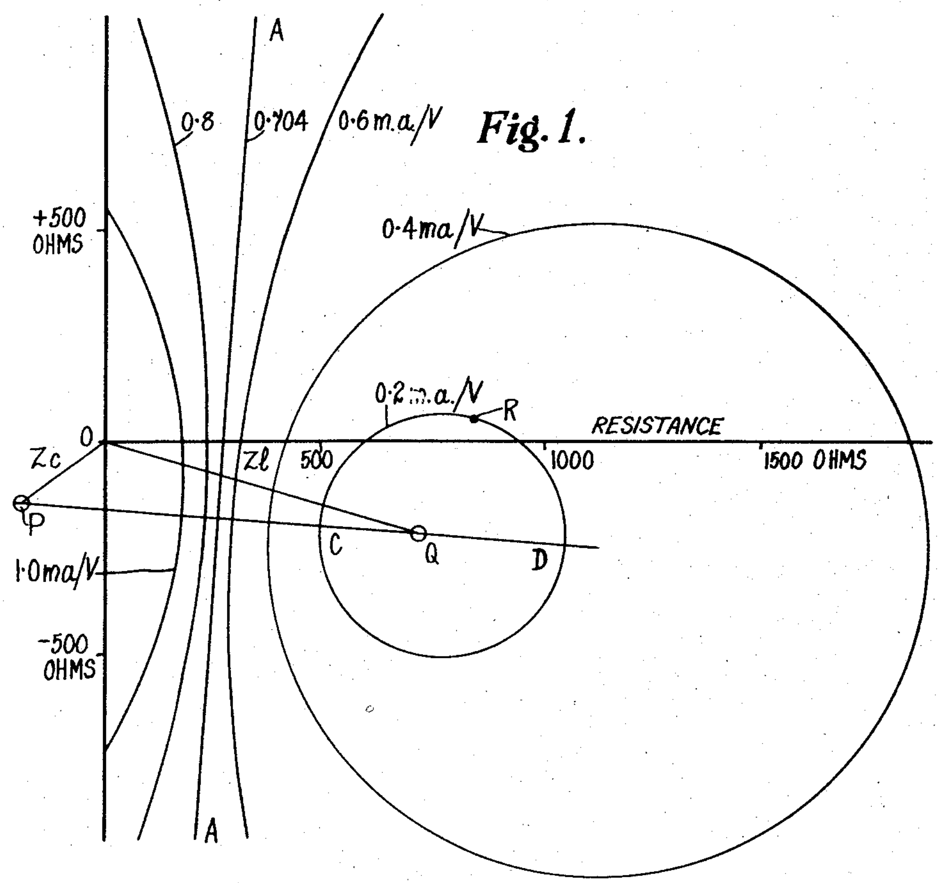


Fig. 8.

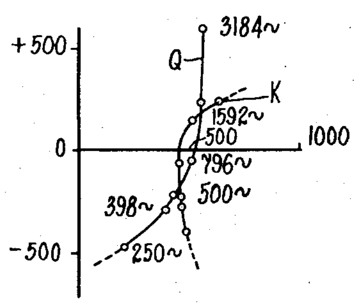
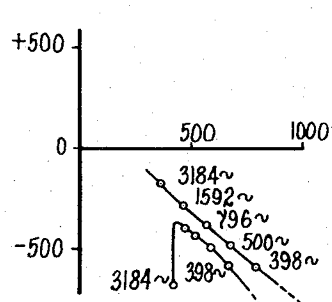


Fig. 9.



Edmund Ramsay Wigan
Inventor

By Chas. M. Candy
Atty.

Fig. 2.

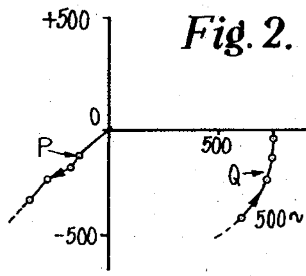


Fig. 4.

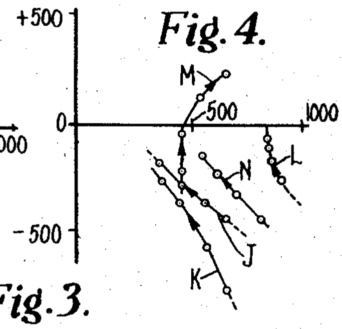


Fig. 3.

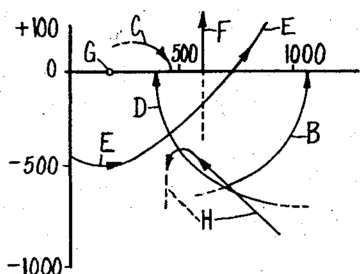


Fig. 5.

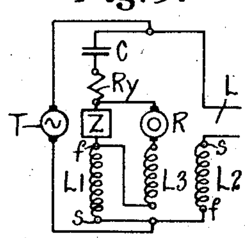


Fig. 6.

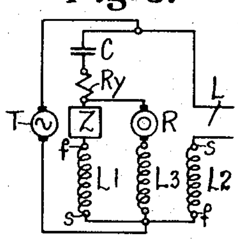


Fig. 7.

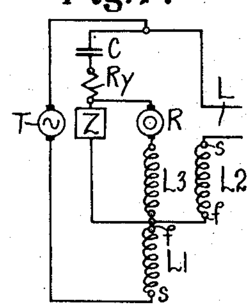


Fig. 10.

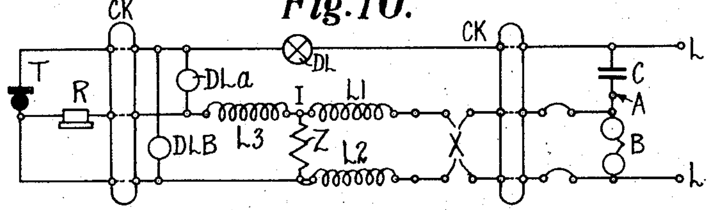
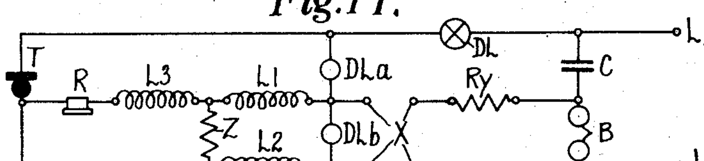


Fig. 11.



Edmund Ramsay Wigan
Inventor
By Chas. McCandy
Atty.

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UNITED STATES PATENT OFFICE

EDMUND RAMSAY WIGAN, OF LONDON, ENGLAND, ASSIGNOR TO SIEMENS BROTHERS & COMPANY LIMITED, OF LONDON, ENGLAND

TELEPHONE INSTRUMENT CIRCUIT

Application filed January 28, 1932, Serial No. 589,472, and in Great Britain February 7, 1931.

This invention relates in general to telephone substation circuits and the principal object of the invention is to provide an improved substation circuit in which side-tone is reduced to a negligible minimum when connected to different lines having varying characteristics and impedances.

Another object of the invention is to provide a new and improved substation circuit in which by choice of suitable constants for the circuit the side-tone level, while remaining low, may be varied with the line impedance in a selective manner.

A further object of the invention is to provide an improved substation circuit having induction coil windings and a balancing network in which two superimposed currents may be produced in the receiver circuit by the operation of the transmitter in case of an unbalanced condition between the line and network, one due to the inductive relation of the induction coil windings and the other due to the difference in voltage between the terminals of the receiver circuit where bridged across a part of the balancing network. These superimposed currents may oppose or aid one another dependent upon the connection of the receiver induction coil winding to the impedance in the balancing network.

The extent to which side-tone is suppressed in any substation circuit does not depend upon the substation alone but also depends on characteristics of the line which at the time is connected to the substation circuit. It is known that side-tone may be suppressed when the substation circuit is connected to a line of a particular impedance, but when a given substation circuit is connected to lines of varying impedances the side-tone may vary considerably. Another factor affecting the reduction of side-tone is the frequency of the currents involved. Therefore, if line impedance and instrument impedance vary with frequency, the reduction of side-tone is bound to be effected. In practice various line conditions and characteristics are encountered and a connection to a substation circuit involves not only the local line but varying junction or trunk lines to complete a telephone connection.

It might be mentioned here that total elimination of side-tone is not desirable except in the noisiest situations, as the side-tone to some extent serves as a guide to the telephone user in regulating the loudness of his speech, and also the absence of sound in one ear gives a feeling of deafness.

Referring now briefly to the drawings:—

Fig. 1 shows the relation between the voltage applied at the microphone terminals and the current generated in the receiver circuit for a particular circuit at a frequency of 796 cycles per second.

Fig. 2 shows the loci of the points P and Q taken from Fig. 1 as the frequency is varied for a particular circuit.

Fig. 3 shows the effect on the locus of Q when the characteristics of the different parts of the circuit are varied.

The loci shown in Fig. 4 represent the movement of the head of the impedance vector in different cases in practice at varying frequencies.

Figs. 5, 6, and 7 show three different substation or instrument circuits having their induction coil windings connected in different ways.

The two loci shown in Figs. 8 and 9 show the effect of the difference between two circuits.

Fig. 10 shows a substation circuit and connections in a desk instrument for an automatic telephone system.

Fig. 11 shows a substation circuit and connections wherein a resistance and a condenser is used to form a spark quenching circuit for the dial impulse springs.

In the present invention circuits are proposed involving a three winding induction coil and a balancing network, the receiver circuit being shunted across a part of the balancing network and the transmitter being shunted across a part of the network containing a winding of the induction coil and a condenser in series. For side-tone reduction the receiver and the third winding of the induction coil are tapped off the whole or a part of the impedance in the balancing network. Several modifications are shown in which the windings of the induction coil are connected in different ways.

Referring now in particular to Fig. 5 it will be seen that the transmitter feed current from the line flows through the winding L2 of the induction coil and the transmitter T. During reception of signals there is a source of alternating potential across the line conductors tending to drive a current through a path in the substation circuit over the upper line conductor through the transmitter T and winding L2 to the lower conductor. The current passing through the winding L2 induces a current flow in the winding L3 which actuates the receiver R.

During transmission and considering the transmiter T as a source of E. M. F., current flows out to the junction point between the windings L1 and L2 of the induction coil and then divides, part going through the winding L2 out over the line and part through the winding L1 and the balancing network comprising Z, TY, and C. Since the current flowing through these two windings are in opposite directions, the inductive effect upon the winding L3 is towards neutralization depending upon the balance of the circuits. In case the two circuits are out of balance then voltage will be induced in winding L3. In addition, since there is current flow over the balancing network and since the terminals of the receiver circuit are bridged across the impedance Z, an E. M. F. from the primary circuit is produced in the receiver circuit. The induced E. M. F. and the E. M. F. from the primary circuit may oppose or aid each other dependent upon the connection of the terminals of the receiver circuit across the impedance Z.

The characteristics of the circuit shown in Fig. 6 are substantially the same as that shown in Fig. 5. The L1 winding of the induction coil is connected in series with the impedance Z and then bridged across the receiver circuit including the receiver R and winding L3.

The characteristics of the circuit shown in Fig. 7 are substantially the same as that shown in Fig. 5. The induction coil winding L1 in this case has been reversed with respect to the winding L2 and the winding L1 is now included in the transmission bridge including the transmitter T and winding L2.

When the substation circuit is to be installed in a certain location, the average impedance of the lines in use therein will be approximated and the windings of the induction coil will then be connected in such a manner as to give the best results as regards side-tone reduction.

Mathematical consideration of the circuit relations are given with a view to facilitating design so that a maximum output and the inherent advantages of side-tone suppression can be obtained.

I have investigated mathematically the variation of side tone with line impedance and have found an equation which expresses the variation.

The equation is

$$i_B = -e_A\, P\angle a . K\angle c \frac{\Delta L}{(Zc+ZL)\ (Zc+Z_L+\Delta L)}$$

where i_B is the side tone current due to a voltage e_A generated in the microphone when the line impedance is equal to $Z_L+\Delta L$.

Z_L is that value of line impedance which gives zero side tone at the frequency considered.

ΔL is the vector difference between Z_L and the line impedance under consideration.

Zc is the impedance of the instrument circuit measured from the line terminals with the microphone and receiver connected.

$P\angle a$ is a voltage step up ratio equal to the ratio of the open circuit a. c. voltage at the line terminals to an E. M. F. applied at the microphone terminals.

$K\angle c$ is the current step-down ratio, equal to the ratio of the receiver current to the incoming line current.

Zc, $P\angle a$ and $K\angle c$ can be ascertained by measuring methods in a particular instrument.

The equation shows that the side tone current is related as follows: (1) to the product of the transmission and reception efficiency of the circuit. The transmission efficiency is proportional to

$$\frac{P\angle a}{(Zc+Z_L+\Delta L)}$$

and the reception efficiency to

$$\frac{K\angle c}{(Zc+Z_L+\Delta L)}$$

(2) to the microphone voltage e_A.

It varies as line impedance alters, other factors being constant and is proportional to

$$\frac{\Delta L}{(Zc+Z_L+\Delta L)}$$

The values ΔL, Zc and ZL are vector values.

It is also clear that the side tone current cannot be zero for all values of ΔL so long as $P\angle a$ and $K\angle c$ are finite and further if the two efficiencies are high, small changes in line impedance result in relatively large changes in side tone.

Fig. 1 should be referred to which depicts a particular case (experimentally confirmed) at a particular frequency of 796 cycles per second. Values along the abscissa axis from the point O represent resistance component values of line impedance. The values along the ordinate axis through O represent reactance component values of the line impedance. Positive values are above the abscissa axis, negative below. The value of Zc for the instrument circuit is given by PO and OQ represents the line impedance for which the side tone is zero.

If the instrument circuit is connected to a line the impedance is represented by the point R, the impedance being OR then ΔL is represented by the line QR and the ratio

$$\frac{\Delta L}{(Zc+Z_L+\Delta L)}.$$

is given by the ratio of QR to PR.

For a given constant ratio of lengths QR to PR the locus of R is a circle although the circle may have infinite diameter as evidenced by the line locus AA which is at right angles to the line PQ. Any particular locus shows how ΔL may vary whilst the side tone current remains constant although altering in phase. The values such as 0.2 m. a/V indicate for the particular circuit considered the receiver current is 0.2 milliamperes per volt a. c. generated at the microphone. A value of 0.5 appears to be tolerable. A value over 0.6 becomes annoying and a value below 0.2 gives a sensation of deafness to the user.

A 600 ohm non-reactive junction line connected to the instrument through a stone bridge would provide a line impedance of 600−j.200 ohms approximately. The side tone ratio with zero local line resistance would be about 0.1 m. a./V. With 450 ohm local line the side tone ratio would be about 0.2 m. a./V all taken at 796 cycles per second. It has to be remembered that due to the drop in feeding current in a common battery circuit with increased line resistance, the a. c. voltage falls by about 50% between zero and 450 ohm line resistance so that the side tone level would be the same in both cases.

Again for a particular circle for instance that on which R is situated the ratio of

$$\frac{\Delta L}{Zc+Z+\Delta L}$$

is the same for the points C and D. Let this ratio be S then it can be shown that the radius of the circle is the length PQ multipled by

$$\frac{S}{1-S^2}$$

and the centre of the circle is on a line passing through P and Q and is distant from P by an amount

$$PQ\cdot\frac{1}{1-S^2}$$

Given one circle and the value of milliamps per volt the circles for other values of milli-amps per volt can be drawn.

The radius of the circle is

$$PR.\frac{S}{1-S^2}$$

or in other words

$$(Zc+ZL).\frac{S}{1-S^2}$$

From the above results it appears that the larger the value of Z_L+Zc for which the instrument circuit has no side tone, the greater the area in the locus diagram, Fig. 1, for which side tone is below a given value.

Again for a particular instrument circuit it may be ascertained whether the line impedances of the lines with which the instrument may be used entails too much side tone and an adjustment of the circuit made accordingly.

The voltage and current parameters $P\angle a$ and $K\angle c$ may be ascertained by direct measurement.

Whilst an instrument circuit with anti-side tone arrangements may give rise to no side tone when connected to a line of a particular impedance and the currents involved are of a specified frequency, it does not follow that this occurs at other frequencies. In this connection Fig. 2 should be referred to which shows for a particular instrument circuit the loci of the points P and Q as the frequency is varied. The direction of increasing frequency is indicated by the arrow heads. The four points indicated refer to frequencies of 500, 796, 1592 and 3184 per second.

The locus forms of Fig. 1 remains circular with frequency variation. It will be clear that with the instrument circuit which gives the loci shown in Fig. 2, side tone may be expected if the head of the line impedance vector does not move with Q, i. e. it must have the same value and phase angle as the vector OQ.

Figs. 5, 6 and 7 represent three instrument circuits included in the present invention. In these figures, the receiver is designated R, the transmitter by T. The line terminals are denoted by L, C is a condenser, Ry is a resistance and Z an impedance. The bell is omitted but would be as is usual connected between one line branch and the condenser, the condenser being a necessity in the case of common battery working.

The induction coil has three windings denoted L1, L2, L3. The letters *s* and *f* denote the start and finish of windings. The start and finish of coil L3 is not shown for a reason which will later appear. The windings being wound in the same direction round the core the terms start and finish have the well understood meanings.

The impedance Z, resistance Ry and condenser C is a unit which plays a major part in determining the Z_L value of the instrument circuit. Ry and Z may be tapped so that L3 and the receiver R may be shunted across a part or the whole of the series connection of the two.

With the circuits shown in Figs. 5, 6 and 7 the form of the locus of Q of Fig. 1 when frequency varies depends among other things on the values of C, Ry and Z. If this connection contains only capacity and resistance, loci such as B, C and D in Fig. 3 are obtained which have their upper limits on the resistance axis. In the case of B the start of winding L3 and finish of winding L1 are connected together. Locus D may be obtained by using a winding L3 of comparatively low inductance. The locus C may be obtained by reversing the connection of winding L3 that is by connecting its "finish" end to *f* of winding L1.

Loci which cross over the resistance axis such as E and F are produced when the impedance Z contains inductance or capacity. For locus F R*y* is comparatively large.

The single point G results from a condenser and resistance of special values in the balancing part. The locus H is produced in cases in which there is appreciable leakage inductance in the induction coil windings and is a modification of the locus D. The locus H has certain advantages.

Clearly by suitable design of the instrument circuit the movement of Q in Fig. 1 when the frequency changes may be varied considerably and offers the possibility of suiting the instrument to lines on which it may be used.

Fig. 4 shows graphs of cases which occur in practice. A locus here such as L shows the movement of the head of an impedance vector with frequency. As to any one locus shown the points which are encircled refer as in Fig. 2 to frequencies of 500, 796, 1592 and 3184 cycles per second. The impedance vector, of course, has one end at O and its head on a locus.

The locus J is the locus of the head of the impedance vector for a long length of standard cable in series with a 150 ohm local line. The locus K represents the same circuit in which however is included a stone feeding bridge with a 2 m.f. condenser in each wire. Locus L refers to a long junction line of 150 lb. aerial wire with a local line of 150 ohms. Locus M refers to a case in which the impedance which faces the instrument is that of a non-junction connection between two subscribers using similar instrument circuits on the same automatic exchange the local line resistance being assumed to be 150 ohms to each instrument. To keep the side tone zero the point Q for an instrument circuit would have to move coincidently with the line impedance on the locus concerned in Fig. 4. In any case a divergence is permissible and in fact desirable as exact co-incidence, i. e. no side tone, as noted before has a disturbing effect on the user.

No one instrument circuit can fit in with the several loci of Fig. 4 and for an instrument of general use, an "average" locus such as N may be taken into account and the instrument designed with this in view.

Having pointed out the important factors influencing the design of the anti-side tone circuit of the present invention, certain formulæ will be given for the circuits of Figs. 5, 6 and 7. These formulæ indicate the value of ZL for an instrument, that is the line impedance for which side tone is zero, and its variation with frequency, in other words an equation is given for the Q locus. Adjustments of the constants within the equations may be necessary to give the greatest electrical efficiency as regards speech transmission but electrical efficiency may be largely ignored provided that the side tone level is low. The practical value of the circuits is very closely related to the latter factor as by satisfactory side tone reduction a relatively silent background is provided against which received speech is contrasted and simplicity and cheapness may be given due consideration in design.

Certain assumptions have been made in deriving the equations, for instance the equation relating to the Fig. 5 circuit is given on the assumption that the microphone will have a resistance much lower than the impedance of the lines to which the circuit would be connected.

Consequently the windings L1 and L2 are connected as an auto-transformer giving a step up of voltage from the microphone to the line. The size of the winding L3 has an effect on the shape of the Q locus but may be arranged to give good reception efficiency. Windings L1 and L2 in Figs. 6 and 7 act also as step up transformers L2 in Fig. 7 having more turns than L1.

It may be noted that the increase of effective resistance of the induction coil windings with frequency disturbs the equations except where L1 to L2 is unity when its effect is reduced.

In the equations it is convenient to refer all the winding ratios to the receiver or L3 winding. It is assumed that the ratio of turns will be proportional to the square root of the ratio of inductances and that the coupling coefficients between windings are unity.

For the circuit of Fig. 5

$$Z_L = T2 \cdot \frac{Ry + Z(1 \pm T2 + T1) - \frac{j}{wC}}{T1 \pm \frac{jZ}{wL3}} \quad (1)$$

For the circuit of Fig. 6

$$Z_L = T2 \cdot \frac{Ry + Z\left(1 \mp \frac{T1 + T2}{1 \pm T1}\right) - \frac{j}{wC}}{T1 \pm \frac{jZ}{wL3\ (1 \pm T1)}} \quad (2)$$

For the circuit of Fig. 7

$$Z_L = (T2 - T1) \cdot \frac{Ry + Z\ (1 \pm T2) - \frac{j}{wC}}{T1 \pm \frac{jZ}{wL3}} \quad (3)$$

In these equations

ZL = Line impedance giving zero side tone.

Ry, Z and C are the elements before mentioned.

$T1=\sqrt{\frac{L1}{L3}}$; $T2=\sqrt{\frac{L2}{L3}}$, $L1$, $L2$, $L3$ being the inductances of the three windings shown $W=2\pi$ times the frequency, j is the operator $\sqrt{-1}$.

The plus or minus signs are used according to the connection of the receiver winding L3. The upper sign is used when the finish of L3 is connected to the receiver and the lower (minus) sign when it is the start that is connected to the receiver.

If $T1=T2=1$ for the case covered by Equation (1)

$$Z_L=\frac{Ry+3Z-\frac{j}{wC}}{1+\frac{jz}{wL3}} \qquad (4)$$

or

$$\frac{Ry-Z-\frac{j}{wC}}{\frac{1-jz}{wL3}} \qquad (5)$$

according to whether the positive or negative sign is used.

In Equation (5) the numerator and denominator can each represent an impedance equivalent to a condenser and a resistance in series. Such a circuit arrangement can be adjusted in such a way that the impedance ZL is independent of frequency, that is, becomes a pure resistance. The arrangement is then aperiodic. Each Equation 1, 2 and 3 allows of an aperiodic arrangement. In the case of Equations 1 and 3 the lower sign of the two alternative signs is used. In the case of Equation 2, the lower sign is used if T1 is less than unity and the upper sign if T1 is greater than unity.

The adjustment required of the constant may be gathered from Equation (1). If ZL is to be independent of frequency the numerator and denominator of the fraction must have the same angular value at all frequencies.

Equating tangent values

$$wC\left(\frac{1}{Ry+Z\,(1\pm T2+T1)}\right)=\frac{Z}{T1.wL3}$$

The value of ZL then becomes

$$T2\cdot\frac{L3}{CZ}$$

which is independent of frequency when Z is a pure resistance.

This value of the ZL gives the locus G in Fig. 3.

The resistances of the induction coil windings are not taken account of in the equations for the reason that they are designedly low and although they may rise with frequency do not disturb the equations to an extent greatly influencing design.

The effect of leakage inductance is to add to ZL a negative reactance equal to the positive reactance of the leakage inductance at each frequency.

To meet the special case of the line for which the graph or locus M is given in Fig. 4 the circuit of Fig. 5 may have the following values: $T1-T2=1$, $Ry=200$ ohms, $Z=70$ ohms resistance with 10 milli-henries inductance, $C=2$ microfarads, $L3=93$ milli-henries. The sign of connection of receiver winding is positive.

The induction coil windings may have a d. c. resistance of about 20 ohms each.

The locus of Q is shown in Fig. 8 for this case. The locus marked K gives the impedance locus of a circuit of the same impedance (e.g. a distant "twin" instrument) measured with 150 ohms in series and seen through a Stone bridge with 150 ohms on the outgoing side. The two loci overlap but there is no great divergence at the main speech frequencies.

The case represented in Fig. 4 by the graph or locus J can be met by another arrangement the form shown in Fig. 5.

The circuit is made up with the following values:

$T1=1$, $T2=4$, $Ry=224$ ohms, $Z=35$ ohms, $L3=36$ milli-henries. The sign of connection of the receiver winding is negative.

The locus of Q here is of the form marked H in Fig. 3. This may be compared with the locus J of Fig. 4 which concerns a cable standard 20 lb. wire as measured from the end of a 150 ohm loop through a repeating coil exchange circuit. The two loci are shown in Fig. 9. The inflexion in the locus H is due to leakage inductance in the induction coil.

A circuit giving good all round performances has the Q locus shown in Fig. 2 and the constants are as follows: $T2=T1=1$, $Ry=525$ ohms, $C=2$ m. f., $Z=75$ ohms, $L3=93$ milli-henries. The circuit is as in Fig. 5 and the sign of connection of the receiver winding is positive.

In the foregoing examples the receiver impedance was 124+j.230 ohms at 796 c. p. a. The transmitter had a resistance of the order of 50 ohms and the induction coil windings had an a. c. resistance of the order of 20 ohms.

The resistance Ry may however be included in the winding of L1 in the cases of Fig. 5 by winding the coil with a high resistance alloy or with small gauge copper wire. Resistance in Z may go in coil L1 in the case of Fig. 6.

Both resistance Ry and impedance Z may be tapped so that both may be adjusted to suit the line with which the instrument may be used.

It is pointed out that as will be seen in the equations the use of the resistance Ry (as considered separate from Z) gives considerable and simple control of the position of the Q locus on the diagram as distinct from the shape. In place of Ry an inductive resistance may be used. The Equations (1), (2) and (3) are general and the effect of any such substitution will be perceived. The effect of the presence or absence of the condenser C will also be perceived.

An instrument circuit is shown in Fig. 10 in a conventional manner to illustrate the connection in a table instrument for an automatic telephone system.

T and R are transmitter and receiver respectively of a hand micro-telephone. I is the induction coil situated in the base. In the separate bell box are the condenser C and bell B. L and L are line terminals. Three conductor cords CK are used for the connection between separate parts. DL is the dial and DLa and DLb are dial off-normal contacts. Switch hook contacts are situated at X and are closed when the instrument is taken into use.

As to the induction coil the same designations L1, L2, L3 are used as in Fig. 5. The resistance Ry is formed by the high resistance winding L1. The impedance Z may be resistance or resistance and reactance.

The resistance (Ry) may however be associated with the condenser in the bell box and if desired may be included so as to be in series with the bell or condenser. The talking circuits of Fig. 10 are substantially the same as those described for Fig. 5 and therefore need not be described in detail.

Fig. 11 shows a case in which the resistance Ry is used in conjunction with the condenser C to form a spark quench for the dial impulse contacts. The talking circuits of Fig. 11 are somewhat similar to those described for Fig. 5. When the calling device DL is operated the dial off normal springs DLa and DLb close to provide the impulse circuit which may be traced as follows: from the upper line L, impulse springs DL, off normal springs DLa and DLb, the lower switchhook springs X and to the lower line L. The circuit for quenching the spark at the impulse springs DL may be traced from springs DL, condenser C, resistance Ry, and off normal springs DLa back to the impulse springs DL.

It is essential to the invention to have two impedances such as (C and Ry) and Z in series.

I desire to state however that as regards the circuit arrangement shown in Fig. 5, I make no claim for such circuit when Ry is zero, C has a finite value and the impedance Z is a pure resistance.

What I claim as new and desire to secure by Letters Patent is:

1. In a substation telephone circuit comprising a transmitter, a receiver, two impedances connected in series, an induction coil having three windings, a line, a series circuit including the second of said windings and said transmitter in series connected in bridge of said line, a second series circuit including said two impedances and the first of said windings in series connected in bridge of said transmitter, and circuit means connecting the third of said windings in series with said receiver across one of said impedances.

2. In a substation telephone circuit comprising a transmitter, a receiver, two impedances connected in series, an induction coil having three windings, a line, a series circuit including the second of said windings and said transmitter in series connected in bridge of said line, a second series circuit including said two impedances and the first of said windings in series connected in bridge of said transmitter, and circuit means for connecting the third of said windings in series with said receiver in bridge of that portion of said second series circuit including one of said impedances and said first winding.

3. In a substation telephone circuit comprising a transmitter, a receiver, two impedances connected in series, an induction coil having three windings, a line, a series circuit including the first and second of said windings and said transmitter in series connected in bridge of said line circuit, a second series circuit including said two impedances in series connected in bridge of that portion of said first series circuit including said first winding and said transmitter, and circuit means connecting the third of said windings in series with said receiver across one of said impedances.

4. A substation telephone circuit comprising a transmitter, a receiver, a first impedance including a resistance and a condenser in series, a second impedance connected in series with said first impedance, an induction coil having three windings, a line, an impulse transmitting device for transmitting impulses over said line, a first series circuit including the second of said windings and said transmitter in series connected in bridge of said line, a second series circuit including the third of said windings and said receiver in series connected in bridge of said second impedance, a third series circuit including said first and second impedances and the first of said windings connected in bridge of said transmitter, and a spark quenching circuit including said first impedance and said transmitting device.

5. In a substation telephone circuit comprising a transmitter circuit including one winding of an induction coil and a transmitter, a balancing network for side tone reduc-

tion including two impedances and another winding of the induction coil in series bridged across said transmitter, and a receiver circuit including a receiver and a third winding of the induction coil in series connected in a bridge of one of said impedances.

6. In a substation telephone circuit, a transmitter circuit including a transmitter and one winding of an induction coil, a balancing network for side tone reduction including two impedances and another winding of the induction coil in series connected in bridge of said transmitter, a receiver circuit including a receiver and a third winding of the induction coil connected in bridge of one of said impedances, means including said windings and connections responsive to the operation of said transmitter during speech transmission for causing two superimposed currents to flow in said receiver circuit.

7. In a substation telephone circuit, a transmitter circuit including a transmitter and one winding of an induction coil, a balancing network for side tone reduction including two impedances and another winding of the induction coil in series connected in bridge of said transmitter, a receiver circuit including a receiver and a third winding of the induction coil connected in bridge of one of said impedances, means including said windings and connections responsive to the operation of said transmitter during speech transmission for causing two superimposed currents to flow in said receiver circuit, said superimposed currents assisting or opposing each other dependent upon the connection of the receiver circuit to said one impedance.

8. In a substation telephone circuit comprising a transmitter circuit including a transmitter and one winding of an induction coil, a balancing network for side tone reduction including another winding of the induction coil, an impedance, a pure resistance, and a condenser in series connected in bridge of said transmitter, and a receiver circuit including a receiver and a third winding of the induction coil in series connected in bridge of said impedance.

9. In a substation telephone circuit comprising a transmitter circuit including a transmitter and one winding of an induction coil in series, a balancing network for side tone reduction including another winding of the induction coil, a first pure resistance, a second pure resistance, and a condenser in series connected in bridge of said transmitter, and a receiver circuit including a receiver and a third winding of the induction coil in series connected in bridge of said first resistance.

10. In a substation telephone circuit comprising a transmitter circuit including a transmitter and one winding of an induction coil in series, a balancing network for side tone reduction including another winding of the induction coil, a first pure resistance, a second pure resistance, and a condenser in series connected in bridge of said transmitter, and a receiver circuit including a receiver and a third winding of the induction coil in series connected in bridge of said first resistance, the line impedance of the substation circuit for zero side tone being substantially independent of frequency when used on a line circuit having the same impedance.

11. In a substation telephone circuit comprising a transmitter circuit including a transmitter and one winding of an induction coil in series, a balancing network for side tone reduction including another winding of the induction coil, an impedance, a tapped resistance, and a condenser in series connected in bridge of said transmitter, and a receiver circuit including a receiver and a third winding of the induction coil in series connected in bridge of said impedance.

EDMUND R. WIGAN.