Spring May 9, 1932

Improvements relating to Telephone Circuits

Edmund Ramsay Wigan, *Siemens*

PATENT SPECIFICATION

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Complete Left: Dec. 7, 1931.

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PROVISIONAL SPECIFICATION.

Improvements relating to Telephone Instrument Circuits.

We, SIEMENS BROTHERS & CO. LIMITED, of Caxton House, Tothill Street, Westminster, London, S.W. 1, a Company registered under British Law, and EDMUND RAMSAY WIGAN, of 18, Cambridge Road, Lee, London, S.E. 12, a British subject, do hereby declare the nature of this invention to be as follows:—

This invention relates to telephone instrument circuits for common battery telephone systems, and has in view improved arrangements for diminishing side tone.

In a commonly used circuit, one line wire from the exchange is connected to one terminal of one of the windings of an induction coil this winding being hereinafter referred to as the primary winding. The other terminal of the winding is connected through the transmitter to the other line wire, and also through a branch circuit comprising the receiver, the other winding of the induction coil (hereinafter referred to as the secondary winding) and a condenser in series, to the other line wire.

To reduce side-tone it has been proposed to remove the receiver from the branch circuit and place it across the terminals of a third winding on the induction coil. It has also been proposed to introduce a P.D. into the local circuit consisting of the third winding and the receiver by connections to some other part of the instrument circuit.

However, the extent of side-tone elimination in such circuits depends not only upon the apparatus constants but also on line impedance. It has not been found possible to design an instrument circuit on the lines referred to which will reduce the side-tone to zero for all values of line impedance. The present invention has in view an instrument circuit in which by choice of suitable constants for the circuit the side-tone level, while remaining low, varies with line impedance in a selected manner. For instance it may be preferred to render side-tone a minimum when the line is electrically short.

In the present invention the local circuit is bridged across the whole or a portion of an impedance included in the branch containing the secondary winding of the induction coil. This impedance may have a variety of forms. The local circuit may be connected across any portion of this impedance. The type of impedance inserted in the secondary circuit, and the portion included in the local circuit, depends on the constants of the apparatus used in the telephone instrument circuit and upon the line impedance. When the impedance inserted in the secondary circuit contains a resistance, only a portion of which is included in the local circuit, the remainder of the resistance may be made integral with the secondary winding of the induction coil by making the winding either of small gauge copper wire or resistance alloy wire or both. Under these conditions the resistance component of the impedance across which the local circuit is bridged may either be wound non-inductively as a separate unit or the whole or part of it may be included in the windings of a separate inductance.

The impedance may also be provided with several tappings so that the impedance in series with the secondary winding of the induction coil is adjustable, and so that the portion of this impedance included in the local circuit is similarly adjustable. The tappings are chosen so that the variation in side-tone level with line impedance has the desired characteristic. The terminals of the third winding may be brought out so that the direction of connection into the local circuit may be reversed to secure more effective suppression of side-tone according to whether the line impedance has a positive or negative phase angle.

If the line has a relatively large positive reactance the third winding of the induction coil is connected so that (the secondary winding and the third winding being wound in the same sense) its start is in the most direct connection with the start of the secondary winding. If the line has a relatively large negative reactance the finish of the third winding is in the most direct connection with the start of the secondary winding.

When the impedance inserted in the secondary circuit consists of a resistance

alone this may be wound on the induction coil so that a complete unit having four terminals is obtained which can replace the coils of existing instruments.

A portion of the resistance may be used for spark quenching during dialling where automatic telephone circuits are concerned.

The term "impedance" should be understood to comprise capacity and reactance.

Dated this 7th day of February, 1931.

SIEMENS BROTHERS & CO., LIMITED,
By their Attorney,
F. A. Lawson,
For Selves and Co-Applicants.

COMPLETE SPECIFICATION.

Improvements relating to Telephone Instrument Circuits.

We, SIEMENS BROTHERS & CO. LIMITED, of Caxton House, Tothill Street, Westminster, London, S.W. 1, a Company registered under British Law, and EDMUND RAMSAY WIGAN, of 18, Cambridge Road, Lee, London, S.E. 12, a British subject, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to telephone instrument circuits for telephone systems and has in view improved arrangements for diminishing side tone.

In the common instrument circuit an induction coil is provided which coil has two windings one winding being in series with the receiver and the condenser, the transmitter being in parallel with this circuit.

Circuits have been proposed involving an induction coil with three windings. In one such arrangement the line is connected to a circuit comprising the three windings and a balancing or auxiliary resistance in series, the receiver being shunted across a part of the series containing a winding of the coil and the balancing resistance. The transmitter is shunted across a part containing another coil and a condenser. In connection with this arrangement mathematical consideration of the circuit relations were given with a view to facilitating design so that a maximum output and the inherent advantage of side tone suppression could be obtained. In a further arrangement intended particularly to obtain suppression of side tone the receiver in the above mentioned common circuit is removed from the branch in which it is situated and a resistance included in its place across which resistance is shunted a series connection of a third winding and the receiver, the intention being that by suitably proportioning the values of the resistance of the impedance and the third winding voltage relations are such that the current in the receiver during transmission are substantially zero. The mathematical considerations of the circuit relations are not entered into.

The extent to which side tone is suppressed in any anti-side tone system or circuit does not depend on the instrument circuit alone as has been recognised in proposals in which a balancing circuit is provided the characteristics of which are related to the line characteristics in order that complete suppression may be obtained.

In practice however various line conditions and characteristics obtain, and a connection to an instrument involves not only the local line i.e. the line to the exchange, but any junction or trunk line involved in the connection between subscribers.

It is clear therefore that although side tone may be suppressed when the instrument is connected to a line of a particular impedance it is not always suppressed and may vary considerably. The variations for a given instrument circuit with lines of varying impedance do not appear to have been considered. A further factor affecting reduction of side tone is the frequency of the currents involved. If the line impedance and instrument impedance varies (as is most usual) with frequency the reduction must be affected.

The present invention relates to instrument circuits embodying three winding induction coils which are arranged so that side tone may be readily controlled. We may remark here that we do not consider total elimination of side tone to be 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 whilst external sound reaches the other is disturbing giving a feeling of deafness.

The circuits have the general feature of the ordinary circuit in that as viewed from the line the transmitter and receiver are in parallel circuits. For side tone reduction the receiver and the third winding of the induction coil are tapped off the whole or a part of an impedance.

The type of circuit involved is illus-

trated in Figs. 5, 6 and 7 of the accompanying drawings which figures are hereinafter more particularly referred to.

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

The equation is

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

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 $ZL+\Delta L$. ZL is that value of line impedance which gives zero side tone at the frequency considered, and ΔL is the vector difference between ZL 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, and $K\angle c$ is the current step-down ratio, equal to the ratio of the receiver current to that in the incoming line circuit. 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

$\frac{P\angle a}{(Zc+ZL+\Delta L)}$ and the reception efficiency to

$\frac{K\angle c}{(Zc+ZL+\Delta L)}$ (2) to the microphone voltage e_A.

It varies as line impedance alters other factors being constant and is proportional to $\frac{\Delta L}{(Zc+ZL+\Delta L)}$. 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 of the accompanying drawings 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 representing resistance values as regards 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 the vector 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 of which is represented by the vector 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 C.B. 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

$\frac{\Delta L}{Zc+Z_L+\Delta L}$ 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 $PQ.\frac{1}{1-S^2}$.

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 $PQ.\frac{S}{1-S^2}$ or in other words $(Zc+Z_L).\frac{S}{1-S^2}$.

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 cycles per second.

The locus forms of Fig. 1 remain 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 C.B. working.

The induction coil has three windings denoted L_1, L_2, L_3. The letters s and f denote the start and finish of windings, the start and finish of coil L_3 is not shown for a reason which will later appear. The windings being wound in the same direction round the core the term 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 L_3 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 L_3 and finish of winding L_1 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 L_3 that is by connecting its "finish" end to f of winding L_1.

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 Ry 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 formula will be given for the circuits of Figs. 5, 6 and 7. These formula indicate the value of Z_L 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

Consequently the windings L_1 and L_2 the circuit would be connected.

are connected as an auto-transformer giving a step up of voltage from the microphone to the line. The size of the winding L_3 has an effect on the shape of the Q locus but may be arranged to give good reception efficiency. Windings L_1 and L_2 in Figs. 6 and 7 act also as step up transformers L_2 in Fig. 7 having more turns than L_1.

It may be noted that the increase of effective resistance of the induction coil windings with frequency disturbs the equations except where L_1 to L_3 is unity when its effect is reduced.

In the equations it is convenient to refer all the winding ratios to the receiver or L_3 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

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

For the circuit of Fig. 6

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

For the circuit of Fig. 7

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

In the equations

Z_L = Line impedance giving zero side tone.

Ry, Z and C the elements before mentioned.

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

The plus-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 sign when it is the start that is connected to the receiver.

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

$$(4)\ Z_L = \frac{Ry + 3Z - \frac{j.1}{wC}}{1 + \frac{j.z}{wL3}} \text{ or } \frac{Ry - Z - j.\frac{1}{wC}}{1 - j.\frac{z}{wL3}} \quad (5)$$

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 Z_L 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 alternate signs is used. In the case of equation 2, the lower sign is used if T1 is less than unity the upper sign if T1 is greater than unity.

The adjustment required of the constants may be gathered from equation (1). If Z_L 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

$$\frac{1}{wC(Ry+Z.(1-(T2+T1))} = \frac{Z}{T1.(wL3)}$$

The value of Z_L then becomes $T2 \cdot \frac{L3}{CZ}$ which is independent of frequency when Z is a pure resistance.

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

The resistance 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 Z_L 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 of the form shown in Fig. 5.

The circuit is made up with the following values.

T1=1; T2=4; Ry=224 ohms; C=2 m.f.; 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 case of standard 20 lb. cable 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 performance has the Q locus shown in Fig. 2 and the constants are given viz. 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+j230 ohms at 796 c.p.s. The transmitter had a resistance of the order of 50 ohms and the induction coil windings had a d.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 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 is 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 of winding L1. The impedance Z may be resistance or resist-

ance 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.

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.

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

We desire to state however that as regards the circuit arrangement shown in Fig. 5 we make no claim for such circuit when Ry is zero C has a finite value and the impedance Z is a pure resistance and the appended claims should be read subject to this disclaimer.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A telephone instrument circuit including a three winding induction coil, a receiver, a transmitter and a side tone controlling part comprising two impedances in series in which a third winding of the induction coil (L3) and the receiver are connected in series across one of the said impedances, a line winding (L2) of the induction coil is traversed by the whole of the line current and the two impedances form a branch connected in parallel with the transmitter whether or not the remaining winding of the coil is included in that branch or in series with the transmitter substantially as described.

2. A telephone instrument circuit according to Claim 1 in which the receiver and third winding of the induction coil are bridged across one impedance and the other impedance is pure resistance and a condenser.

3. A telephone instrument according to Claim 2 in which the bridged impedance is a pure resistance.

4. A telephone instrument according to Claim 3 in which the line impedance (Z_L) for no side tone is substantially independent of frequency.

5. A telephone instrument according to Claim 2 in which the resistance is tapped.

6. A telephone instrument circuit for automatic telephone systems according to Claim 2 in which the said resistance is (in conjunction with the condenser) used as a spark quench as regards the number dial of the instrument.

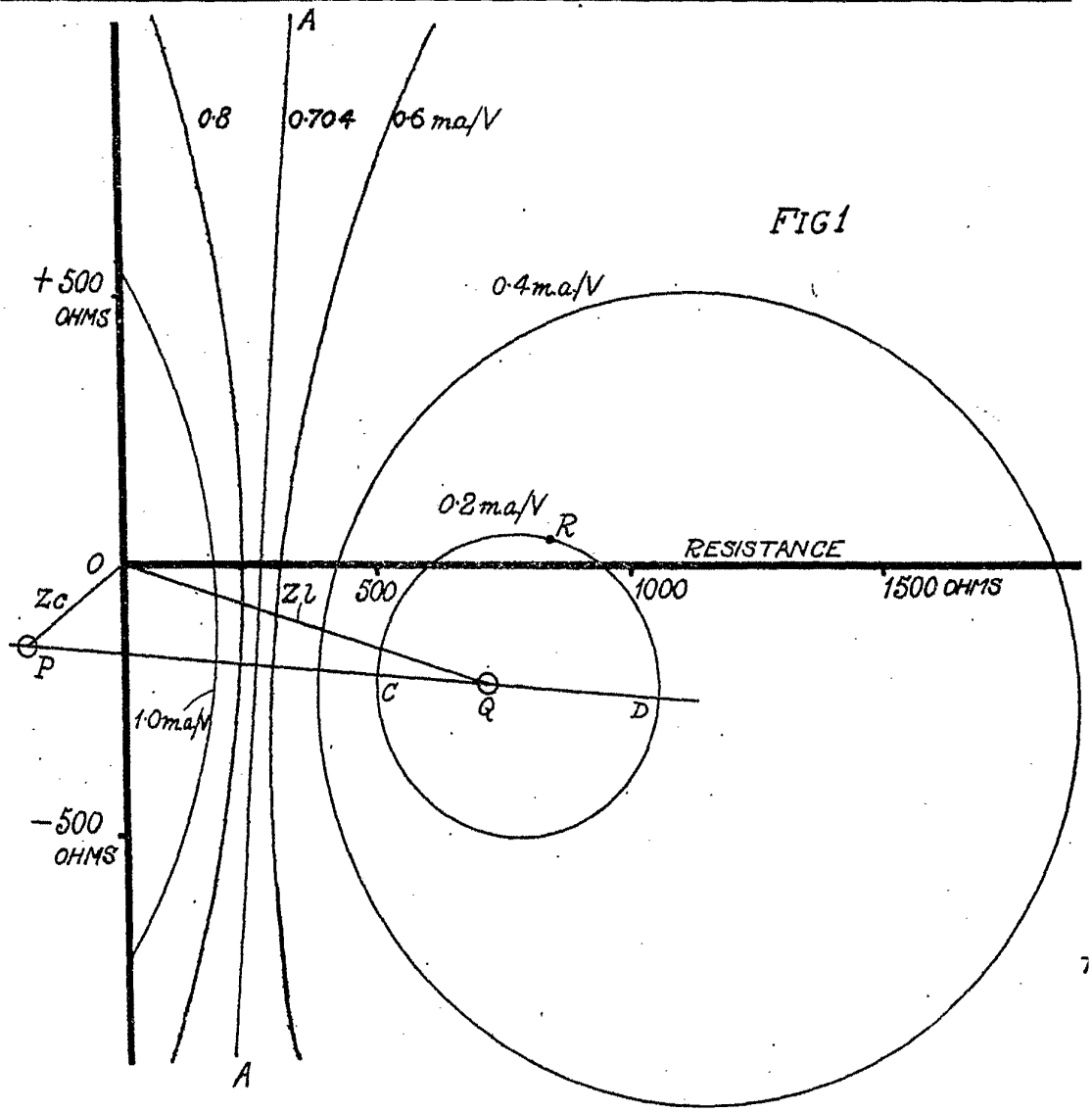
7. A telephone instrument circuit according to Claim 2 in which the bridged impedance contains resistance and inductance.

8. A telephone instrument circuit as claimed in Claim 1 having the hereinbefore specified values of T1, T2, Ry, Z, L3 and C.

Dated this 7th day of December, 1931.

SIEMENS BROTHERS & CO.,
LIMITED,
By their Attorney,
F. A. Lawson,
For Selves and Co-Applicants.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1932



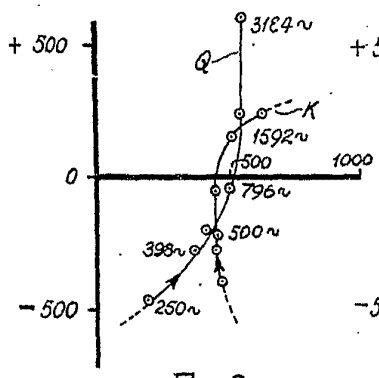


FIG 8

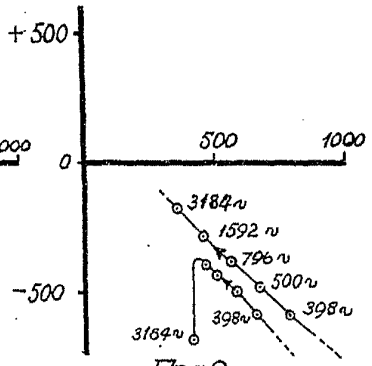


FIG 9

[This Drawing is a reproduction of the Original on a reduced scale.]

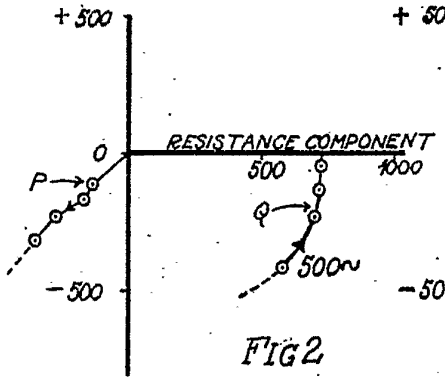


FIG 2

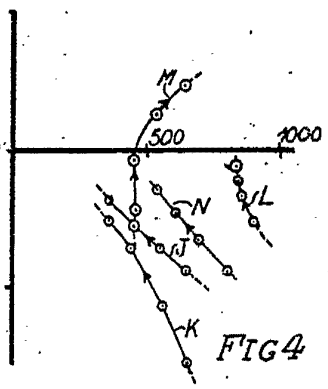
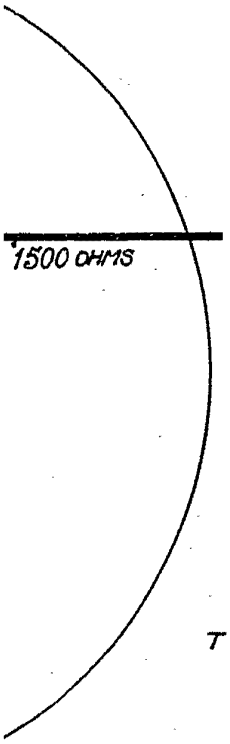


FIG 4



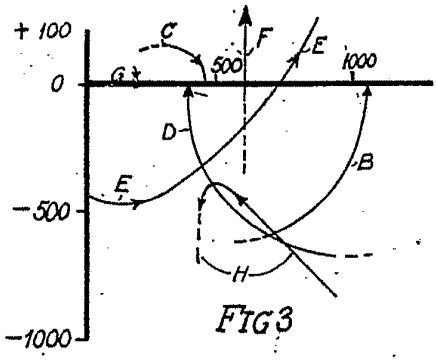


FIG 3

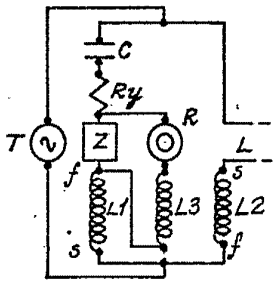


FIG 5

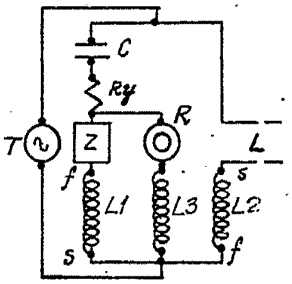


FIG 6

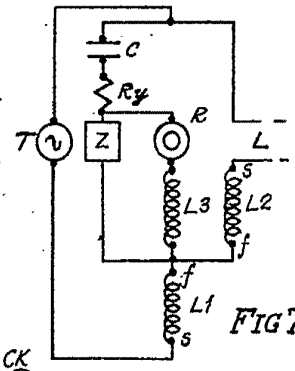


FIG 7

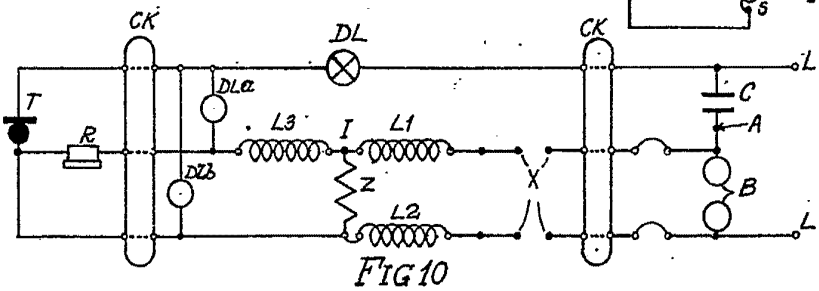


FIG 10

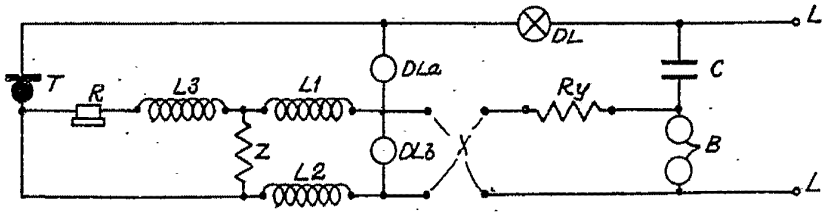


FIG 11

Charles & Read Ltd. Photo Litho.

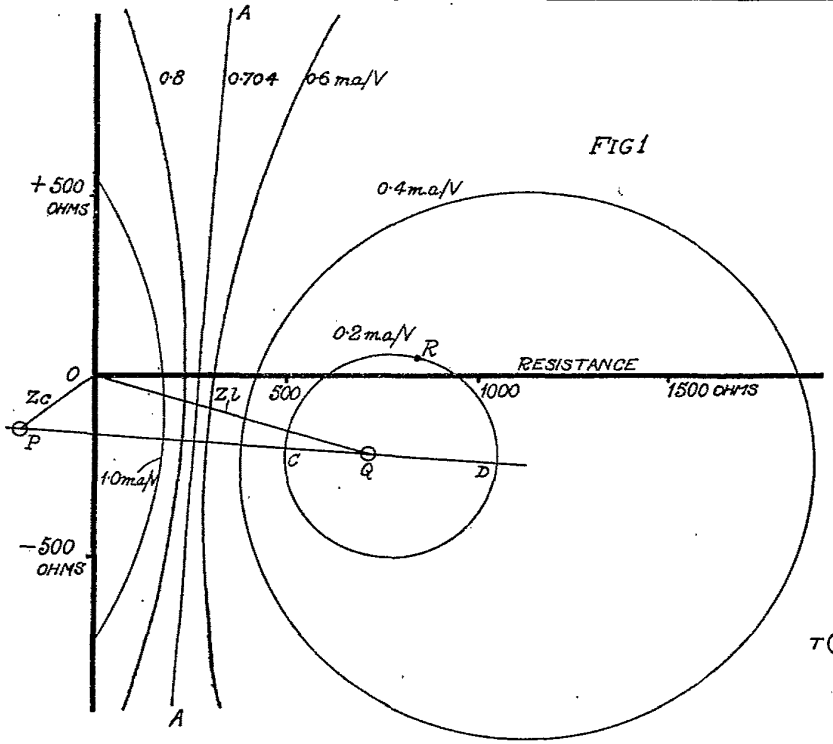


FIG 1

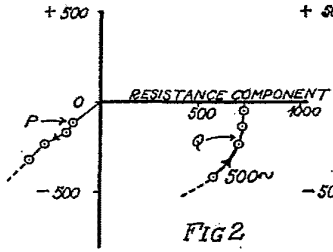


FIG 2

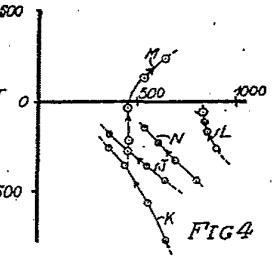


FIG 4

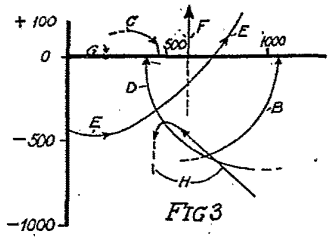


FIG 3

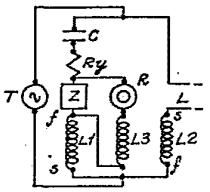


FIG 5

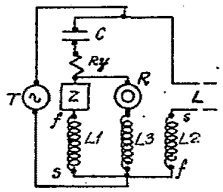


FIG 6

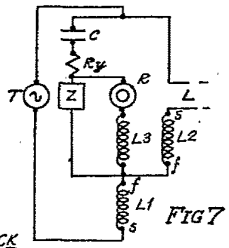


FIG 7

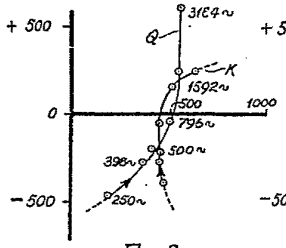


FIG 8

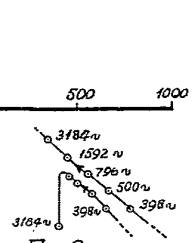


FIG 9

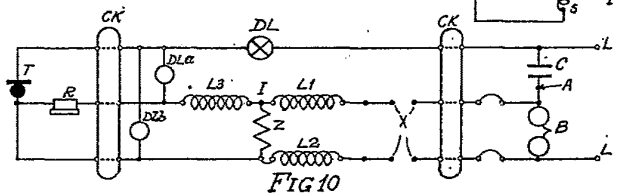


FIG 10

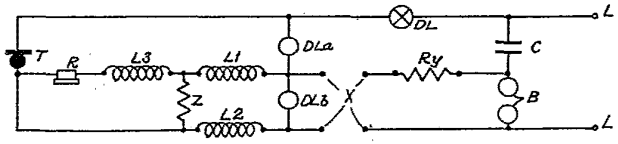


FIG 11

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