

Feb. 25, 1941.

J. S. STONE

2,232,891

CONDENSER TELEPHONE TRANSMITTER CIRCUIT

Filed April 5, 1938

2 Sheets-Sheet 1

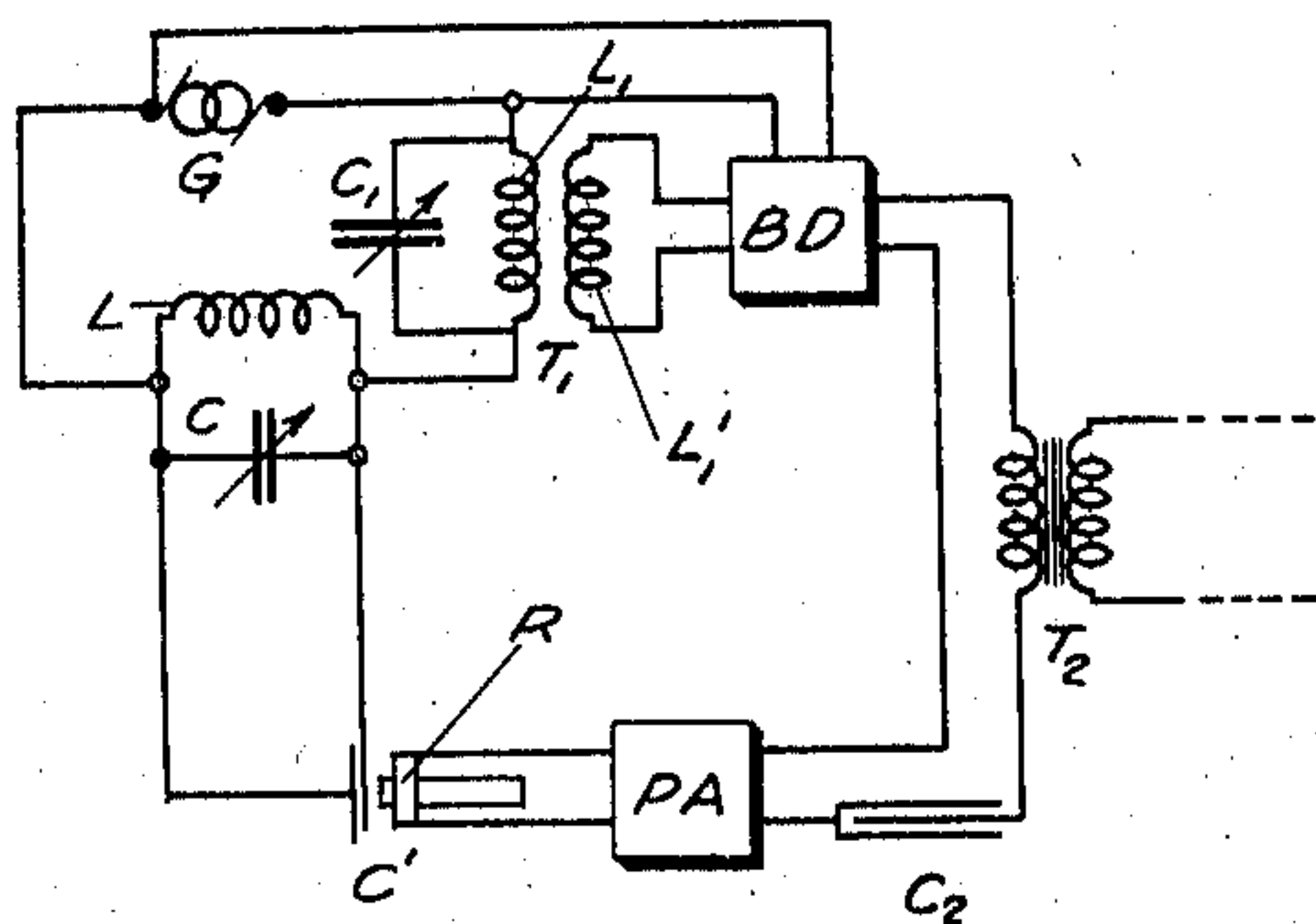


Fig. 8.

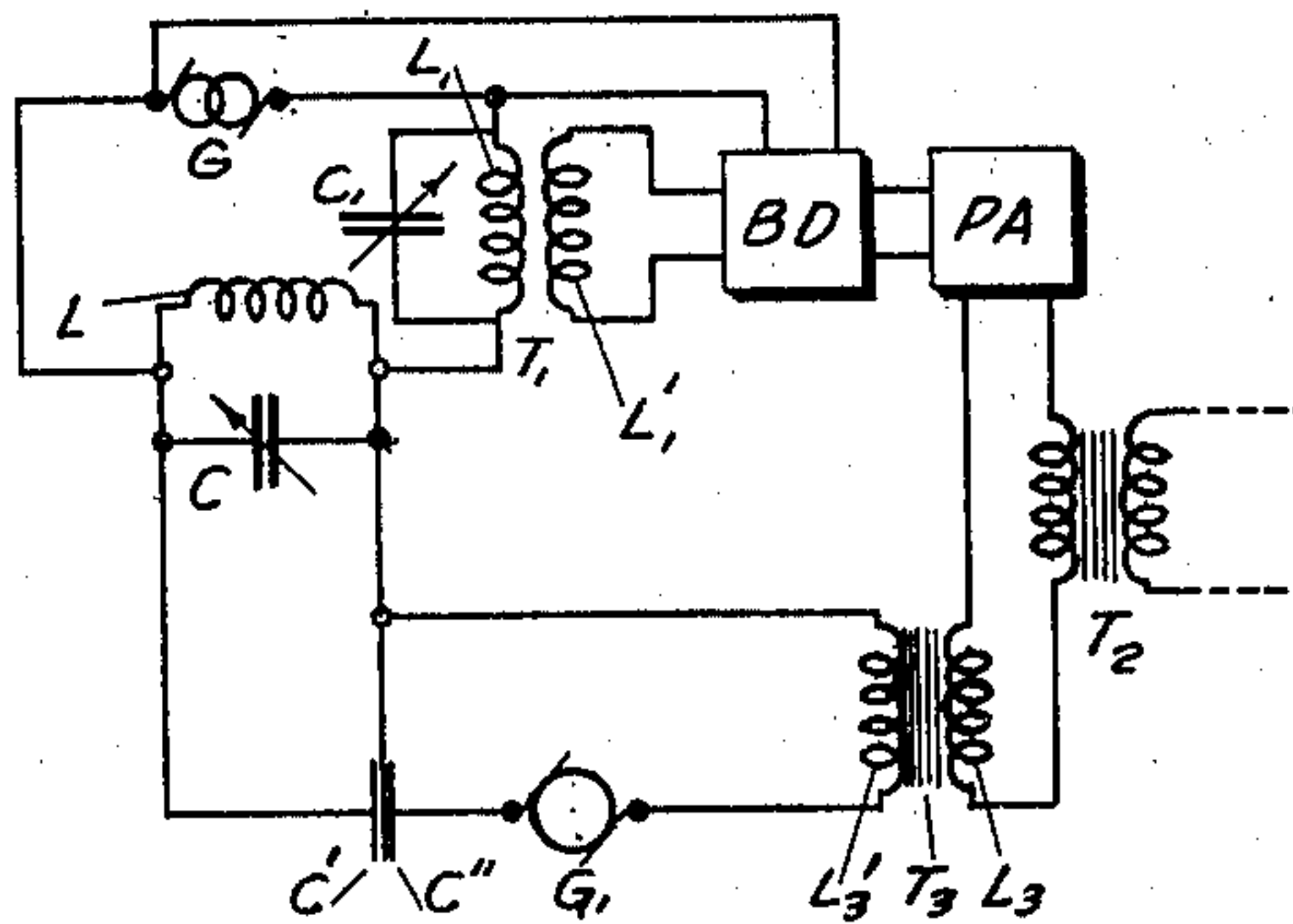


Fig. 9.

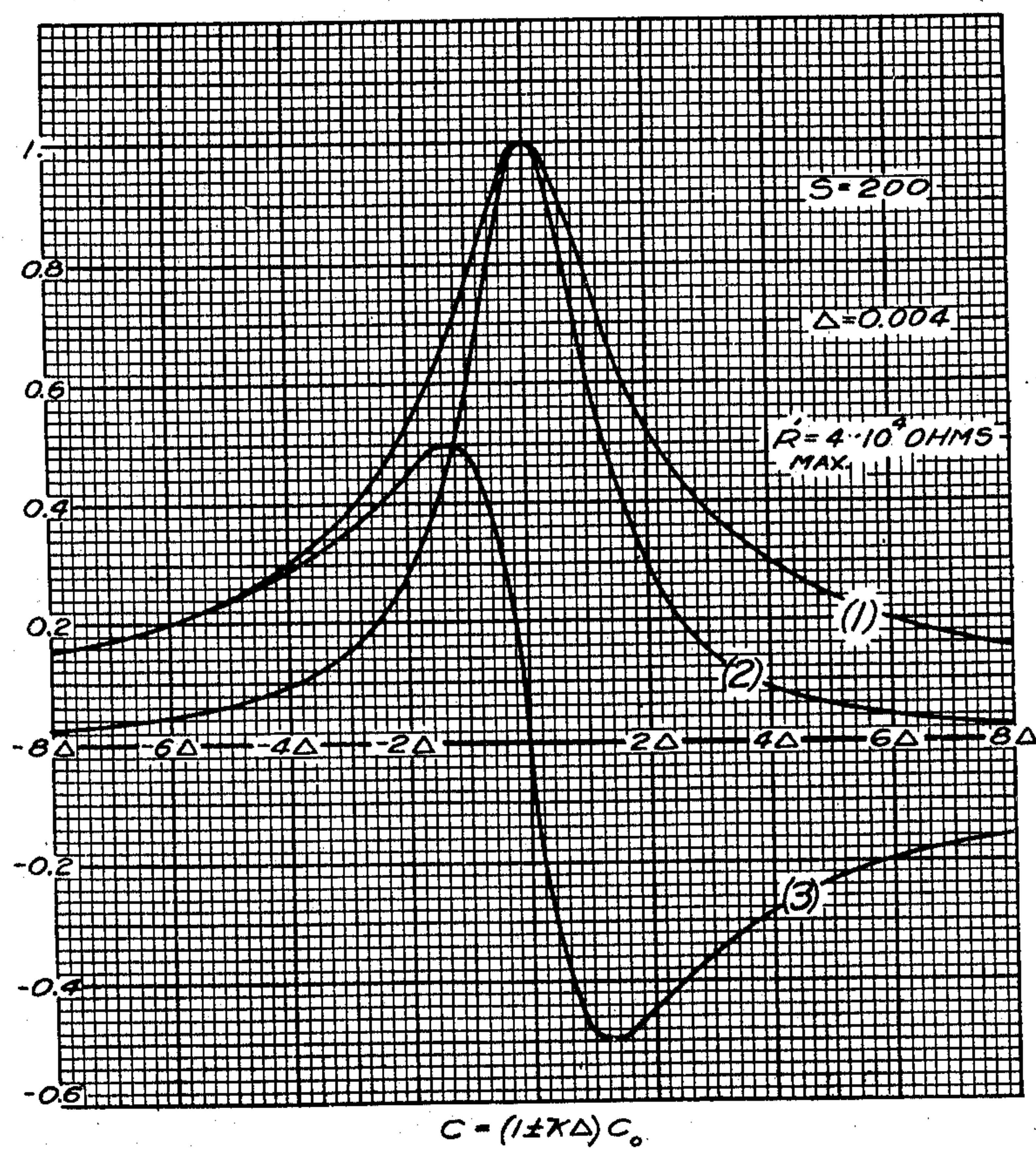


Fig.1.

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2 Sheets-Sheet 2

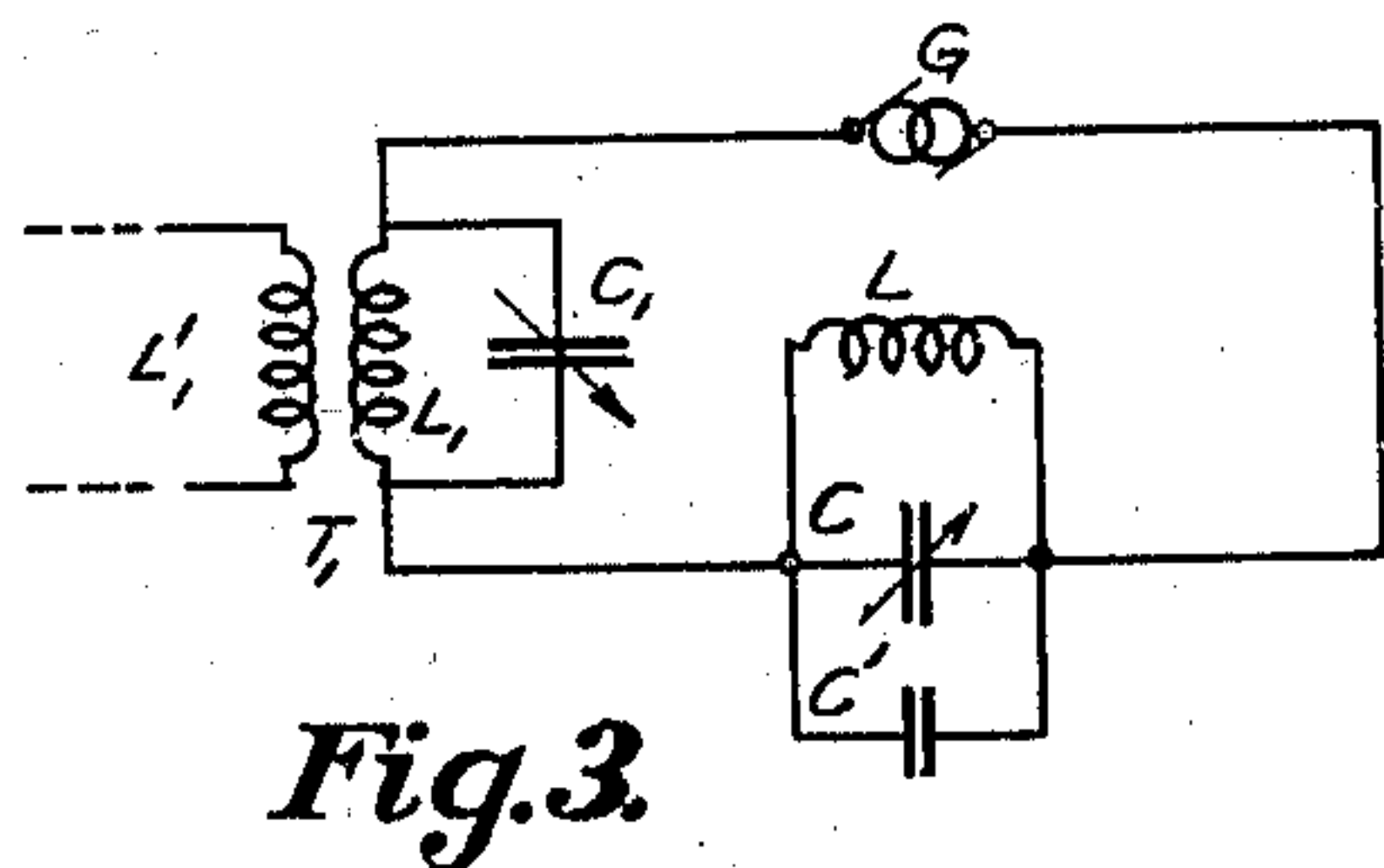


Fig. 3.

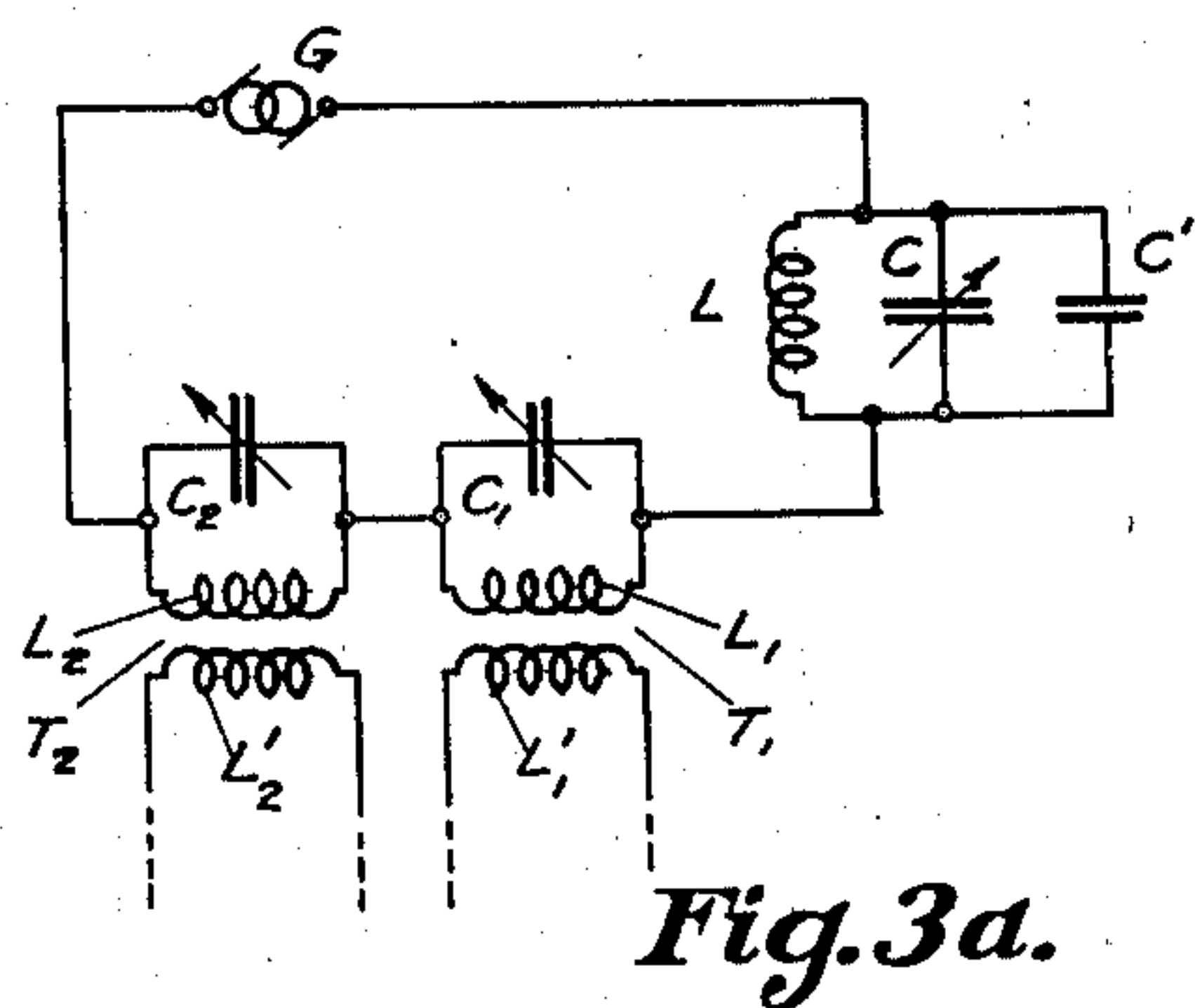


Fig. 3a.

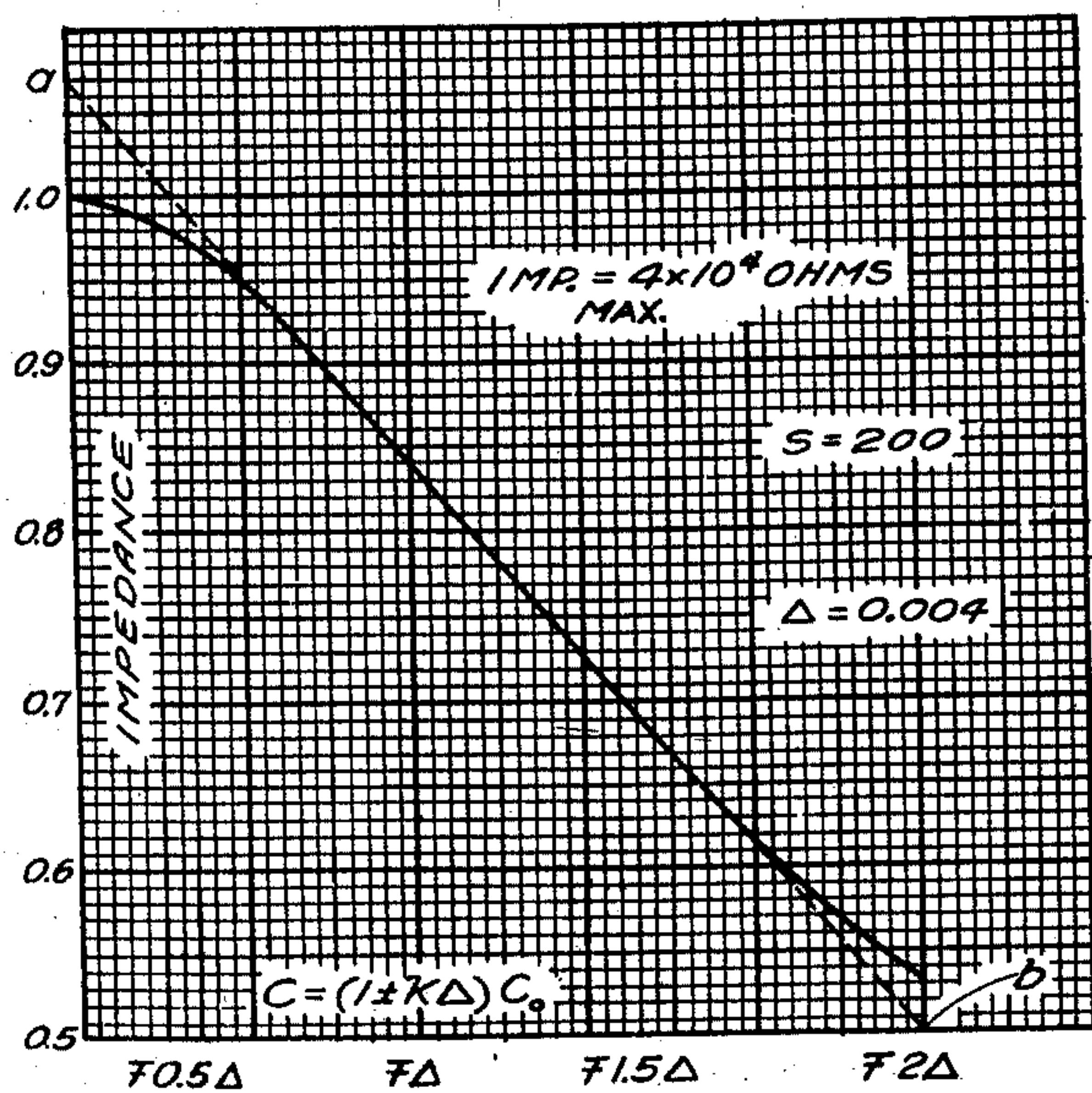


Fig. 2.

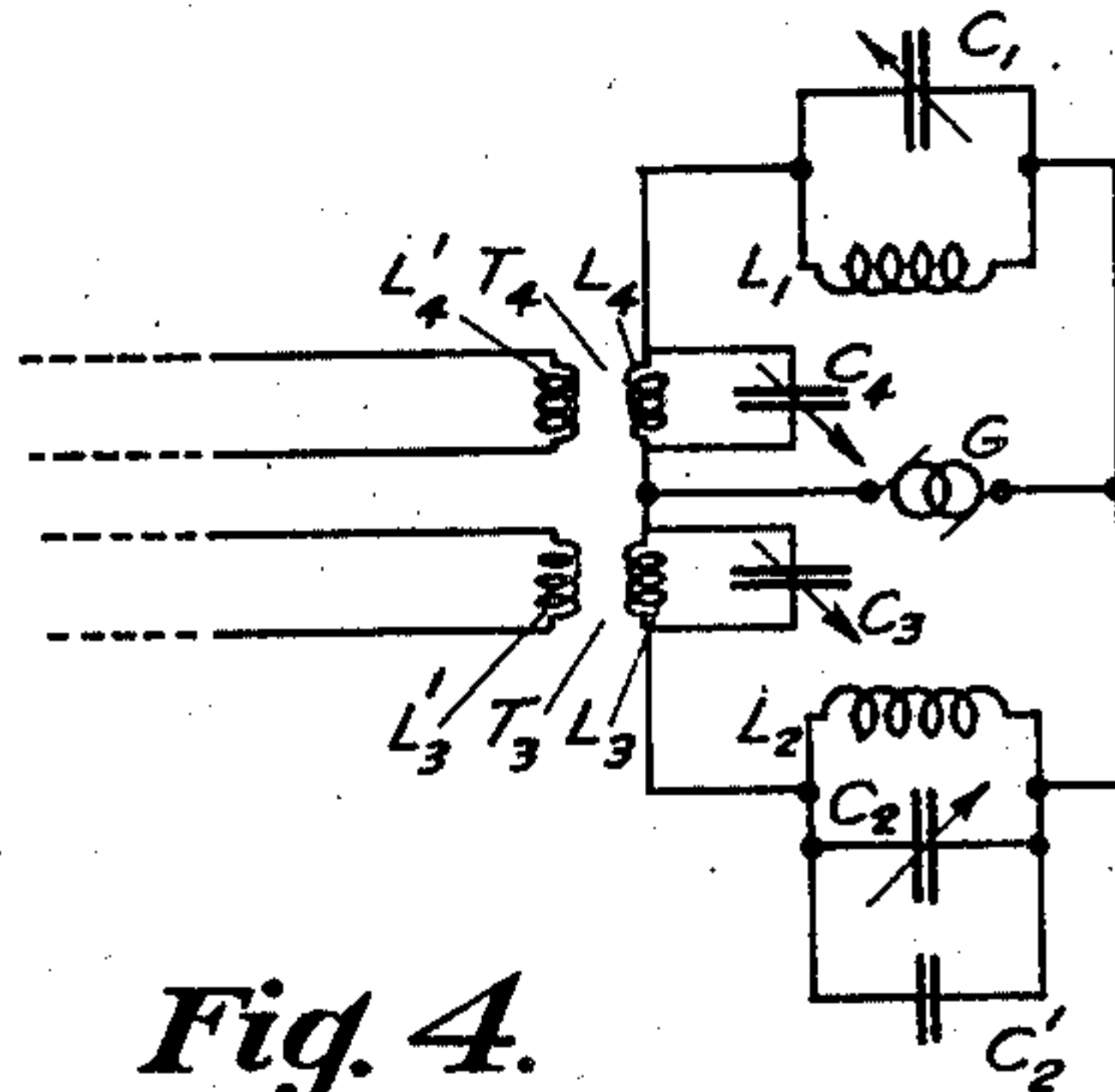


Fig. 4.

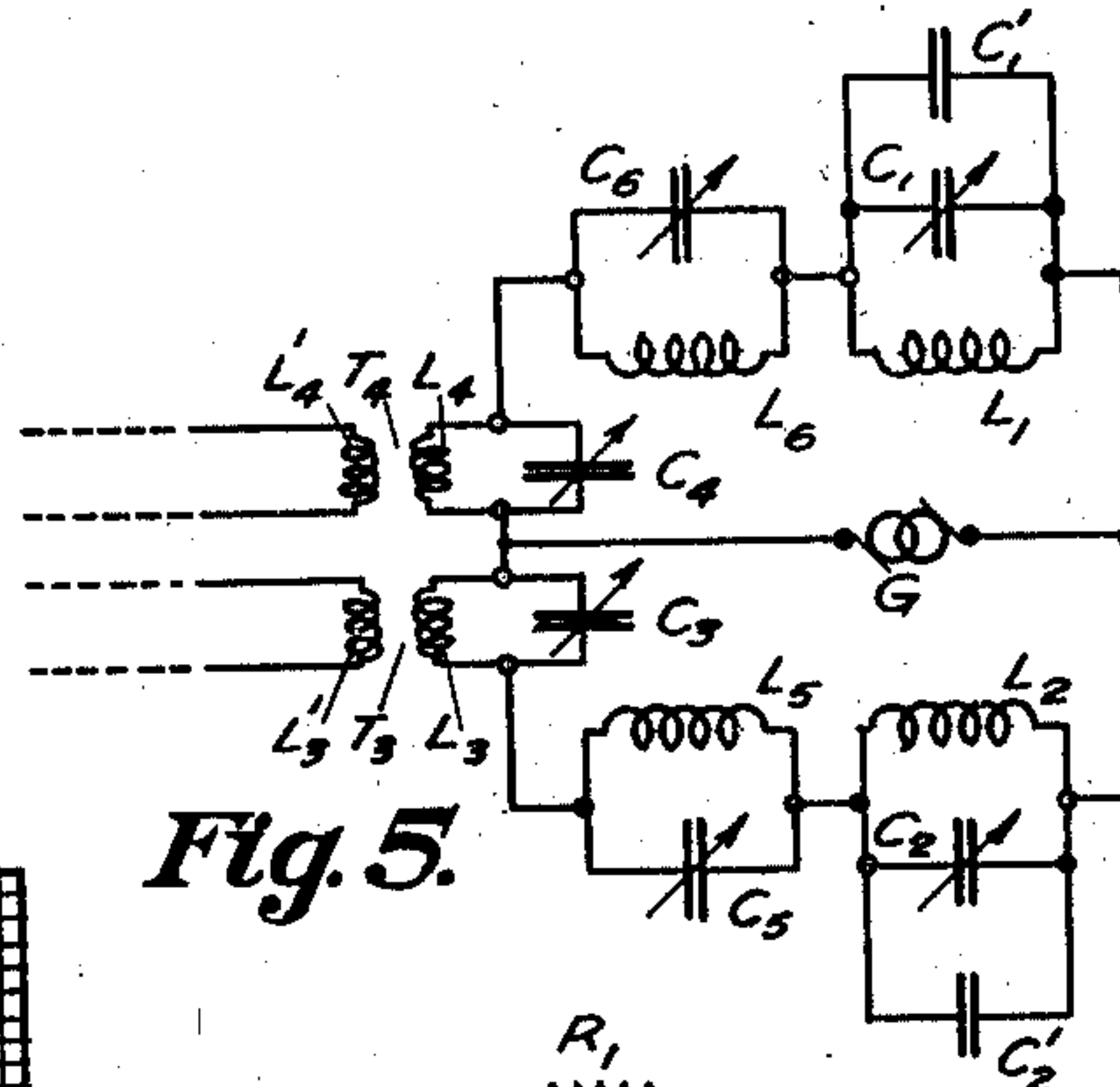


Fig. 5.

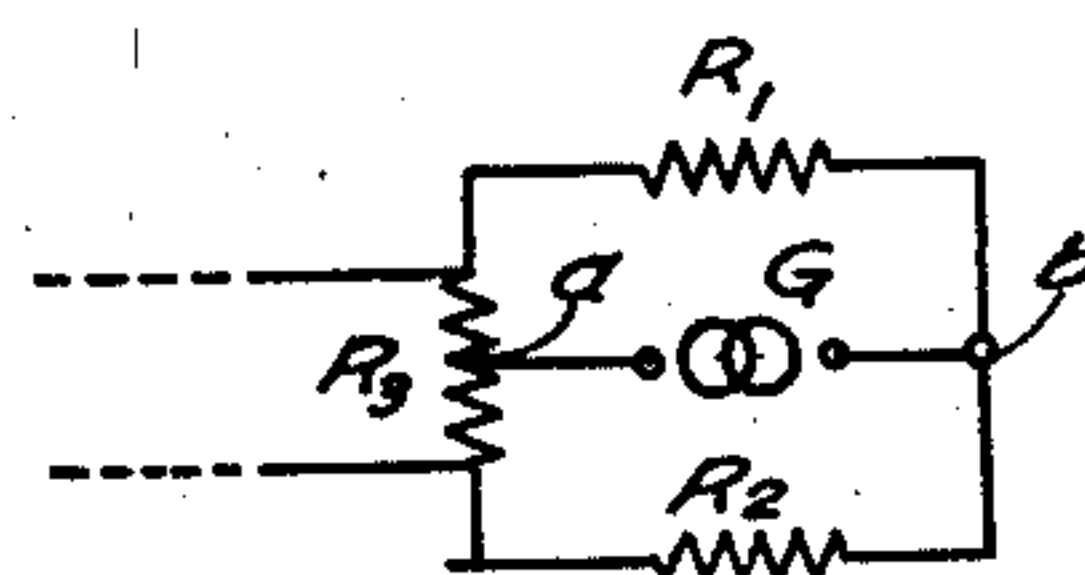


Fig. 6.

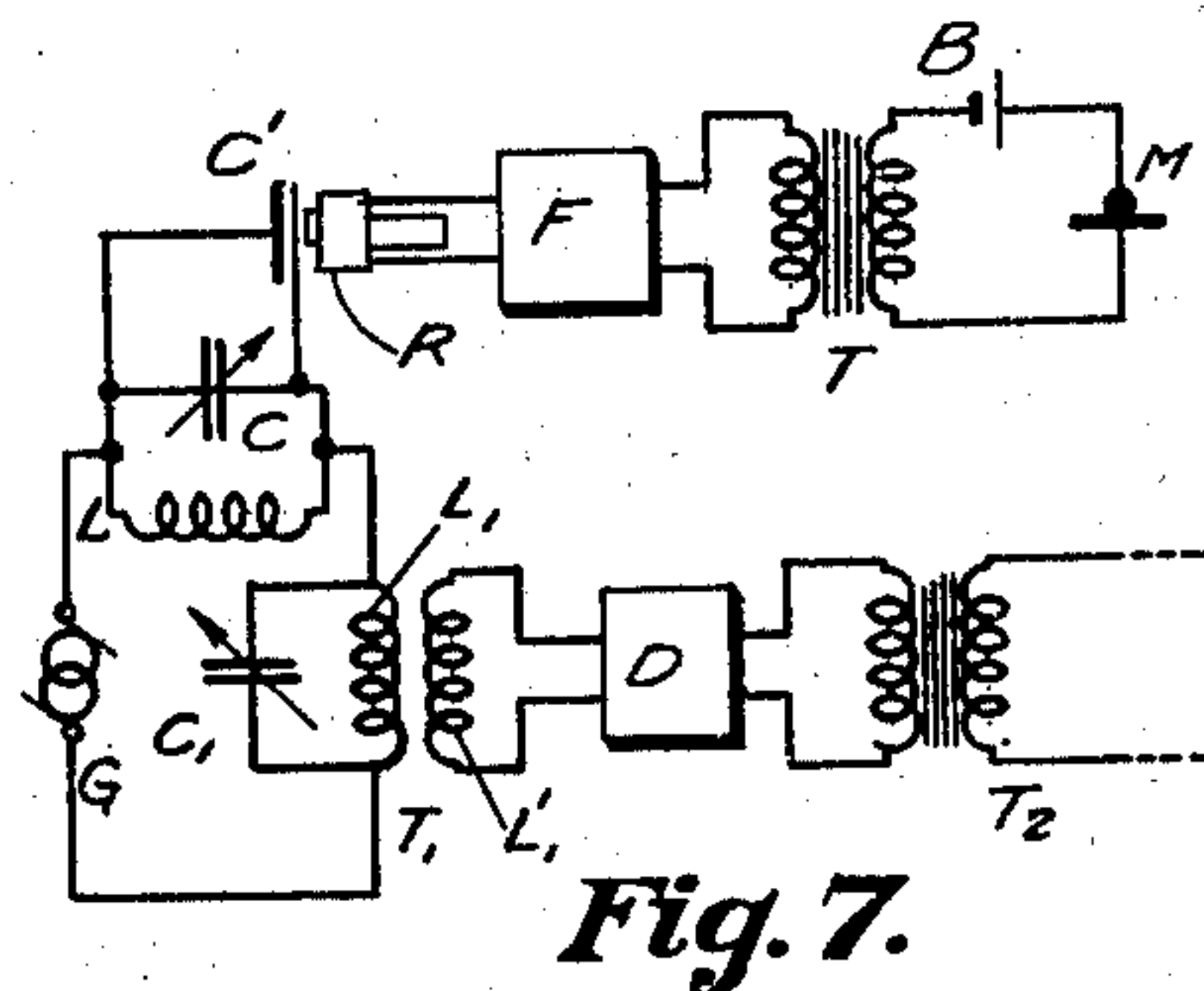


Fig. 7.

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2,232,891

CONDENSER TELEPHONE TRANSMITTER
CIRCUITJohn Stone Stone, San Diego, Calif., assignor to
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Application April 5, 1938, Serial No. 200,058

10 Claims. (Cl. 179—171.5)

An object of my invention is to greatly enhance the sound to electric currents translating power of the condenser telephone transmitter. Another object of my invention is to secure an amplification of audio frequency telephone currents with no sensible distortion thereof. Another object of my invention is to secure voice or other sound modulation of a superaudio frequency carrier current with insensible distortion. Another object of my invention is to produce a combined voice or other sound modulator and amplifier of superaudio frequency currents. Another object of my invention is to produce a voice or other sound modulation of a superaudio frequency carrier current combined with the suppression of the unmodulated component of such carrier current. Another object of my invention is to secure a combined voice or other sound modulation, amplification and unmodulated carrier frequency component suppression of a superaudio frequency carrier current. Another object of my invention is to secure such combined modulation, amplification and carrier frequency suppression without sensible distortion. Another object of my invention is to produce an audio frequency or superaudio frequency sustained oscillation train.

By superaudio frequency current in this specification is meant any current which is inaudible in a telephone receiver by reason only of its high frequency and such currents will, hereinafter, be referred to simply as high frequency currents.

In the following specification, I disclose a limited number of ways in which my invention may be carried into practice. It will be understood that the following text relates principally to these specific examples of procedure under this invention and that the scope of the invention is indicated in the appended claims.

Attention is drawn to the fact that the accomplishment of the various objects of my invention is secured through the use of a common unifying principle and by means of a common unifying embodiment of that principle. That common principle and its common embodiment will be very explicitly and meticulously disclosed. Attention is also drawn to the fact that no new instrumentalities are made use of in the disclosed embodiment of my invention, the novelty residing in the new combinations of well known instrumentalities and the mode of operation of these combinations in the realization of the purposes of my invention. For this reason, there will be little reference in this specification to the mode of construction of the devices employed,

but exact specifications will be given as to the relations of their electrical constants.

Referring to the drawings, Figs. 1 and 2 are quantitative curves depicting the mode of operation of certain parts of the apparatus and are designed to supplement the disclosure of its mode of operation. Fig. 3 and Fig. 3a are circuit diagrams illustrating two of the simplest embodiments of my invention, when used to enhance the sound to electric current translating power of a condenser transmitter and to secure voice or other sound modulation of a high frequency current with insensible distortion. Fig. 4 is a circuit diagram illustrating an embodiment of my invention which secures combined sound modulation of a high frequency current, its amplification, and the suppression of the unmodulated component of the current. Fig. 5 is a refinement of the organization of Fig. 4 by which greater amplification is secured and traces of distortion eliminated. Fig. 6 is a circuit diagram illustrating one of the best known forms of bridges or induction balances. This diagram is designed to elucidate the mode of operation of the organizations of Figs. 4 and 5, and to assist in predicating the best relative proportions of their parts to satisfy given conditions.

Fig. 7 is a circuit diagram, illustrating an embodiment of my invention by which a sound modulated audio frequency current may be amplified with no sensible distortion. Figs. 8 and 9 are circuit diagrams illustrating an embodiment of my invention by which a sustained audio frequency or high frequency current of extremely constant intensity and frequency may be secured.

The underlying principle of my invention will be best understood by having reference to Figs. 1, 2, 3 and 3a. In Fig. 3, G is a constant frequency source of superaudio frequency current, L is an inductance coil, C is a condenser, and C' is a condenser telephone transmitter. T₁ is a transformer consisting of the coils L₁ and L₁'. The primary coil L₁ is bridged by a condenser C₁ such that the loop antiresonant circuit so formed has a high selectivity and is tuned to the frequency of the source G. These devices are all characterized by being carefully designed as in the case of radio or carrier frequency telephony to minimize the effects of magnetic and electric hysteresis, distributed capacity and "skin effect" resistance rises. The circuit composed of the coil L and the two condensers C and C' constitutes an antiresonant loop element in the circuit comprising the source G and the primary L₁ of the transformer T₁. The effective resist-

ance R' , effective reactance X' and effective impedance $Z' = \sqrt{R'^2 + X'^2}$ of this antiresonant element, when considered as an element of the primary circuit of the transformer T_1 , are quantitatively illustrated in Fig. 1, wherein curve 1 is the effective impedance, 2 is the effective resistance and curve 3 is the effective reactance, all in the case of an antiresonant loop circuit whose selectivity S is 200. This value of the selectivity of the antiresonant loop is what may be termed the maximum inherent selectivity of a high frequency resonant or antiresonant circuit. It is the selectivity attained by the exercise of the ordinary precautions used in designing the coils and condensers for high frequency resonant or tuning circuits. Lower selectivities may be secured by the purposeful addition of a resistance to the circuit, but higher selectivities up to about 400 can be secured only through the exercise of extraordinary precautions and skill. The mathematical expressions for the quantities R' and X' as functions of the periodicity ω of the current developed by the source G are,

$$R' = R \frac{S^2}{1 + S^2 \alpha_0^2} \frac{\omega_0^2}{\omega^2} \quad (1)$$

$$X' = -RS \frac{\omega_0}{\omega} \frac{1 + S^2 \frac{\omega}{\omega_0} \alpha_0}{1 + S^2 \alpha_0^2} \quad (2)$$

Where R is the resistance of the loop, ω_0 is the periodicity to which the loop would be resonant were its capacity C_0 , S is its selectivity, and α_0 is its frequency function.

In terms of circuit constants,

$$\omega_0 = \frac{1}{\sqrt{LC_0}} \quad (3)$$

$$S^2 = \frac{L}{C_0 R^2} = \frac{L^2 \omega_0^2}{R^2} = \frac{1}{C_0^2 R^2 \omega_0^2} \quad (4)$$

$$\alpha_0 = \frac{\omega^2 - \omega_0^2}{\omega \omega_0} \quad (5)$$

Where L is the inductance of the loop and C_0 is the capacity which the combined condensers of the loop would need to have in order to make it resonant to the periodicity ω_0 . The actual capacity of the loop will be defined as

$$C = (1 \pm k\Delta) C_0 \quad (6)$$

In the foregoing expression, k is a small numeral ranging from 0 to ± 8 in Fig. 1 and from 0 to ± 2 in Fig. 2. The capacity increment coefficient Δ is given the value 0.004 in both figures. The maximum values of the effective resistance and effective impedance of the loop is shown as unity in the curves in order that the other values may readily indicate percentages of these maxima, but the actual maxima are 40,000 times the resistance R of the loop. Had the "maximum attainable" selectivity of 400 been chosen instead of the "maximum inherent" selectivity of 200, the maximum effective resistance and effective impedance of the loop would have been 160,000 times the resistance of the loop.

The value of the capacity of the loop when the condenser telephone transmitter is not actuated by sound waves we shall call the "normal" capacity of the loop and we shall designate it by the symbol C_n . This value is so chosen that

$$\frac{d^2 Z'}{d^2 C} = 0 \quad (7)$$

In other words, it is the values of C corresponding to the two points of inflection of the impedance-capacity characteristic of Fig. 1. In the

specific case we have chosen, of $S=200$, these points of inflection occur at very nearly $k=1$, so that we have $C_n = (1 \pm \Delta) C_0$ and C_n may have either the value 1.004 C_0 or 0.996 C_0 .

Attention is here drawn to the fact that the antiresonant loop circuit is purposely detuned by a predetermined and prescribed frequency interval that brings the effective impedance of the loop to the value it has at the two inflection points on its characteristic curve. The reason for this specific detuning is made clear by having reference to Fig. 2. The full line curve of Fig. 2 is a portion of the impedance curve 1 of Fig. 1 drawn to a bigger scale. The dotted line is a straight line sensibly coincident with the impedance curve for values of C from 1.0016 C_0 to 1.0064 C_0 and between 0.9984 C_0 and 0.9936 C_0 .

Clearly when the fluctuations in the values of C from its normal value of C_n do not exceed $\pm 0.0024 C_0$ the resulting fluctuations in the effective impedance Z' of the loop will be sensibly proportional to such fluctuations of capacity. The tangent to the curve of Z' at its points of inflection when the selectivity S of the loop is 200 and its resistance is $R=10$ ohms are expressed by the equation

$$Z' = 4 \times 10^5 \left(76.5684 - 75.4825 \frac{C}{C_0} \right) \quad (8)$$

From which we deduce

$$\frac{dZ'}{d(C/C_0)} = 75.4825 \times 4 \times 10^5 \quad (9)$$

or that the rate of change of the effective impedance of the loop for changes in the capacity ratio

$$\frac{C}{C_0}$$

is 3.0193×10^7 . This relation is important since it is the fluctuations of the effective impedance Z' resulting from very small fluctuations of the capacity ratio

$$\frac{C}{C_0}$$

about the normal capacity ratio

$$\frac{C_n}{C_0}$$

that are relied upon in this invention to effect the sensibly nondistortional modulation and amplification sought.

The mode of operation and the efficiency of the organization of Fig. 3 as a means of translating the vibrations of the diaphragm of the condenser telephone transmitter into modulated high frequency currents will be best understood if we compute the intensity of the modulated component of the current in the primary circuit of the output transformer loop $C_1 L_1$ under reasonable assumptions as to the proportions of the circuit constants and impressed electromotive forces. To this end we shall assume that the selectivities of the antiresonant loops

$$(C + C') L$$

which we shall call the transmitter loop, and $C_1 L_1$, which we shall call the output loop, are both 200 and that the resistances of these two loops are both 10 ohms. We shall further assume that the electromotive force developed at the terminals of the source G is such as to produce a high frequency potential difference of amplitude 350 volts across the terminals of the transmitter loop. We shall assume that this loop is so detuned that its impedance is at one

of the two inflection points of its impedance-capacity curve, that is to say we assume that the capacity of loop $L(C+C')$ is C_n . The choice of 350 volts is dictated by the fact that this is slightly below the minimum spark producing voltage. We shall assume that, under the influence of sound waves, the diaphragm of the condenser telephone transmitter C' is executing sustained uniform periodic vibrations resulting in the production of sustained uniform capacity variation of amplitude $0.001 C_n$. The effect of these sustained uniform periodic variations of the capacity C will be to produce corresponding sustained uniform periodic fluctuations or vibrations in the effective impedance of the transmitter loop. From the value found for

$$\frac{dZ'}{d(C/C_0)}$$

it results that the amplitude of these effective impedance fluctuations will be 3.0193×10^4 ohms.

The normal effective impedance of the transmitter loop, namely its impedance when its capacity is C_n , is $Z'_n = 3.2244 \times 10^5$. From this it may be shown that the intensity of the modulated component of the high frequency current in the main or supply circuit is 0.09294 milliamperes. Because the selectivity of the output loop circuit is 200, the intensity of this modulated component in that circuit will be 18.59 milliamperes. Audio frequency telephone currents of intensity 0.09294 milliamperes correspond to fairly loud speech reproduction, while currents of 18.59 milliamperes correspond to sound broadcasting practice in which two or more loud speakers are connected in parallel.

If the capacity of the condenser telephone transmitter supply the entire capacity of the transmitter loop, if the telephone transmitter diaphragm be very thin, be clamped at the edges, be under high tension, and if the distance between the diaphragm and the fixed electrode be $\frac{1}{1000}$ of an inch (all common practice in condenser telephone transmitter construction), it may be shown that the large modulated high frequency current components noted in the operation of Fig. 3 are engendered by vibration amplitudes at the center of the diaphragm of 2.39 millionths of an inch. It is significant here to point out that the organizations of Fig. 3 and Fig. 3a make it possible not only to detect but to measure sustained vibrations at the center of a diaphragm when the amplitude of these vibrations are as small or smaller than $50 \mu\mu$. In other words, an amplitude equal to one tenth of the average wave length of light or smaller.

The effective impedance of the transmitter loop is composed of an effective resistance component $R'_n = 2.584 \times 10^5$ ohms and an effective reactance $X'_n = \pm 1.928 \times 10^5$. The effective impedance of the output loop is the pure resistance $R'_o = 4 \times 10^5$, hence the total effective impedance of the main or supply circuit external to the source G is

$$10^5 \sqrt{(6.584)^2 + (1.928)^2} = 6.8605 \times 10^5 = Z_1 + Z_n \quad (10)$$

If e_n be the fall of potential at the terminals of the transmitter loop, and e be the electromotive force developed at the terminal of the source G , then

$$e = e_n \frac{Z_1 + Z_n}{Z'_n}$$

Substituting the value assumed for e_n and the values found for the impedances, we find

$e = 744.78$ volts as the terminal voltage of the source G . It is the high voltage of this source which permits of the great amplification of power controlled by the minute motions of the condenser telephone diaphragm.

It remains to illustrate how nearly linear is the characteristic of the modulation system of Fig. 3. To this end, let E be the electromotive force of the source G , Z_g be its impedance and Z_m be the modulated component of the effective impedance in the supply circuit. Then the current in that circuit will be

$$\frac{E}{Z + Z_m}$$

where $Z = Z_g + Z_1 + Z_n$. This current may therefore be expressed as

$$\frac{E}{Z} \left\{ 1 - \frac{Z_m}{Z} + \left(\frac{Z_m}{Z} \right)^2 - \left(\frac{Z_m}{Z} \right)^3 + \dots \right\} \quad (11)$$

Clearly the proportionality between the amplitude of the modulated component of the high frequency current and the fluctuations of the capacity of the condenser telephone transmitter is the more nearly attained the smaller the ratio of Z_m to Z . To illustrate: When Z_g is negligible,

$$\frac{Z_m}{Z}$$

is 0.044 and the current in the supply circuit is

$$(1 - 0.0421) \frac{E}{Z}$$

while when $Z_g = 4 \times 10^5$ ohms,

$$\frac{Z_m}{Z} = 0.0028065$$

and the current is

$$(1 - 0.0273) \frac{E}{Z}$$

In the organization shown in Fig. 3a, everything is the same as that of Fig. 3 except that an additional antiresonant loop circuit composed of the condenser C_2 and coil L_2 is added. This loop is an output loop, the coil L_2 constituting the primary of the output transformer T_2 , its frequency being that of the source G and its selectivity being 200 as in the case of the other output loop $C_1 L_1$.

The organization of Fig. 3a is an improvement over that of Fig. 3 in three respects. In the first place, the added impedance of the second output loop $C_2 L_2$ tends to establish a linear relationship between the displacement of the transmitter diaphragm and the corresponding modulation of the high frequency current for the reason set forth in connection with Equation 11; in the second place, the use of two antiresonant loop output circuits permits of doubling the modulated power output; and in the third place, the secondary coils L_1' and L_2' of the transformers T_1 and T_2 may be connected either in parallel or in series, thereby tending respectively toward a constant potential or constant current output of modulated high frequency power.

In the amplification of the modulated component of the current, there is a close cooperation between the source G , the transmitter loop and the output loop or loops. All the power for the modulated current component comes from the source. When no amplification is required, this source may have as small an electromotive force as desired; but when maximum amplification is demanded the electromotive force of the source must be such as to produce a transverse voltage

at the transmitter loop which is but moderately less than that required to develop a spark between the juxtaposed electrodes of the condenser telephone. At atmospheric pressure, 350 volts is slightly less than is required to produce a spark between parallel conducting surfaces, no matter how close they may be together.

Again, in respect to the close cooperation referred to, the antiresonance of the output loop or loops produce a magnification of the modulated current component, but not necessarily magnification of its available power, if the electromotive force of the source be not correspondingly increased with the addition of an extra output loop. But this is just what the addition of a resonant output loop makes possible. Through the addition of its resistance R to the supply circuit, it permits the electromotive force of the source to be raised while still maintaining a transverse voltage across the transmitter loop not in excess of the minimum sparking voltage. This increase in E results in a corresponding increase in the power amplification of the modulated component of the high frequency current. This power amplification relation ties together functionally the elements $(C+C')L$, C_1L_1 , C_2L_2 and G in an inseparable combination.

Though two antiresonant loop output circuits are shown in the circuit diagram of Fig. 3a, as many such loops may be used in series in the supply circuit as may be required to secure linearity of response, enhancement of amplification and ratio of output electromotive force to output impedance.

The organizations of Fig. 4 and Fig. 5 are essentially induction balances or bridges of the well known type illustrated in Fig. 6. These organizations which embody the fundamental principles of Fig. 3 and Fig. 3a are so devised and constructed as not only to effect the voice or other sound modulation of a high frequency current and its amplification, but also to effect the suppression in the outgoing circuit of the unmodulated component of the high frequency current. In these diagrams, G is a constant frequency source of high frequency current circuits, C_3L_3 and C_4L_4 are antiresonant loop circuits tuned to the frequency of the source G and corresponding functionally to the tuned loop C_1L_1 and C_2L_2 of Fig. 3 and Fig. 3a. T_3 and T_4 are output transformers corresponding functionally to the transformers T_1 and T_2 of Figs. 3 and 3a, L_3 and L_4 are the primary coils of the transformers T_3 and T_4 , while L_3' and L_4' are the secondary coils of these transformers. The loop circuits $(C_1+C_1')L_1$ and $(C_2+C_2')L_2$ are predeterminedly detuned antiresonant transmitter loop circuits, corresponding functionally to the detuned antiresonant transmitter loops $(C+C')L$ of Figs. 3 and 3a. The antiresonant loop circuit C_1L_1 of Fig. 4 is a detuned loop circuit used to balance the induction balance of the organization of that diagram. The antiresonant loop circuits C_5L_5 and C_6L_6 of Fig. 5 are detuned antiresonant loops used to assist in the balancing of the induction balance of that diagram.

In the diagram of Fig. 6, R_1 , R_2 and R_3 are three resistances and the point of attachment a of the power branch ab to the resistance R divides that resistance into two equal parts, each having resistance

$$\frac{1}{2}R_3$$

As the mode of operation of the organization of

Figs. 4 and 5 will be best understood by having reference to the elementary theory of the induction balance or bridge of Fig. 6, this elementary theory will be given first.

We shall designate by r_1 the resistance of the branch comprising the resistances R_1 and

$$\frac{1}{2}R_3$$

while we shall designate by r_2 the resistance of the branch comprising the resistances R_2 and

$$\frac{1}{2}R_3$$

The electromotive force generated by the source G will be designated by E , the resistance of that source will be designated by r and the potential difference at the terminals of the resistance coil R_3 will be designated by e_3 . Then

$$e_3 = \frac{Er_3}{2} \frac{r_2 - r_1}{r(r_1 + r_2) + r_1r_2} \quad (12)$$

The bridge will be balanced when $r_1 = r_2 = r_0$, as indicated by the fact that e_3 then vanishes. It is necessary, because of the organization of Fig. 4, to consider what happens when the resistance r_2 fluctuates about its normal value of r_0 by a small increment δr_0 , so that we have the condition $r_1 = r_0$, $r_2 = (1 \pm \delta)r_0$. Then

$$e_3 = \frac{Er_3}{2} \frac{\mp \delta}{r(2 \pm \delta) + r_0(1 \pm \delta)} \quad (13)$$

There are three contrasting conditions under which the bridge may be used. First, when the source G is a constant potential source under which circumstances

$$\frac{r}{r_0}$$

is negligible. Then there results

$$\frac{de_3}{d\delta} = \frac{Er_3}{2r_0} (\mp 1 + 2\delta \mp 3\delta^2 + 4\delta^3 \dots) \quad (14)$$

All terms containing δ indicate distortion and since δ is always a comparatively small fraction, the degree of distortion is sensibly determined by the term containing the first power of δ .

The second contrasting condition of the bridge is when G is a constant source, under which circumstances

$$\frac{r_0}{r}$$

is negligible. Then

$$\frac{de_3}{d\delta} = \frac{Er_3}{4r} \left(\mp 1 + \delta \mp \frac{3}{4}\delta^2 + \frac{1}{2}\delta^3 \mp \frac{5}{16}\delta^4 \dots \right) \quad (15)$$

Here the distortion is about one half as great as in the last case.

The third contrasting condition is when the ratio

$$\frac{r}{r_0}$$

is unity or greater. When it is unity,

$$\frac{de_3}{d\delta} = \frac{Er_3}{6r_0} \left(\mp 1 + \frac{4}{3}\delta \mp \frac{12}{9}\delta^2 + \frac{32}{27}\delta^3 \mp \frac{80}{81}\delta^4 \dots \right) \quad (16)$$

When

$$\frac{r}{r_0} = 2$$

$$\frac{de_3}{d\delta} = \frac{Er_3}{10r_0} \left(\mp 1 + \frac{6}{5}\delta \mp \frac{27}{25}\delta^2 + \frac{108}{125}\delta^3 \dots \right) \quad (17)$$

Equations 16 and 17 show that it is not necessary to greatly increase the ratio

$$\frac{r}{r_0}$$

beyond unity in order to secure practically all the advantage in minimization of distortion secured in the case of Equation 15.

Because of the organization of Fig. 5, it is necessary to consider the case when r_1 and r_2 fluctuate similarly but in opposite phase as defined by $r_1 = (1 \pm \delta)r_0$ and $r_2 = (1 \mp \delta)r_0$ then

$$e_3 = \frac{Er_3}{r_0} \frac{\mp \delta}{2\frac{r}{r_0} + 1 - \delta^2} \quad (18)$$

When the source is a constant potential source

$$\frac{r}{r_0}$$

is negligible and

$$\frac{de_3}{d\delta} = \frac{Er_3}{r_0} (\mp 1 \mp 3\delta^2 \mp 5\delta^4 \mp 7\delta^6 \dots) \quad (19)$$

When the source is a constant current source,

$$\frac{r_0}{r}$$

is negligible and

$$\frac{de_3}{d\delta} = \mp \frac{Er_3}{2r} \quad (20)$$

When the source is neither a constant potential nor a constant current source, as when

$$\frac{r}{r_0} = 1$$

$$\frac{de_3}{d\delta} = \frac{Er_3}{3r_0} (\mp 1 \mp \delta^2 \mp \frac{5}{9}\delta^4 \mp \frac{7}{27}\delta^6 \dots) \quad (21)$$

When

$$\frac{r}{r_0} = 2$$

$$\frac{de_3}{d\delta} = \frac{Er_3}{5r_0} (\mp 1 \mp \frac{3}{5}\delta^2 \mp \frac{1}{5}\delta^4 \mp \frac{7}{125}\delta^6 \dots) \quad (22)$$

The case of Equation 20 is the only one which obliterates all distortion, but since all cases under Equation 18 contain no terms in δ which are of less power than the second, and since δ will usually be a small fraction, the distortion terms in the case of Equations 19 to 22 inclusive will usually be completely insensible. In the numerical case given in illustration of the mode of operation of Fig. 3, it was assumed that $S=200$, $R=10$, and the fluctuations of the capacity of the transmitter loop about the normal value C_n were assumed to be

$$\pm \frac{C_n}{1000}$$

Under these conditions the ratio of the modulated to the unmodulated component of the supply circuit is 0.044. But δ is this ratio of impedance, so in the numerical case considered, $\delta=0.044$ and $\delta^2=0.00194$. Such a distortion factor as this δ is easily negligible in effect and that corresponding to δ^2 is altogether insensible.

In the organization of Fig. 4, the detuning of the loop circuits C_1L_1 and $(C_2+C_2')L_2$ is in the same sense as well as being the same in degree, so that these two circuits balance each other completely. The loop circuits C_3L_3 and C_4L_4 , as affected by their associations with their respective secondary circuits, are also so proportioned as to balance each other. Therefore normally none of the energy from the high frequency source G passes out of the balance or bridge through the transformers T_3 and T_4 .

But when the condenser transmitter C_2' is spoken to or otherwise activated, the bridge is unbalanced and the modulated component of the

high frequency currents in the output loops C_3L_3 and C_4L_4 cooperate to induce electromotive forces in the external circuit composed of the coils L_3' and L_4' . For the reasons given in the description of the mode of operation of Fig. 3a, two or more output loops may often with advantage be substituted for each of the single output loops of Fig. 4, but the impedances of the output loops in the two branches of the bridge or induction balance must accurately balance each other.

In the organization of Fig. 5, the transmitter loop circuits $(C_1+C_1')L_1$ and $(C_2+C_2')L_2$ are identical in all respects but one. They are detuned to the same degree, but in opposite senses. That is to say, the antiresonant periodicities of the two loops bear to each other the relation of $\omega_1 = (1 \pm k\Delta)\omega_0$ and $\omega_2 = (1 \mp k\Delta)\omega_0$, where ω_0 is the periodicity of the source G and where ω_1 and ω_2 are the periodicities at which the similar impedance curves have their opposite inflection points. The result of this, as may be seen by an inspection of Fig. 1, is that the scalar impedances of the two loops in question are the same, but their vector impedances are different because the reactance of one circuit is positive and that of the other is negative. This difference prevents these loops from balancing the arms of the bridge, and to correct for this, the loops C_5L_5 and C_6L_6 are added. These loops have the common selectivities and resistances of loops $(C_1+C_1')L_1$ and $(C_2+C_2')L_2$. Loop C_5L_5 is detuned to exactly the same extent and sense as loop $(C_1+C_1')L_1$, while loop C_6L_6 is detuned to exactly the same extent and in the same sense as loop $(C_2+C_2')L_2$. The effective reactances in each of the two arms of the bridge of Fig. 5 are thus neutralized, and only the balanced effective resistances of the four loops remain.

The foregoing description of the balancing of the bridge or induction balance of Fig. 5 applies when the voice or other sound waves actuating the condenser telephones C_1' and C_2' are equal and in phase; but when these sound waves though equal in intensity are opposite in phase or sense, the balancing conditions are changed. Under these conditions, the transmitter loops $(C_1+C_1')L_1$ and $(C_2+C_2')L_2$ are not only detuned to the same degree but in the same sense, as may be exemplified by the relation

$$\omega_2 = \omega_1 = (1 \pm k\Delta)\omega_0$$

The result of this is that the reactances of the two transmitter loops are not only equal but of the same sign. This being the case, the loops C_5L_5 and C_6L_6 are no longer required and may be dispensed with. However they may be retained, though not to balance the arms of the induction balance or bridge. When retained, they will be detuned to the same common degree as the transmitter loops but in the opposite sense, and so effect a neutralization of the reactances of the branches as before.

We have spoken of actuating two condenser telephone transmitters by sound waves equally but in opposite phase or sense. This implies that the sound waves act only on the front or outer surface of the diaphragm of the first transmitter after the normal fashion, but act solely on the back or anterior surface of the diaphragm in the case of the second transmitter. Mechanically this may be effected by capping the front of the second transmitter and admitting the sound waves to the inner chamber of that transmitter through apertures piercing the back of the transmitter or through the fixed electrode.

In the organization of Fig. 7, M is a variable resistance telephone transmitter, B is a transmitter battery, T is a telephone induction coil, F is a filter circuit, R is a telephone receiver, C' is a condenser telephone transmitter, C and L are the tuning condenser and coil of the transmitter loop $(C+C')L$, G is a constant frequency source of high frequency current, C_1 and L_1 are the condenser and inductance of the output loop C_1L_1 , T_1 is a high frequency output transformer of which the coils L_1 and L_1' are the primary and secondary respectively. D is a detector, translating high frequency to unidirectional currents, T is an audio frequency or telephone transformer. Any suitable telephone transmitter system, such as a condenser telephone transmitter may be substituted for the variable resistance telephone transmitter system shown, and any suitable telephone receiver such as a condenser telephone receiver may be used in place of the usual telephone receiver R shown. The filter circuit F may be dispensed with though its use is the preferred form. In the operation of this device, the audio frequency voice currents passing through the filter F have removed from them the needless frequencies and are translated into mechanical vibrations of the diaphragm of the condenser telephone C'. The part of the organization comprising the elements C', C, L, G, C_1 , L_1 and L_1' is similarly proportioned to that of Fig. 3 and its mode of operation is the same. Therefore the secondary coil of the output transformer T_1 delivers to the detector D a modulated high frequency current in which the modulations correspond to the telephone current delivered to the telephone receiver R. The detector D translates these high frequency currents into a corresponding unidirectional current, the modulated component of which only is passed to its secondary coil T_2 . Because of the amplifying properties of the organization intervening between the receiver R and the detector D already described in connection with Fig. 3a, the energy of the modulated component of the high frequency current delivered to the detector D is greater than the energy delivered to the telephone receiver R, this extra energy being derived from the source G. In this connection it should be noted that all such devices as multiple output circuit loops for increasing the amplification or increase of the selectivity of the loops for the same purpose, increase the voltage of G required to develop the critical terminal voltage of 350 volts at C', indeed if there were no more direct means of determining the increase of amplification effected, the increase in the required voltage of the source G would supply the required information.

In Fig. 8 the elements R, C', C, L, C_1 , L_1 , L_2 and T_2 all are the same as the corresponding elements in Fig. 7 and have the same functions and mode of operation. BD is a beat detector, C_2 is a blocking condenser and PA is a phase adjuster. The beat detector receives unmodulated current direct from the high constant frequency source G and a high frequency current with sustained uniform periodic modulation from the output transformer T_1 . The modulations are caused by the vibrations of the diaphragm of the condenser telephone transmitter C', they are therefore of the same frequency as that of the diaphragm vibrations. The output electromotive force of BD is thus a modulated direct voltage component and a high frequency component of a double the frequency of the source G. The blocking condenser C_2 prevents the development

of an unmodulated direct current component while the impedance of the primary coil of the transformer T_2 is of a character to suppress the development of a high frequency component of current, so the only current in the output circuit of the beat detector is a sustained uniform alternating current of the frequency of the modulations of the high frequency current delivered to the detector BD. This modulation current acting upon the telephone receiver R causes it to vibrate the diaphragm of the condenser transmitter C' and so correspondingly modulate the high frequency current in the output circuit C_1L_1 . When the phase of these impressed vibrations are such as to reinforce the preexisting vibrations of the condenser transmitter's diaphragm, a condition of sustained uniform periodic vibration is set up and the power supplied by the source G maintains these vibrations. The phase adjuster PA is used to maintain the proper phase relation between the impressed mechanical force acting on the condenser transmitter diaphragm and its preexisting vibrations.

In the organization of Fig. 9, all but the parts marked T_3 , G_1 and C'' are the same in character and in function as the correspondingly marked parts in the organization illustrated in Fig. 8. The transformer T_3 keeps all but the sustained uniform alternating modulation current out of the circuit L_3G_1C'' . G_1 is a direct current generator maintaining a potential difference of about 350 volts at the terminals of the condenser telephone receiver C''. In the operation of the organization, the vibrations of the condenser telephone diaphragm creates a uniform sustained periodic modulation of the high frequency current in the output loop C_1L_1 . The secondary coil L_1' of the transformer T_1 impresses a modulated high frequency electromotive force upon the beat detector BD. The modulation is uniform, sustained and of the same frequency as the vibrations of the condenser telephone diaphragm. The source G imposes a uniform sustained high frequency electromotive force upon the beat detector BD. The output circuit of the beat detector, therefore, has impressed upon it a sustained uniformly modulated direct electromotive force component and a modulated high frequency component of electromotive force whose frequency is double that of the constant frequency source G. The transformers T_2 and T_3 inhibit the development of a high frequency current in their primary circuits, so that the current in that circuit consists of a modulated direct current, the alternating component of which is of the frequency of the source. The transformer T_3 passes only the energy of the alternating component of the modulated direct current to the circuit L_3G_1C'' . This sustained uniform alternating modulation current acting on the condenser telephone C'' reinforces its preexisting vibrations if the phase is in unison with that of these vibrations. The necessary phase relation to maintain the sustained vibrations of the transmitter diaphragm is secured by the phase adjuster PA. When this is done, the primary of the transformer T_2 is the seat of a sustained uniform alternating component of current whose frequency is determined by the mechanical properties of the combined condenser transmitter and receiver C'C''. If this device be maintained at constant barometric pressure and constant temperature, the frequency of the current drawn from the secondary coil of the transformer T_2

may be made of as constant frequency as may be desired.

For the sake of compactness and clarity, I shall, in the claims that follow, use the expression "a modulator" for the phrase "Means for modulating a high frequency current in accordance with the vibration of sound waves." I shall use the expression "an antiresonant circuit" or simply "an antiresonant loop" to mean "a resonant circuit or mesh, the inductance and capacity elements of which are separately segregated and serially connected with respect to the loop or mesh circuit, but are parallel connected with respect to external circuits or networks of which the loop or mesh form a part" and with respect to the impressed electromotive force. I shall use the expression "a telephone transmitter loop" or simply "a transmitter loop" to mean "an antiresonant loop circuit adapted to modulate high frequency currents traversing it transversely."

I claim:

1. A modulator circuit including a loop circuit therein of the antiresonant type, means for applying a carrier frequency to said loop, said loop being detuned with respect to said carrier frequency by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, and means for fluctuating the circuit constant of one of the tuning elements of said loop in accordance with the vibrations of sound waves.

2. A modulator circuit including a loop circuit therein of the antiresonant type, means for applying a carrier frequency to said loop, said loop being detuned with respect to said carrier frequency by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, and a condenser telephone transmitter for fluctuating the capacity tuning element of said loop in accordance with the vibrations of sound waves.

3. A modulator circuit including a loop circuit therein of the antiresonant type, a constant high frequency source of electric power adapted to maintain a transverse voltage across said loop, which voltage is but slightly less than that required to develop a spark between the electrodes of the capacity element of said loop, said loop being detuned with respect to the frequency of said source by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, and means for fluctuating the circuit constant of one of the tuning elements of said loop in accordance with the vibrations of sound waves.

4. A modulator circuit including a loop circuit therein of the antiresonant type, a constant high frequency source of electric power adapted to maintain a transverse voltage across said loop, which voltage is but slightly less than that required to develop a spark between the electrodes of the capacity element of said loop, said loop being detuned with respect to the frequency of said source by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, and a condenser telephone transmitter for fluctuating the capacity tuning element of said loop in accordance with the vibrations of sound waves.

5. A modulator circuit including a transmitter

loop circuit therein of the antiresonant type, a constant high frequency source of electric power adapted to maintain a transverse voltage across said transmitter loop, which voltage is but slightly less than that required to develop a spark between the electrodes of the capacity element of the loop, an antiresonant output loop tuned to the frequency of said source, said transmitter loop circuit being detuned with respect to said source by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, and means for fluctuating the circuit constant of one of the tuning elements of said transmitter loop in accordance with the vibrations of sound waves.

6. A modulator circuit including a transmitter loop circuit therein of the antiresonant type, a constant high frequency source of electric power adapted to maintain a transverse voltage across said transmitter loop, which voltage is but slightly less than that required to develop a spark between the electrodes of the capacity element of the loop, an antiresonant output loop tuned to the frequency of said source, said transmitter loop circuit being detuned with respect to said source by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, and a condenser telephone transmitter for fluctuating the capacity tuning element of said transmitter loop in accordance with the vibrations of sound waves.

7. An amplifying modulator producing a speech or other sound modulated high frequency current having no unmodulated component, said modulator including an induction balance or bridge, the conjugate branches of which bridge include a constant high frequency source of sustained and constant amplitude, the output members of said bridge each including an antiresonant output loop tuned to the frequency of said source, one of the balanced branches of said induction balance or bridge including also a transmitter loop of the antiresonant type serially connected with respect to said antiresonant loop, said transmitter loop being detuned with respect to the frequency of said source by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, and a correspondingly detuned balancing loop circuit of the antiresonant type serially connected in the other balanced branch with an antiresonant output loop tuned to the frequency of said source.

8. An amplifying modulator productive of a speech or other sound modulated high frequency current having no unmodulated component, said modulator including an induction balance or bridge, the conjugate branches of said bridge including a constant high frequency source of sustained and constant amplitude, the output members of said bridge each including an antiresonant output loop tuned to the frequency of said source, the balanced branches of said induction balance or bridge each including also a transmitter loop of the antiresonant type serially connected with respect to said antiresonant output loop tuned to the frequency of said source, and each of said transmitter loops being detuned with respect to the frequency of said source by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it

has at an inflection point of the characteristic curve of the loop.

5 9. An arrangement for amplifying a telephone current, said arrangement including a transmitter loop serially connected in circuit with a constant high frequency source of sustained and constant amplitude, an antiresonant output loop tuned to the frequency of said source, said transmitter loop being detuned with respect to the frequency of
10 said source by a predetermined frequency interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, means whereby said telephone current may
15 affect corresponding fluctuations in the circuit constant of one of the tuning elements of said loop, and means whereby the modulated high frequency wave developed in the output loop is translated into audio-frequency or telephone current.
20

10. An arrangement for maintaining an alternating current of constant sustained amplitude and of constant frequency in a circuit, said ar-

rangement including a transmitter loop of the antiresonant type, a monotone condenser telephone transmitter forming one of the tuning elements of said transmitter loop, a high frequency supply circuit including a source of high frequency current and an antiresonant output loop, said transmitter loop being detuned with respect to said source by a predetermined interval which brings the effective impedance of the loop approximately to the value it has at an inflection point of the characteristic curve of the loop, means for fluctuating the capacity of said condenser transmitter in accordance with said high frequency current, means for translating the modulated high frequency current drawn from
15 said output loop back into an alternating current of said sustained constant amplitude and frequency, and means for utilizing a part of the energy of said alternating current to maintain said fluctuations of the capacity of said condenser
20 transmitter.

JOHN STONE STONE.