May 21, 1935. N. M. RUST **2,002,192**

ELECTRICAL CIRCUIT ARRANGEMENT

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Fig. 1

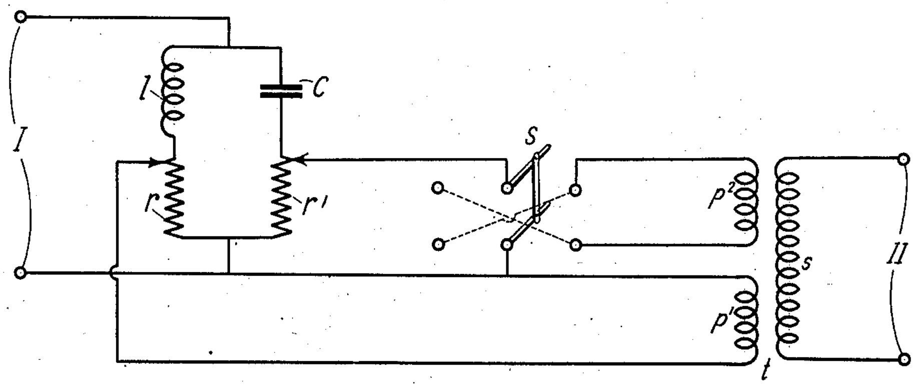


Fig. 2

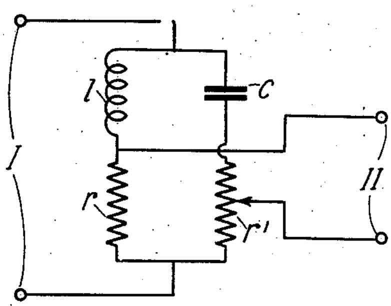


Fig. 3

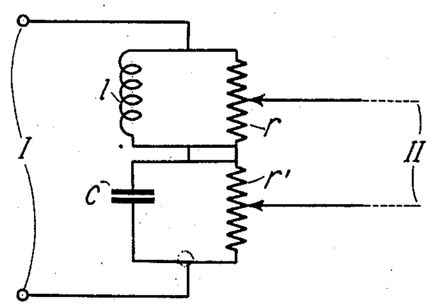


Fig. 4

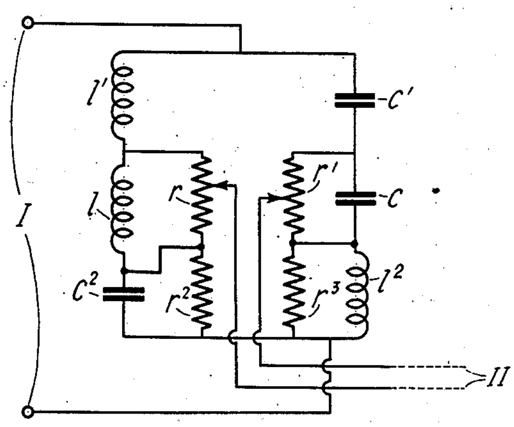
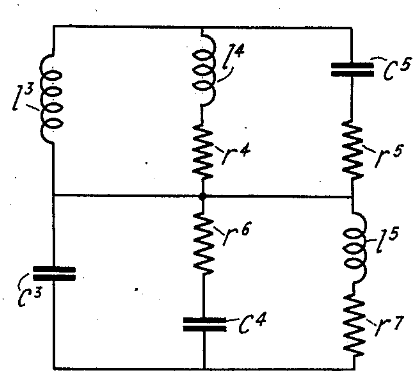


Fig. 5



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ELECTRICAL CIRCUIT ARRANGEMENT

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Fig. 6

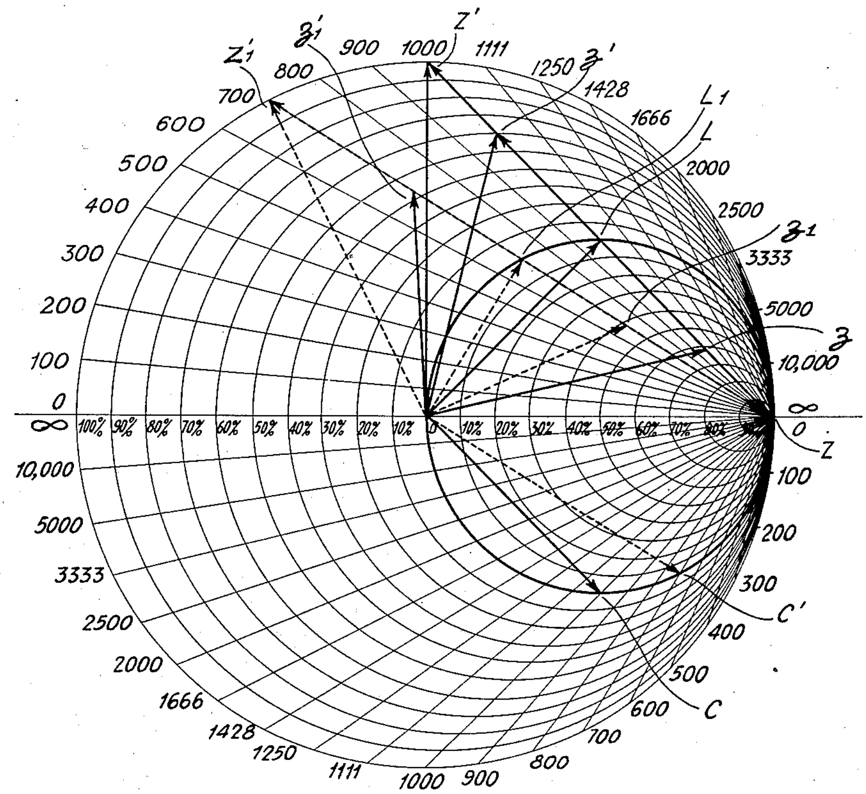


Fig. 6a

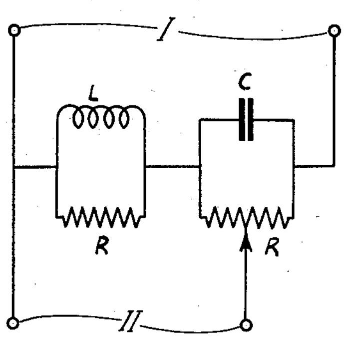
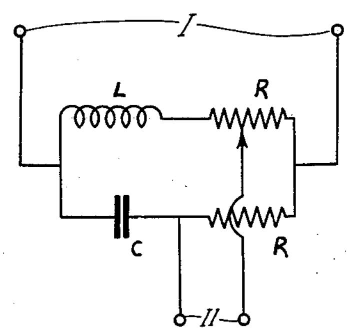


Fig. 6b



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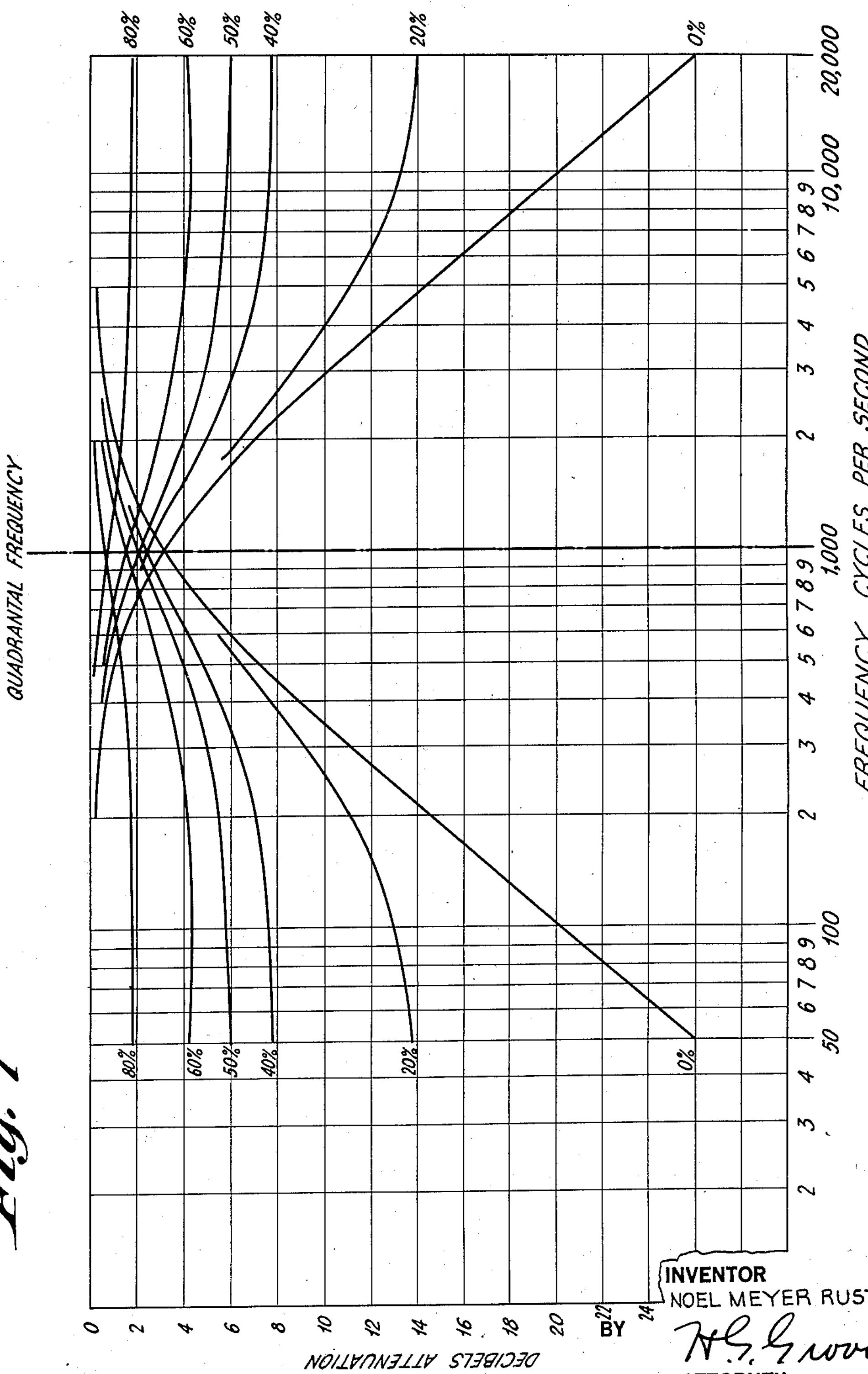

Fig. 7

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Fig. 8

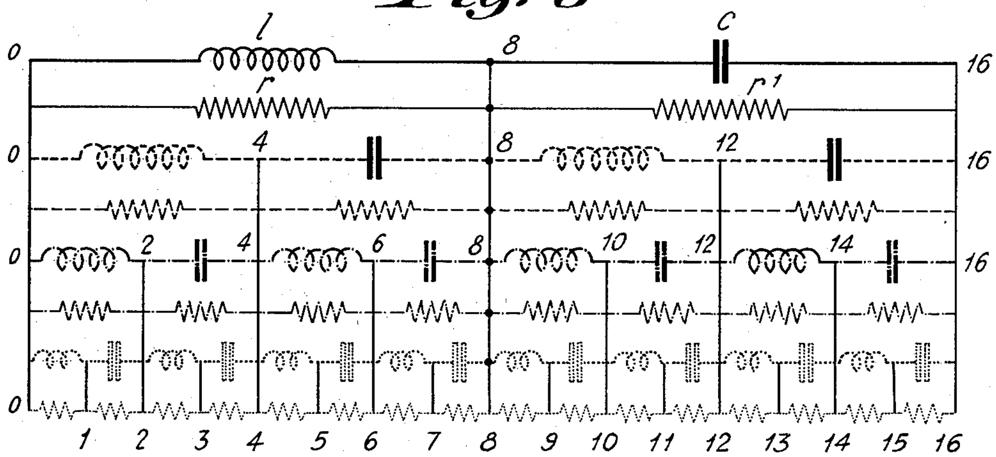

Fig. 9

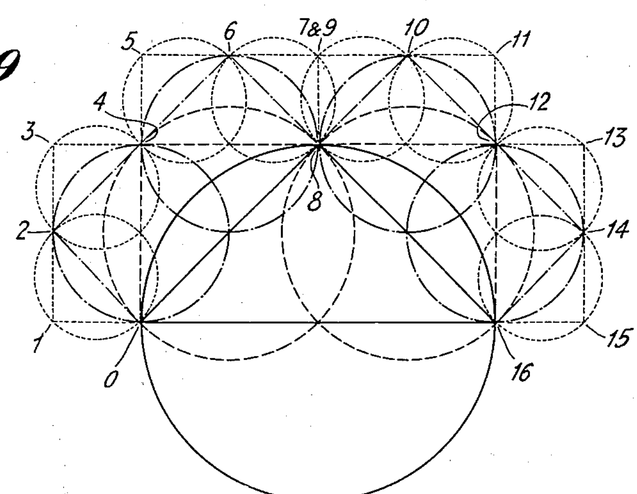

Fig. 10

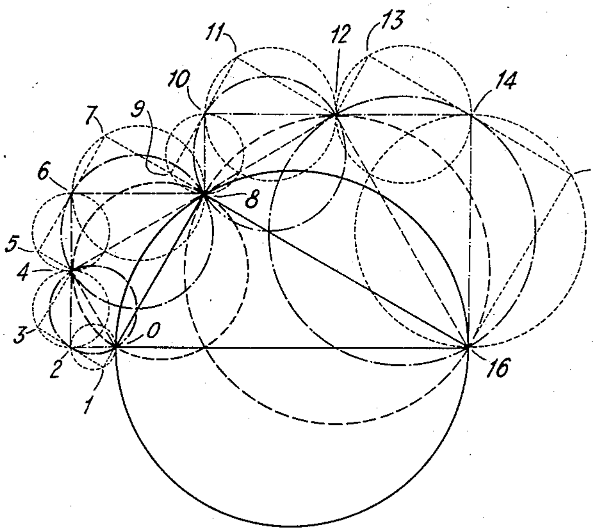

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Fig. 11

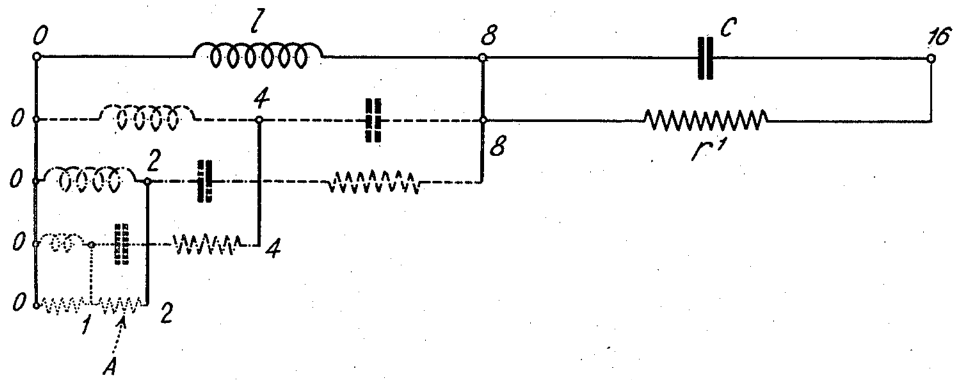


Fig. 12

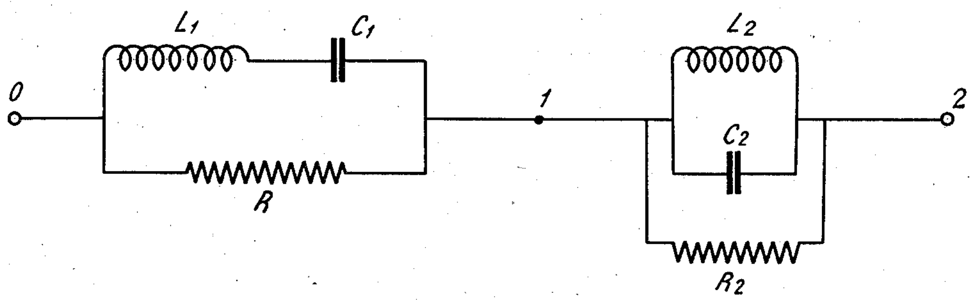


Fig. 13

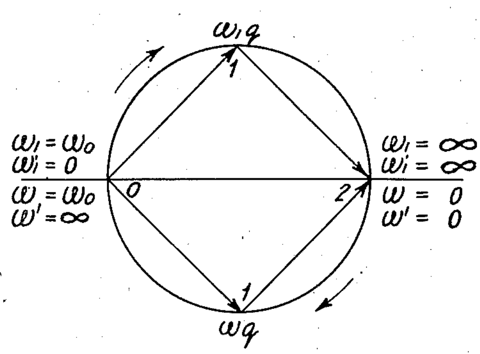
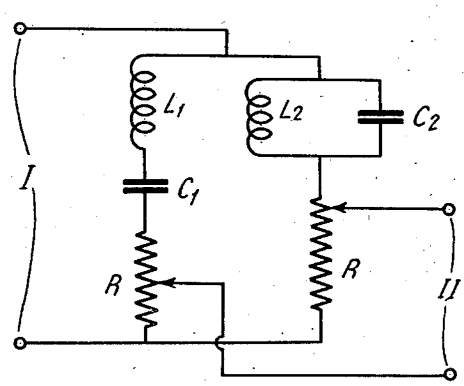


Fig. 14



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Patented May 21, 1935

2,002,192

UNITED STATES PATENT OFFICE

2,002,192

ELECTRICAL CIRCUIT ARRANGEMENT

Noël Meyer Rust, Chelmsford, England, assignor to Radio Corporation of America, a corporation of Delaware

Application December 18, 1931, Serial No. 581,930
In Great Britain December 24, 1930

9 Claims. (Cl. 178—44)

This invention relates to electrical impedance networks and has for its object to provide a circuit arrangement of substantially constant impedance, which is adapted to be employed for frequency correction purposes.

It is, of course, well known that the impedance offered by a parallel circuit consisting of inductance, resistance and capacity or by a combination of such circuits is "over-all non-reactive" (i. e. of zero total reactance though having reactance in the component elements) and is equivalent to that of the ohmic resistance if the inductance, capacity and resistance are so proportioned that the last quantity is equal to the square root of the quotient of the capacity into the inductance. For example, a circuit consisting of two parallel branches, the one comprising inductance and resistance in series, and the other capacity and resistance in series, offers for all frequencies a substantially constant impedance equal to that of a pure resistance of value equal to the actual ohmic resistance present in each branch, provided that the said ohmic resistance (in each branch respectively) is numerically equal to the square root of the quotient of the capacity into the inductance.

The present invention envisages the utilization of a substantially over-all non-reactive (i. e. of zero total reactance though having reactance in the component elements) constant impedance circuit of this kind to provide voltages suitable for use for frequency correction purposes.

According to this invention a frequency correction circuit comprises a substantially constant impedance over-all non-reactive network, means for tapping off voltages set up across resistances in the inductive and in the capacity branches of said network, and means for combining said voltages to give a resultant voltage which may be employed for correction purposes.

Preferably means are provided for changing at will the sense of the combination of the tapped-off voltages.

The invention is illustrated and explained in connection with the accompanying drawings wherein Figure 1 illustrates a particular embodiment of this invention and Figures 2 to 5 are further modifications thereof. Figure 6 is a vector diagram chart of the circle type illustrating circuit characteristics of the key circuits shown in Figures 6A and 6B. Figure 7 illustrates a group of curves which may be used to assist in the design of a correction circuit for any particular case. Figure 8 is a complex network diagram wherein branched sub-networks are shown substituted for the resistances in the circuits of Figures 1 to 5. Figures 9 and 10 are vector diagrams showing the principal vectors for the complex network of Figure 8. Figure 11 illustrates a simplified complex network diagram of a circuit arrangement such as is shown in Figure 8. Figure 12 illustrates a further circuit scheme embodying the principles of the present invention. Figure 13 is a vector diagram illustrating the effect of varying the circuit characteristics of Figure 12. Figure 14 illustrates a "phase correction" circuit arrangement embodying the principles of this invention.

Referring to Figure 1 which shows one way of carrying out the invention, a correction circuit comprises a network consisting of two parallel branches, the one comprising an inductance l and a resistance r in series, and the other a capacity c and a resistance r' in series. Means are provided for tapping off the voltage set up across the resistance portions in the two parallel branches. These two voltages are applied, each to one of the primaries p_1 or p_2 of a double primary transformer t across whose secondary s will be generated the voltages required for correction purposes. One primary p_1 is thus connected between the junction point of the resistance members in the parallel branch circuits and a tapping point at the other end of the resistance r in one branch of that circuit, the other primary p_2 being similarly connected across the resistance r' in the other branch of the circuit. Preferably a reversing switch S is included in the circuit of one primary so that the sense of combination of the voltage set up in the two primaries may be reversed when desired. The resistance-inductance-capacity network is so proportioned that each resistance r or r' is equal to the square root of the quotient of the capacity into the inductance. If the primaries be associated with the secondary in one sense the correction obtained will be (relatively) an amplitude correction (see the vectorial analysis given below) while with the primaries associated in the other sense the correction obtained will be (relatively) a phase correction. In the drawings I indicates voltage input terminals and II output terminals.

Preferably the tapping points upon the branches of the network are movable as indicated in Figure 1, and it will be seen that when the reversing switch S is in the position giving constant amplitude and no phase change, if the tapping point in the capacity branch of the circuit be moved down the resistance r' in that branch (i. e. towards the junction point of the resistances in the two branches) the effect will be to produce a response characteristic dropping in amplitude as the frequency is raised. If, on the other hand, this tapping point be kept stationary, and the other tapping point be varied the reverse effect i. e. a rising characteristic, will be produced, the amount of "tilt" produced being governed by the position of the tapping points on the resistances. Obviously, the frequency at which correction begins to be obtained depends on the relative values of the inductive reactance and of the capacity reactance to the resistance. From this it follows that if a correction is required on low frequencies (e. g. for low notes) large values of inductance and capacity are required, whilst if a correction operative on higher frequencies (e. g. corresponding to high notes) is required, smaller values of inductance and capacity must be chosen, the value of the square root of the quotient of the capacity into the inductance being, of course, in all cases equal to the resistance. This arrangement is thus suitable for what may be termed "amplitude correction". With the reversing switch in the other position what may be termed "phase corrections" may be obtained; or a combination of phase and amplitude corrections may be obtained.

It is not always necessary to employ a transformer for combining the voltage tapped off from the two resistances. For example, in the case of "phase correction" the transformer may be dispensed with and the circuit of Figure 2 adopted, combined voltages being, of course, set up across the terminals II. Figure 3 shows a further form of circuit which may be adopted in the case of "amplitude correction". The impedance of the circuit receiving the correcting voltages and connected at II should of course be of relatively high impedance compared to the resistances r r^1.

In place of using the simple forms of constant impedance overall-non-reactive network above described, many more complicated forms of substantially constant impedance overall-non-reactive networks may be employed. For example, such a network may be as shown in Figure 4 and may comprise two parallel branches, one consisting of a first inductance l^1 in series with a second inductance and capacity c^2 the last mentioned two reactances being each shunted by a resistance r or r^2 and the other consisting of a capacity c^1 a second capacity c and an inductance l^2 all in series, the last mentioned two reactances being each shunted by a resistance r^1 or r^3. In this case the movable tapping points giving the combined voltages for the transformer primaries can be tapped upon the resistances shunting the second inductance and the second capacity respectively (or upon the other resistances respectively—according to the effect it is desired to obtain). In yet another arrangement of overall-non-reactive substantially constant impedance network shown in Figure 5 the network comprises two "parallel" circuits in series, the first "parallel" circuit consisting of an inductance l^3 shunted by an inductance l^4 and resistance r^4 in series, and also shunted by a capacity c^5 and a resistance r^5 in series, and the second "parallel" circuit consisting of a capacity c^3 shunted by a resistance r^6 and a capacity c^4 in series, and also shunted by an inductance l^5 and a resistance r^7 in series.

If desired, any of the resistances included in any of the illustrated arrangements may be replaced by a branched sub-network and any of the resistances in the branched sub-networks may themselves be replaced by further branched-sub-networks and so on to any desired degree of complexity, the substituted branched sub-networks being, of course, themselves networks in accordance with this invention. It is not necessary that all the component branched networks making up a composition network should be all designed to have the same quadrantal frequency and it may be desirable in many cases to design the various networks to have different quadrantal frequencies. The substitution of such branched "sub-networks" for simple resistances in (relatively) "main" networks permits of what may be termed "multiplication of correction effects" and further facilitates the obtaining of desired impedance values to accord with any given input-output impedance requirements. This substitution of sub-networks for resistances in (relatively) "main" networks is illustrated in Figure 8 in which l r c r_1 represent the parts of a "main" network as shown in Figure 3. In Figure 8 the resistances r and r_1 are shown in thin lines to indicate that these may be replaced by sub-networks similar to the "main" network (though not necessarily of the same quadrantal frequency) these substitution sub-networks being shown in Figure 8 in broken lines. Similarly the resistances in the sub-networks may be replaced by further sub-networks as indicated in chain lines while, in their turn, the resistances in the sub-networks shown in chain lines may be replaced by sub-networks as shown in dotted lines . . . and so on. The broken line network which is a sub-network relatively to the network l r c r_1 is a "main" network relatively to the chain line network, which is in turn a "main" network relatively to the dotted line network. The various numbered points in Figure 8 will be referred to in the vectorial description later.

Arrangements in accordance with this invention are readily applicable to line circuits where it will be found that the values of inductance and capacity generally required are quite convenient. The invention is also suitable for use in connection with valve circuits.

An incidental, but important, advantage in connection with the invention, is that owing to the fact that a correction device in accordance therewith has a substantially constant impedance, it can conveniently be incorporated at the receiving end of a line, and where so incorporated may be so arranged as to give rise to substantially no difficulties due to reflection for, in many cases, the constant input impedance may be chosen to be equal to the surge impedance of the line at whose end the device is connected.

The combining transformer or other device (if any) employed to combine the voltages set up in the branches of the substantially non-reactive network, should of course be so arranged that substantially no load is thrown back into the network, for, if any appreciable load be thrown back, the condition for constant input impedance is disturbed.

The accompanying Figure 6 shows vectorially the action of certain cases and adjustments of circuits in accordance with the invention drawn on a chart whereby the effect of any given set of conditions and adjustments may be predicted. This chart may be employed in connection with the prediction of the results obtained with either of the key circuits Figures 6A and 6B shown in connection with this figure and below the chart proper.

Figure 6 is, in essence, a vector diagram chart of the well known circle type drawn for the cases shown in the key figures and in which the quadrantal frequency i. e. the frequency at which the inductive impedance numerally equals the capacitative impedance, the vectorial sum of these impedances being (as in all other cases in accordance with this invention) equal to R. L, C and R are respectively the inductance, capacity and resistance so indicated in the key figures, I being the voltage input terminals and II the voltage output.

Referring to the chart, the diameter of the circle O, L, Z, C is the vectorial representation of the resistance R. Then it may be shown that OL represents, in Figure 6A, the impedance of the inductive section i. e. the impedance of L and R in parallel. Also it may be shown that OC represents the impedance of the capacitative section CR. The overall impedance is therefore the resultant of OL and OC=vectorial sum

$$OL+LZ=OZ=R.$$

If, however, the tapping upon the resistance shunting the capacity in Figure 6A be moved, say to include only 60% of the voltage across the capacity the voltage between the terminals II will no longer be given by the vector OZ but will obviously equal the vectorial sum $OL+Lz=Oz$. This of course is for the case in which the voltages due to the inductance and the capacity are combined in like sense. If, however, these voltages are combined in opposite sense i. e. that across the condenser is reversed before combination as by employing a combining transformer as shown in Figure 1 with primaries in opposition the capacity vector LZ becomes LZ' Lz becomes Lz' and OZ and Oz become OZ' and Oz' respectively. Similar considerations apply to Figure 6B (the vectors for Figure 6B at a frequency of 700 cycles are shown in broken lines) except of course that for Figure 6B the vectors within the circle OLZC apply to combination of voltages in opposed sense and the vectors without the circle apply to voltages combined in the same sense. For the sake of varying the example, L_1z_1 and $L_1z'_1$ have been taken as 40% of L_1Z and $L_1Z'_1$ respectively. In the chart the diametrical abscissæ are percentage values of R and the peripheral ordinates values of frequency from 0 to ∞. The chart proper consists of the circles and the lines radiating from Z to the periphery of the largest circle. The actual vectors shown in Figure 6 relate, of course, to the particular cases just described.

In Figure 7 are shown a number of curves illustrating the effect of various adjustments of the tapping point upon R in terms decibels of attenuation (ordinates) plotted against frequency, the horizontal scale being logarithmic. The curves marked 0% 20% 40%. . . and so on give the results obtained with adjustments of the tapping points (see key Figures 6A and 6B) to 0% 20% 40%. . . and so on of resistances R. The group of curves showing maximum attenuation at the lower frequencies relate to settings of the tapping point upon the resistance R in shunt across the condenser C for the case of Figure 6A or to settings of the tapping point upon the resistance R in series with the inductance L of Figure 6B. A set of curves as shown in Figure 7 may be conveniently employed to assist in the design of a correction circuit for any particular case as follows:—

The attenuation curve of the circuit to be corrected is plotted out on the same logarithmic paper as the curves of Figure 7 and to the same scale in decibels attenuation but with attenuation values rising upwards from a zero line at the bottom of the paper instead of downwards from a zero at the top. The logarithmic paper employed is transparent, and the curve to be corrected for is moved over the curves of Figure 7 until it is superimposed upon that curve of Figure 7 which is found to be nearest to the curve to be corrected for. The percentage correction is noted, and from the relative position of the frequency lines on the two sets of curves the required quadrantal frequency is immediately determinable. For example, if it were found that the attenuation curve of Figure 7 nearest to the curve for which correction was required was the 40% curve, but that the 10,000 frequency line of the curve to be corrected for coincided with the 1,000 frequency (quadrantal frequency) line of Figure 7 the constants of the circuit employed to effect correction would have to be so chosen to give a quadrantal frequency of 10,000; i. e.

$$\sqrt{\frac{1}{LC}}$$

would have to equal to $10{,}000\times 2\pi$. As however there is also the required impedance condition that

$$R=\sqrt{\frac{L}{C}},$$

L and C are directly determinable.

Figures 9 and 10 are vector diagrams of the same basic type as that of Figure 6 but showing only the principal vectors for the complex network of Figure 8. The diagrams of Figures 9 and 10 are constructed on the same principle as that of Figure 6 and are obvious developments thereof. The number references in Figures 9 and 10 indicate the vectors representing the voltages set up between the correspondingly numbered points in Figure 8. Figure 9 is a vector diagram drawn for the quadrantal frequency while Figure 10 is drawn for a frequency lower than the quadrantal frequency and such that the voltage across any particular inductance is one-half of that of the network (or sub-network as the case may be) of which it forms part. For the sake of simplicity Figures 9 and 10 have been drawn on the assumption that the quadrantal frequency for each network and sub-network is the same though of course this is not a necessary condition. Also for the sake of simplicity in identifying the various vectors, parts of Figures 9 and 10 are drawn in full, broken, chain, or dotted lines according to whether they relate to networks shown in full, broken, chain or dotted lines in Figure 8.

In the case for the quadrantal frequency (Figure 9) the vector

$$0\text{–}1=\frac{\text{vector } 0\text{–}2}{\sqrt{2}}=\frac{\text{vector } 0\text{–}4}{2}=\frac{\text{vector } 0\text{–}8}{2\sqrt{2}}=\frac{\text{vector } 0\text{–}16}{4}$$

each of the vectors 0–1, 0–2, 0–4, 0–8, 0–16 being as shown at 45° to its neighbours.

In the case shown in Figure 10 the vector

$$0\text{–}1=\frac{\text{vector } 0\text{–}2}{2}=\frac{\text{vector } 0\text{–}4}{4}=\frac{\text{vector } 0\text{–}8}{8}=\frac{\text{vector } 0\text{–}16}{16}$$

the phase shift for each step being 60°

The chart of Figure 7 may be utilized as follows for the case of a complex network giving a number of stages of correction.

The 0% curve rising from the left hand side of Figure 7 indicates the output voltage amplitude across the vector 0–8 as related to the input voltage vector 0–16.

Now as the decibels attenuation scale is logarithmic the voltage across vector 0–4 is the summation curve obtained by adding the 0% curve to itself, and as the same quadrantal frequency is used throughout this is equivalent to reading the 0% curve as though the attenuation scale had been doubled. Similarly the voltage across vector 0–2 is obtainable by adding to the summation curve the original 0% curve, or in other words by reading the 0% curve as though the attenuation scale had been multiplied by 3. Similarly the voltage across vector 0–1 is obtained by reading the 0% curve with an attenuation scale multiplied by 4. Where the quadrantal frequencies are different from network to network the curves have to be added, since the one curve cannot be read to different scales.

The same principle may be applied to obtain the phase angle and it is possible in the manner described to obtain the voltage across any two points from the curves.

For any specific requirements inspection will usually show what degree of complexity i. e. how many "stages of correction" are necessary, and it will then commonly be found possible to simplify the circuit and still meet the specific requirements.

For example it might be found that the correction curve best suiting conditions might be between 3 times and 4 times the 0% curve of Figure 7. In such a case the circuit of Figure 8 could be simplified to that shown in Figure 11.

In Figure 11 the output is tapped off between O and A which is an adjustable tapping point on the resistance 1–2. The curve for any tapping position is estimated in this case by reading with a trebled attenuation scale the 0% curve of Figure 7 (above referred to) (of course for the correct quadrantal frequency) and adding to it the curve expressing the voltage relation between OA and O2 from the group of curves.

Of course as above stated, where different quadrantal frequencies are used at each stage of correction i. e. in the different networks and sub-networks the curves for the corresponding quadrantal frequencies respectively must be added.

In any network or sub-network the inductance and condenser may be interchanged and it is also possible to combine networks and sub-networks in such a way as to multiply or add in successive stages, one of the other percentage curves (20%, 40%, 60% and so forth).

Generally speaking it will be found that although the phase is rotated, in correcting for amplitude, the overall effect is such as to tend to correct the phase, and an overall delay effect is produced.

In designing correction circuits in accordance with this invention it is also possible to utilize the phenomena of resonance by designing one or more of the component networks of a circuit to be resonant within the range over which frequency correction is required. A correction circuit so designed may be advantageously employed in many cases where it is desired to correct for a frequency characteristic showing a change occurring within a relatively narrow range of frequencies:—for example, it might be required to correct a transmitter whose frequency characteristic showed a drop of 4 or 5 decibels between 6,000 and 10,000 cycles per second. An ordinary circuit corrector of the simple resonant circuit type may, of course, be used for applying such a correction, but the present invention may also be adapted to give such a correction and offers the practical advantage that a circuit in accordance with the said invention is more readily calculable in its results and more flexible in its application than are simple resonant circuits.

Consider a circuit as shown in Figure 12 and consisting of a series branch L_1C_1R (inductance and capacity in series) and a parallel branch $L_2C_2R_2$ (inductance and capacity in parallel) in series with one another. At frequencies below resonance the series branch behaves as a condenser offering at any frequency lower than the resonant frequency ω_0 an impedance given by the expression

$$\frac{\omega_0^2-\omega^2}{j\omega\omega_0^2C_1}$$

while the parallel branch behaves as an inductance of impedance

$$j\left(\frac{\omega\omega_0^2}{\omega_0^2-\omega^2}\right)L_2.$$

Similarly at frequencies ω_1 above resonance the series branch behaves as an inductance of impedance

$$j\left(\frac{\omega_1^2-\omega_0^2}{\omega_1}\right)L_1$$

while the parallel branch behaves as a capacity impedance

$$j\frac{\omega}{(\omega_1^2-\omega_0^2)C_2}.$$

It follows therefore that the whole circuit will be overall non-reactive at frequencies below resonance if

$$\sqrt{\frac{L_2}{C_1}}=R$$

and it will be overall non-reactive at frequencies above resonance if

$$\sqrt{\frac{L_1}{C_2}}=R.$$

Therefore for the circuit to be overall non-reactive above and below resonance L_1C_1 should be made equal to L_2C_2 i. e. both branches should be made resonant to the same frequency; i. e. ω_0 should be of the same value for both branches.

Obviously there will be a different quadrantal frequency for the two cases of below resonance and above resonance the quadrantal frequency for the former case being found from the relation

$$\frac{\omega\omega_0^2}{\omega_0^2-\omega^2}=\sqrt{\frac{1}{L_2C_1}}=\omega^1{}_q$$

($\omega^1{}_q$ being an equivalent quadrantal velocity below resonance) while for the latter case the expression

$$\sqrt{\frac{1}{L_1C_2}}=\frac{\omega_1^2-\omega_0^2}{\omega_1}=\omega_1{}^1{}_q$$

is employed. $\omega_1{}^1{}_q$ is the corresponding equivalent quadrantal velocity above resonance. It will be clear that in the former case the equivaent angular velocity ω^1 (which is given by the expression

$$\left.\frac{\omega\omega_0^2}{\omega_0^2-\omega^2}\right)$$

becomes infinite when $\omega_0=\omega$ (at resonance) whilst in the latter case when the actual velocity $\omega_1=\omega_0$

(at resonance) the equivalent velocity ω_1^1 corresponding to ω_1 and given by the expression

$$\frac{\omega_1^2-\omega_0^2}{\omega_1}$$

becomes zero. The effect may be expressed in the familiar vector diagram form as shown in Figure 13 the numbered points upon which correspond to the numbered points in Figure 12 in the same way as the numbers in Figures 9 and 10 correspond to the numbers in Figure 8. The circle in Figure 13 is the locus of the vector potential 0–1. At $\omega=0$ the series branch offers infinite impedance and the parallel branch zero impedance hence the vector potential 0–1=vector potential 0–2. In Figure 13 the vectors are drawn for the two quadrantal frequencies indicated at ω_q and ω_{1q} which are the actual frequencies corresponding to the equivalent quadrantal frequencies ω^1_q and ω_{1q}^1 respectively.

It will now be apparent that the frequency range over which a desired correction occurs can be fixed (1) by fixing the resonant frequency to determine the frequencies at which zero or maximum correction occurs and (2) by fixing the relative values of the products L_2C_1 and L_1C_2.

The chart of Figure 7 can be employed for the estimation of correction curves by computing the values of ω^1_q and $\omega_1{}^1_q$ and from this knowledge the attenuation for any correction tapping can be found in terms of ω^1 and ω_1^1. A curve can then be plotted showing the relation between these frequencies and the actual applied frequencies ω (below resonance) and ω_1 (above resonance). For example, suppose it is required to impart a "lift up" of 6 decibels between 5,000 and 10,000 cycles, it being unimportant if an extra loss is effected above 10,000 cycles. Referring to the chart of Figure 7 it will be found that a tapping somewhere about 50% along the condenser branch is required i. e. in Figure 12 about half way along the resistance R in shunt across L_1 and C_1 the other tapping point being of course the point **2**. Now the "lift up" will cease when $\omega^1=\infty$ or $\omega=\omega_0$ and therefore the resonant frequency ω_0 should be chosen at some frequency above 10,000, say 12,000. L_2C_1 would be chosen so that the correction started to come into operation at 5,000 cycles and to secure this result the first quadrantal frequency ω_q could be chosen at about 8,000 cycles the exact values being determined actually by "fitting" the curves. The ω^1 curve woold not be used though it will be noted that the overall attenuation above 10,000 cycles will be actually increased. Under the conditions imposed, however, this is allowable and in certain conditions might prove a definite advantage.

It is clear that the correction effects can be "multiplied" in exactly the same way as with the ordinary non-resonant branch circuits already described (see Figure 12) and that different resonant and quadrantal frequencies may be used at each step of correction if required.

It is also clear that a parallel branch type of circuit as shown in Figure 14 may be employed for "phase correction" and that by means of such a circuit a 360° phase shift can be produced between $\omega=0$ and $\omega=\infty$. By suitably arranging the resonant and quadrantal frequencies the required phase shift may be made to occur in any desired frequency spectrum.

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

1. In combination, a parallel circuit having two branches, one of said branches comprising a resistance and inductance and the other of said branches comprising a capacity and resistance, the resistances in both said branches being equal and also equal to

$$\sqrt{\frac{L}{C}}$$

where L is the inductance and C the capacity of the circuit, an input circuit across said parallel circuit, having a source of electrical energy containing a band of frequencies connected thereto, means for tapping off resultant voltages set up across both said resistances at points which give an output amplitude which is a function of the input frequency, and an output circuit connected to said means.

2. A circuit for correcting for frequency distortion comprising a substantially constant impedance overall non-reactive network having capacitance, resistance and inductance elements so related as to give a constant pure resistance impedance between a pair of terminals to which input voltages of different frequencies are applied, means for tapping off voltages set up across the resistance elements in said network, and means for combining said voltages to give an output voltage which is distorted in inverse sense to the input voltage.

3. A circuit for correcting for frequency distortion comprising a substantially constant impedance overall non-reactive network having capacitance, resistance and inductance elements so related as to give a constant pure resistance impedance between a pair of terminals to which input voltages are applied, means for tapping off voltages set up across the resistances of said network, and means for combining said voltages to give an output voltage for amplitude correction purposes including a switching element for changing at will the sense of combination of the tapped off voltages.

4. A circuit for correcting for frequency distortion comprising a substantially constant impedance overall non-reactive network to which input voltages are applied, said network comprising two series sections, one consisting of an inductance shunted by a resistance and the other of a capacity shunted by a resistance, each resistance being equal to the square root of the quotient of the capacity into the inductance, and means for tapping off the resultant voltages set up across the resistances substantially as described.

5. A circuit for correcting for frequency distortion comprising a substantially constant impedance overall non-reactive network having capacitance, resistance and inductance elements so related as to give a constant pure resistance impedance between a pair of terminals to which input voltages are applied, means for tapping off voltages set up across the resistance elements in said network at points which give an output amplitude which is a function of the input frequency, and means for combining said voltages to give an output voltage for correction purposes in such fashion as to obtain an output which varies with frequency, including a transformer having two primary windings, one primary winding being in circuit with said inductance element and the other primary winding being in circuit with said capacitance element.

6. A circuit for correcting for frequency distortion comprising a substantially constant im-

pedance overall non-reactive network to which input voltages are applied, said network comprising two parallel sections, one comprising an inductance and a resistance in series and the other a capacity and a resistance in series, each resistance being equal to the square root of the quotient of the capacity into the inductance, and a double primary transformer connected to said sections for combining the voltages derived therefrom, one primary winding being across the resistance in the capacitance section and the other primary winding being across the resistance in the inductance section of said parallel arrangement.

7. A circuit for correcting for frequency distortion comprising a substantially constant impedance overall non-reactive network to which input voltages are applied, said network comprising two parallel sections, one comprising an inductance and a resistance in series and the other a capacity and resistance in series, each resistance being equal to the square root of the quotient of the capacity into the inductance, and a double primary transformer connected to said sections for combining the voltages derived therefrom, one primary winding being in circuit with the capacitance section and the other primary winding being in circuit with the inductance section of said parallel arrangement, including a reversing switch connected to one primary winding whereby the sense of combination may be reversed at will.

8. An equalizer circuit comprising a substantially constant impedance overall non-reactive network to which input voltages of different frequencies are applied, said network comprising a series branch including inductance and capacity in series, and a parallel branch including inductance and capacity in parallel, said branches being designed to be resonant at a frequency within a predetermined range of applied frequencies, and means for combining the resultant voltages set up in said branches.

9. An equalizer circuit comprising a substantially constant impedance overall non-reactive network of two paths having capacitance, resistance, and inductance elements so related as to give a constant pure resistance impedance between a pair of terminals to which input voltages of different frequencies are applied, one of said paths including inductance and resistance, and the other of said paths including capacitance and resistance, the resistances in both of said paths being equal, and means for tapping off voltages set up across the resistances at points which are unsymmetrical with respect to the reactance elements.

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