PATENT SPECIFICATION

Application Date: Dec. 11, 1943. No. 20788/43.

573,615

Complete Specification Left: Dec. 11, 1944.

Complete Specification Accepted: Nov. 28, 1945.

PROVISIONAL SPECIFICATION

Improvements in and relating to Electrical Networks

We, EDMUND RAMSAY WIGAN, of 35, Montague Road, Southbourne, Bournemouth, a British Subject, do hereby declare the nature of this invention to be as follows:—

This invention discloses new and simple means for obtaining, in chosen branches of an electrical network, pairs of currents which bear to each other a desired ratio of magnitude and a desired difference of phase angle.

It is a feature of this invention that the pairs of currents which are chosen have magnitude ratios and phase-relationships which are proportional to the ratio of the impedance of two elements of the network.

It is a further feature of this invention that the impedance of the two circuit elements in which the pair of desired currents flows has no effect on the magnitude ratio or upon the phase difference of the currents which flow in them, it being required only that these two circuit elements have identical impedance.

The principle of the proposed network is to be seen from the following general description. Consider part of a network arranged to consist of two paths in parallel with a source of current (A.C. or D.C.). Each of these two paths contains the same number of similar elements, but differently arranged: each path consists of the same two elements (or groups of elements) A and B connected in series across the source; in addition a third element C (or group of elements), appears in each path, in one case across the element A and in the other case across the element B. Then the two elements C will be found to carry currents the ratio of which is equal to the ratio of the impedances A and B across which they are connected.

This ratio is independent of the magnitude of the impedance of the element C.

It is in the significance of the last sentence that the value of the invention lies.

To those skilled in the art there is no difficulty in deriving from the above information a new but "equivalent" network, in which the pair of elements A and B, appear connected in parallel in two groups, these two groups being connected in series across the source of current the third element C is then introduced into the one group in series with element A and also into the other group in series with the element B. The ratio of the currents flowing in the two elements C is, in this case, inversely proportional to the ratio of the impedance of the elements A and B with which they are associated.

As an example of the application of the invention, the case of the phase-shifting network of an A.C. coordinate potentiometer will be dealt with. In all such potentiometers two voltages in quadrature are needed, their magnitudes being known and adjustable. In all known forms of A.C. potentiometer this quadrature is given by networks containing either mutual inductance and resistance, or self inductance, resistance and capacitance. If the principle of the invention is applied it becomes at once clear that the required quadrature can be derived from a network containing resistance and capacitance only, thus eliminating entirely the leakage fields, frequency errors and excessive size weight and expense of self or variable inductances. This is achieved by using for element A a resistance, and for element B a fixed condenser. The elements C become pure resistances from which the desired quadrature potentials can be tapped off as required.

Various refinements will of course be needed to make such a circuit of practical value. Means must be provided to keep the currents in the two resistances C at known, and if possible, equal values at all frequencies. They are conveniently made equal by adjusting the magnitude of A to be inversely proportional to the frequency at which the test is being made. To serve this purpose the elements A may be made as conductance boxes, gradulated in frequency, and built up in decades. Alternatively, if the frequency is not known with precision, the two sets of elements A and B are converted one into a series and one into a parallel combination and are then made into part of a Wien bridge; the elements A are adjusted in both arms simultaneously until the bridge is balanced; it must then follow that the impedance of element A is equal, at the frequency of test, to that of element B. The potentials available from the two potentiometers C must therefore be equal also, as was required. The ratio of this p.d. to the p.d. at the input terminals of the network will not be the same at all frequencies. Means are therefore provided to vary the latter p.d. with frequency, so as to keep the former p.d. constant.

In some applications of the invention the element C is made up of several impedances in series and/or parallel. The current flowing in, or the p.d. across, a part of this combination may then be made use of, rather than, as in the example quoted, the total current or p.d.

If it is found convenient the two elements C may be made variable, without sacrificing the principle of the invention, it being required only that the two elements are varied equally and simultaneously.

Currents of all frequencies, including D.C., may be controlled by the aid of the networks described.

Dated this 8th day of December, 1943.
E. RAMSAY WIGAN,

COMPLETE SPECIFICATION

Improvements in and relating to Electrical Networks

I, EDMUND RAMSAY WIGAN, a British subject, of 35, Montague Road, Southbourne, Bournemouth, Hampshire, 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 electrical networks in which a plurality of currents bearing to each other a desired ratio of magnitude and a desired difference of phase angle, are obtained from a single-phase source of alternating current, and especially to A.C. potentiometers comprising such networks.

The object of the present invention is to provide a new and improved method for obtaining a plurality of currents in this way and in particular a pair of currents.

The invention consists, broadly, in an electric circuit in which between two leads extending from a source of alternating current there are arranged either:—

(1) the following sets of elements arranged in parallel, a first set consisting of an impedance A in series with an impedance B, a second set consisting of a second similar impedance A and a second similar impedance B, and, in the first set, an impedance C in shunt with the first-mentioned impedance B, and in the second set a similar impedance C in shunt with the second-mentioned impedance A, in which case if the phase angles of the two impedances A and B differ by X degrees at any one frequency, there will be obtained in the impedances C two currents which differ by the same phase angle X and bear the same ratio to each other as the two impedances across which the two similar impedances C are bridged, this ratio being entirely independent of the magnitude of the two similar elements C, or

(2) between the leads an impedance A in series with an impedance C with which impedances there is in shunt an impedance B, these three impedances being in turn in series with impedances C and B also in series shunted by an impedance A, in which case if the difference of phase angle of the impedances A and B is chosen at the desired value of X degrees, two currents which bear to each other the same magnitude ratio as A does to B and which differ in phase by the same angle X will be obtained in the two elements C, and voltages may be tapped off the two impedances C by suitably connected potentiometers or transformers which may form part of an A.C. potentiometer. As in the alternative network the two similar elements C may have any magnitude whatever.

The second of the two circuit arrangements does not lend itself so readily to the design of an A.C. potentiometer as the first-mentioned arrangement.

Consequently, an A.C. (Cartesian co-ordinate potentiometer in accordance with the invention is preferably based on the first-mentioned circuit arrangement, the impedance A being in the form of a condenser and the impedance B in the form of a resistance so that the angle X at all frequencies will be equal to 90°, the impedance C being for example a wire wound potentiometer, or a transformer.

With such an arrangement the impedances B are made adjustable so that if at the frequency at which the measurement is to be made, the magnitude of B is equal to the magnitude of A, then the two currents flowing in the two impedances C will be equal and in quadrature.

In all Cartesian co-ordinate potentiometers two voltages in quadrature are needed.

In all known forms of A.C. potentiometer this quadrature is given by networks containing either mutual inductance and resistance, or self-inductance, resistance and capacitance.

Preferably, in accordance with the invention, the required quadrature is derived from a network containing resistance and capacitance only, thus eliminating entirely the leakage fields, frequency errors, and excessive size, weight and expense of high grade self or variable mutual inductance. This is achieved by using for elements B a resistance and for element A a fixed condenser. The elements C may be pure resistances from which the desired quadrature potentials can be tapped off as required. It is pointed out, however, that since the elements C may take any form, two transformers may be substituted provided only that the two transformers are identical in impedance. In certain applications the isolation of secondary and primary windings is advantageous. Moreover, high ratio transformers may be used if large voltages have to be measured.

Various refinements will, of course, be needed to make such a circuit of practical value. Means must be provided to keep the currents in the two resistances C at known, and if possible equal, values at all frequencies. These two currents are conveniently made equal by adjusting the magnitude of B to be inversely proportional to the frequency at which the test is being made. To serve this purpose the elements B may be made as conductance boxes, graduated in frequency and built up in decades. Alternatively, if the frequency is not known with precision, the two sets of elements A and B are converted one into a series and one into a parallel combination and then are reconnected so as to form part of a Wien bridge; if the elements B are adjusted in both arms simultaneously until the bridge is balanced, it must then follow that the magnitude of the impedance of element A is equal, at the frequency of test, to that of element B. The potentials available from the two potentiometers C must therefore be equal also, as was required. The ratio of this potential to the potential at the input terminals of the network will not be the same at all frequencies. Means are therefore provided to vary the latter potential with frequency, so as to keep the former potential constant.

In some applications of the invention the element C is made up of several impedances in series and/or parallel. The current flowing in, or the potential across, a part of this combination may then be made use of rather than, as in the example quoted, the total current or potential.

If it is found convenient the two elements C may be made variable, without sacrificing the principle of the invention, it being required only that the two elements are varied equally and simultaneously.

Currents of all frequencies including D.C. may be controlled by the aid of the networks described in Figures 1 and 2.

The invention will be described further by way of example with reference to the accompanying drawing in which:—

Figure 1 illustrates one form of network;

Figure 2 illustrates a second form of network;

Figure 3 is the basic circuit for a potentiometer embodying the network as shown in Figure 1;

Figure 4 illustrates the circuit of a potentiometer in accordance generally with Figure 3 and illustrating means by which the potentiometer is operated.

Figure 5 illustrates a potentiometer circuit generally as shown in Figures 3 and 4 adapted to be converted into a frequency bridge.

In the construction illustrated in Figure 1 there are provided between the leads 1 and 2, to which voltage from a suitable alternating source may be applied, two parallel paths.

These paths each contain electrically identical elements but in a different arrangement. Each path consists of an impedance A in series with an impedance B, the phase angles of which differ by X degrees at any one frequency so that two currents are obtained which have a magnitude ratio equal to A/B and differ by the same phase angle and flow respectively in each of two similar impedances C connected, the one in the one path in shunt with A and the other in the other path in shunt with B.

In the case of the construction illustrated in Figure 2, there are two sets of impedances which are arranged in series across the leads supplying current.

One set of impedances comprises an impedance A and an impedance C in series and shunted by an impedance B, and the other an impedance C in series with an impedance B and shunted by an impedance A. As in the previous circuit described the element C may have any value whatever.

The impedances B in either of the arrangements may be pure resistances as shown in Figure 3, which generally corresponds with the circuit illustrated in Figure 1, excepting that the impedance A is shown as two condensers arranged on either side of the impedance B which, as stated, is a resistance, and in the other case the impedance B is broken up into two resistance B/2, located on either side of the condenser representing impedance A.

Across the resistance R in the L.H. branch is connected a potentiometer P.1 and across the condenser in the other branch there is connected a potentiometer P.2.

With such an arrangement, in order to make the currents equal in P.1 and P.2 it is necessary that the total resistance R in both branches should be equal to the magnitude, X, of the condenser reactance in each branch. As the frequency changes so the value of X changes. R is therefore constructed so that it can be adjusted to the required value at any frequency as described later. Alternatively the capacity of the condensers may be adjusted and R held constant. Then the voltage on P.1 will be equal in magnitude to the voltage on P.2. This is necessary in order that these two resistances may be marked off with equal scales of voltages.

The absolute magnitude of the voltage V2 across P.1 and P.2 in terms of the voltage V1 (Figure 3) is given by an equation in another paragraph.

A convenient way of adjusting R, (and R/2) in Figure 3, to fulfil the above requirements, is to use a series of sets of fixed resistances which can be brought into circuit at R or R/2 (Figure 3). One set of three such resistances is chosen so that R is equal to the reactance X at a frequency of, for example, 500 c/s, another set is chosen so that R is equal to the reactance X at a frequency of 1000 c/s, another at 1500 c/s and so on. A separate lever switch designated with the appropriate frequency may be used to connect each set of resistances in the correct place in the network.

It will be found that the formula connecting R and X is such that if several of these switches are operated simultaneously the circuit becomes adjusted for a testing frequency equal to the sum of the frequency markings on these switches. Thus, if the 500 c/s switch is thrown at the same time as the 1500 c/s switch, the circuit is correctly adjusted for a frequency of 2000 c/s. This is a great convenience, and reduces the number of resistances required to a small quantity. Further, in order to be able to adjust the circuit for any value of testing frequency within its range, a set of three continuously variable rheostats is employed. These are scaled individually over the frequency range, for example, 200 to 700 c/s.

A practical arrangement of A.C. potentiometer employing the above "frequency addition" principle is illustrated in Figure 4 in association with a phase shifter.

In this case between the leads 1 and 1*a* which are connected to the secondary of an isolating transformer 3, the primary of which is connected by leads 4 and 4*a* to an oscillator, there are connected in parallel two sets of impedance elements arranged generally in the manner shown in Figure 3.

One set of impedance elements comprises two similar condensers C1 and C2 between which is located a plurality of resistances R4, R5, R6, R7, R8, switches S1, S2 and S3 being associated respectively with the resistances R6, R7, R8. R5 is a variable resistance or rheostat.

Resistances R21 and R22, the latter of which is in the form of a slide wire, form the equivalent of P1 in the construction illustrated in Figure 3.

The other set of impedances comprises a condenser C3 of capacity which is the sum of C1 and C2 and the fixed resistances R9, R10, R11, R12, R13 and R14 which are arranged to be put into and out of circuit with the condenser by means of the keys S4. S5, S6, S7, S8 and S9, respectively, and thus brought in parallel with the fixed resistances R15 and R17 and the variable resistances R16 and R18.

The potentiometer of this set of impedances comprises a fixed resistance R20 and a slide wire R19.

The variable resistances or rheostats R5, R16 and R18 are ganged and may be designed for a range of 200/700 c/s.

The switches S1—S4—S7, S2—S5—S8, S3—S6—S9 are also ganged in sets of three and the values of the resistances may be such as to give frequencies of 500, 1000 and 1500 c/s. respectively.

Between the condenser C3 and resistances R19 and R20 there is arranged a reversing switch Z, and between the leads 1 and 1*a* there is arranged a lamp bridge comprising two fixed resistances R2 and R3, a lamp, and a variable resistance R1 with a telephone P connected across them.

The sliding contact of the potentiometer element comprising the fixed resistance R20 and the slide wire resistance R19, is taken out to a lead 4*b* and the sliding contact from the potentiometer which includes the fixed resistance R21 and the slide wire resistance R22 is taken out to a lead 4*c*. The leads 4*b* and 4*c* are connected to the source of potential to be measured via a telephone 5, which may be connected in series with either lead 4*b* or 4*c*.

In this construction from the leads 4, 4*a* extend leads 6, 6*a* to the primary of an isolating transformer 7 and to the secondary of the transformer by leads 8, 8a is connected a phase-shifting network which comprises a rheostat R23 in series with a condenser C4, and in parallel with the resistance R23 and the condenser C4 respectively are variable potentiometers R24, R25, which are each calibrated to indicate from zero to 45° phase shift, the leads from the variable potentiometers being connected by the leads 9, 9a to the input of an amplifier buffer stage from which extend leads 10, 10a by which a connection may be made to the impedance, network, etc. on test.

With this construction the switches may be key switches, one being designated 500 c/s, operating the contacts S1, S4 and S7, another designated 1000 c/s operating the contacts S2, S5 and S8, and a third designated 1500 c/s operating the contacts S3, S6 and S9.

The three rheostats R5, R16, R18 bear individual scales marked off from 200—700 c/s. Fixed resistances R4, R15 and R17 are connected in series with these rheostats so that the lower end of the resistance scale (higher end of frequency scale) shall be "opened out."

Thus, to set the A.C. potentiometer of Figure 4 for a frequency of 2850 c/s the 1000 c/s and the 1500 c/s keys will be operated and the three rheostats R5, R16 and R18 will each be adjusted to a scale reading of 350 c/s.

The circuit illustrated in Figure 4 will be seen to be adjustable to any frequency within the range 200—3700 c/s.

By alternative choice of capacitance C1, C2, C3 and/or resistances R4—R18 other frequency ranges as desired may be covered.

The circuit illustrated in Figure 5 is arranged to convert the A.C. potentiometer circuit of Figure 4 into a frequency bridge, by the throwing of the key K (contacts K1 to K6).

Two subsidiary resistances $2r$ and r (normally shorted out by K5 and K6) are provided to act as the ratio arms of the frequency bridge.

The phones or other null detector normally associated with the A.C. potentiometer are transferred to the detector arm of this frequency bridge by a plug or switch (not shown).

The oscillator is set to the frequency at which the test is to be made. The ganged resistances R1, R2 and R3 are adjusted until the null indicator reads a minimum.

Then if the rheostats R etc. have been calibrated in advance in terms of frequency, the reading of these rheostats checks the oscillator frequency. At the same time it follows from the theory of this simple frequency bridge that R must equal $\frac{1}{\omega C}$ (or, in Figure 1, $/A=/B/$ so that $/i_1/=/i_2/$.) The potential which will be developed across P1 when K is restored to normal must therefore be exactly equal (in magnitude) to that across P2 and in quadrature with it. Consequently the potential scales marked off on the potentiometer P1 and P2 can be relied upon and A.C. potentials accurately measured by means of the potentiometer when so adjusted and at the frequency chosen.

The previous statement is strictly correct only if the absolute magnitude of the currents in, or potentials across P1 and P2 is known. As explained in connection with Figure 4 this can be found either by direct measurement with a valve voltmeter or by the measurement of the voltage fed by the oscillator to potentiometer network. The lamp bridge of Figure 4 serves the purpose. It measures the potential V1 in Figure 5.

The ratio of V_1 to V_2 (the potential across both P1 and P2 when the potentiometer has been set up for test as detailed above) is given by

$$\frac{V_1}{V_2}=\sqrt{\left(1+\frac{1}{\omega CP}\right)^2+1}=\sqrt{\left(1+\frac{R}{P}\right)^2+1}$$

where R = effective resistance of those elements R4—R8 which are in circuit P = R21 + R22 = R19 + R20 and C = capacity of condenser C3 and $\omega=2\pi f$.

From this it is seen that V_1/V_2 will vary with R. On the other hand if R is kept constant and C is varied in inverse ratio to ω the ratio V_1/V_2 remains constant.

The small complication involved in the variation of V_1/V_2 with variation of R is justified by the greater complication involved in the alternative of varying three condensers (C1, C2, C3, Figure 4) simultaneously.

It can be arranged that the magnitude of the ratio V_1/V_2 does not vary very greatly. For example in the typical circuit illustrated in Figure 4 we have P = 4000 ohms and:—

Frequency	Res. R. ohms.	V_1/V_2
4000	100	1.432
2000	200	1.450
1000	400	1.487
800	500	1.562
200	2000	1.805

It will be seen that by increasing P or decreasing R the variation of V_1/V_2 can be made as small as may be wished. For practical reasons, however P, will not be increased beyond about 50,000 ohms. since a wire wound potentiometer must be used to ensure constancy of potential calibration with age and wear. Also R cannot be reduced indefinitely since for a given test frequency this involves very large capacitances at C1, C2, C3 (see Figure 4).

The values chosen in Figure 4 are a good compromise for the audio frequency range 200—4000 c/s.

In certain cases it is desirable to divide the elements P1 and P2 (Figure 3) each into two parts (say P3 and P4). In both branches of the network P3 and P4 are connected in parallel in place of P1 and P2 respectively, but in the one branch the desired potential is tapped off P3 and in the other branch the potential is tapped off P4. Inductance or capacity can be added to P3 or to P4 so as to add to, or subtract from, the original phase shift given by the ratio of the impedance of the elements A and B (Figure 3). For example the condensers C1, C2, C3 used in the embodiment of the invention illustrated in Figure 4 may not be perfect, i.e. the power factor may be significant. As a result the potential across the potentiometer R21 may not be exactly in quadrature with the potential derived from potentiometer R19.

If the condensers C1, C2, C3 are high grade mica types, the power factor will be substantially constant with frequency and equal to about 0.02 over the audio-frequency range. This means that at all frequencies there will be about 89 degrees phase shift instead of 90 degrees between the potentials on R19 and R21.

One way of correcting for this error, approximately, is to connect a small inductance 1 (not shown) in series with R22 on the side remote from R21 and a resistance across R21 and R22 equal in resistance to the sum of R21 and R22; at the same time a shunt consisting of an inductance 1 in series with a resistance equal to R19 and R20 would be placed across the resistance R19 and R20. The phase shift correction produced by this modification is not exact since, to correct for a constant power factor error, 1 should vary with frequency. If, however, 1 is chosen so that its reactance is equal to the resistance component of the condenser impedance at a given frequency, the phase correction will be perfect at that frequency. If this frequency is therefore chosen so as to be in the middle of the working range, phase shift errors can be made small at lower and higher frequencies.

It should be noted, however, that if the dielectric loss in the condenser is such that the effective series resistance of the condensers (C1, C2, C3 of Fig. 4) is largely independent of frequency, then the use of the artifice as just described can be effective in reducing the phase shift error due to the dielectric loss to a small quantity.

The example quoted will serve to illustrate the practical advantages of the fundamental principle illustrated in Figure 1, namely, that the two elements C may have any impedance whatever (provided they are identical) without affecting the ratio of the two currents i_1 and i_2 flowing in them.

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. An electrical network in which between two leads extending from a source of alternating current there are arranged either:—

(1) the following sets of elements arranged in parallel, a first set consisting of an impedance A in series with an impedance B, a second set consisting of a second similar impedance A and a second similar impedance B and in the first set an impedance C in shunt with the first-mentioned impedance B and in the second set an impedance C in shunt with the second-mentioned impedance A, in which case if the phase angles of the two impedances A and B differ by X degrees at any one frequency, there will be obtained two currents, which differ by the same phase angle X and bear the same relation to each other as the two impedances across which the two similar impedances C are bridge, or

(2) between the leads an impedance A in series with an impedance C with which impedances there is in shunt an impedance B, these three impedances being in turn in series with impedances C and B also in series shunted by an impedance A.

2. An alternating current potentiometer comprising electrical networks as as defined under (1) in Claim 1.

3. A potentiometer as claimed in Claim 2 in which the element A and B of the networks contain resistance and capacitance only.

4. A potentiometer as claimed in Claim 3, comprising arrangements to connect the two elements A and the two elements B to form (with two subsidiary impedance elements) a frequency bridge so that by bringing the bridge to "balance" by the adjustment of either A or B at any desired frequency, the elements A and B may be adjusted to have equal impedance magnitudes.

5. A potentiometer as claimed in Claim 3, comprising arrangements to correct the phase shift errors produced by the resistance component of the condenser impedance, by means of a subsidiary branched network containing reactances and/or resistances, the potentials representing the two voltage co-ordinates of the A.C. potentiometer being derived, the one from the current flowing in the one branch, and the other from the current flowing in the other branch, the branched network being connected across impedance element A in the one case, and across impedance element B in the other case.

6. Apparatus and circuits substantially as described and as illustrated in and by the accompanying drawings.

Dated this 11th day of December, 1944.

MARKS & CLERK.

Leamington Spa: Printed for His Majesty's Stationery Office, by the Courier Press.—1945. Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies, price 1s. 0d. each (inland) 1s. 1d. (abroad) may be obtained.

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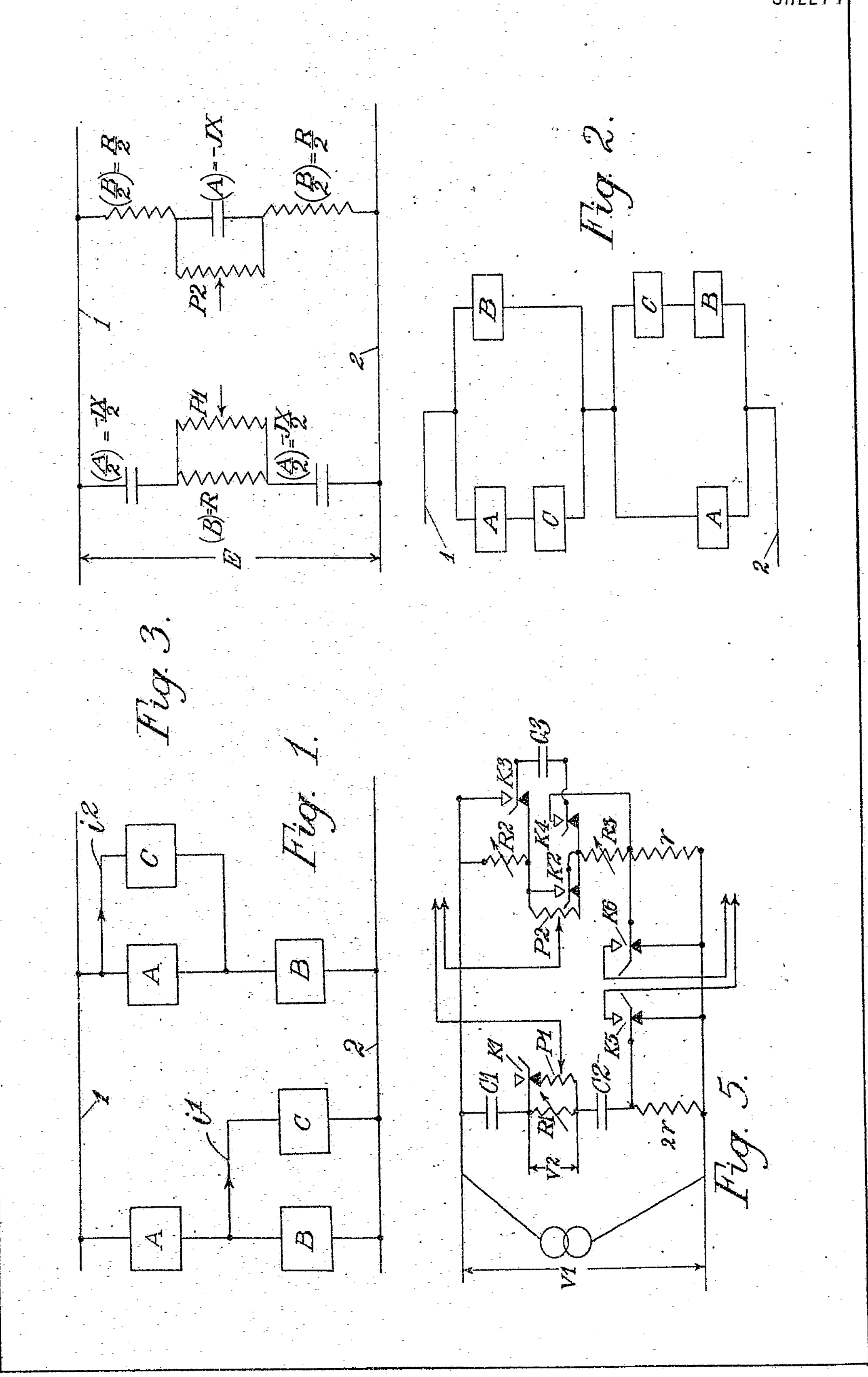

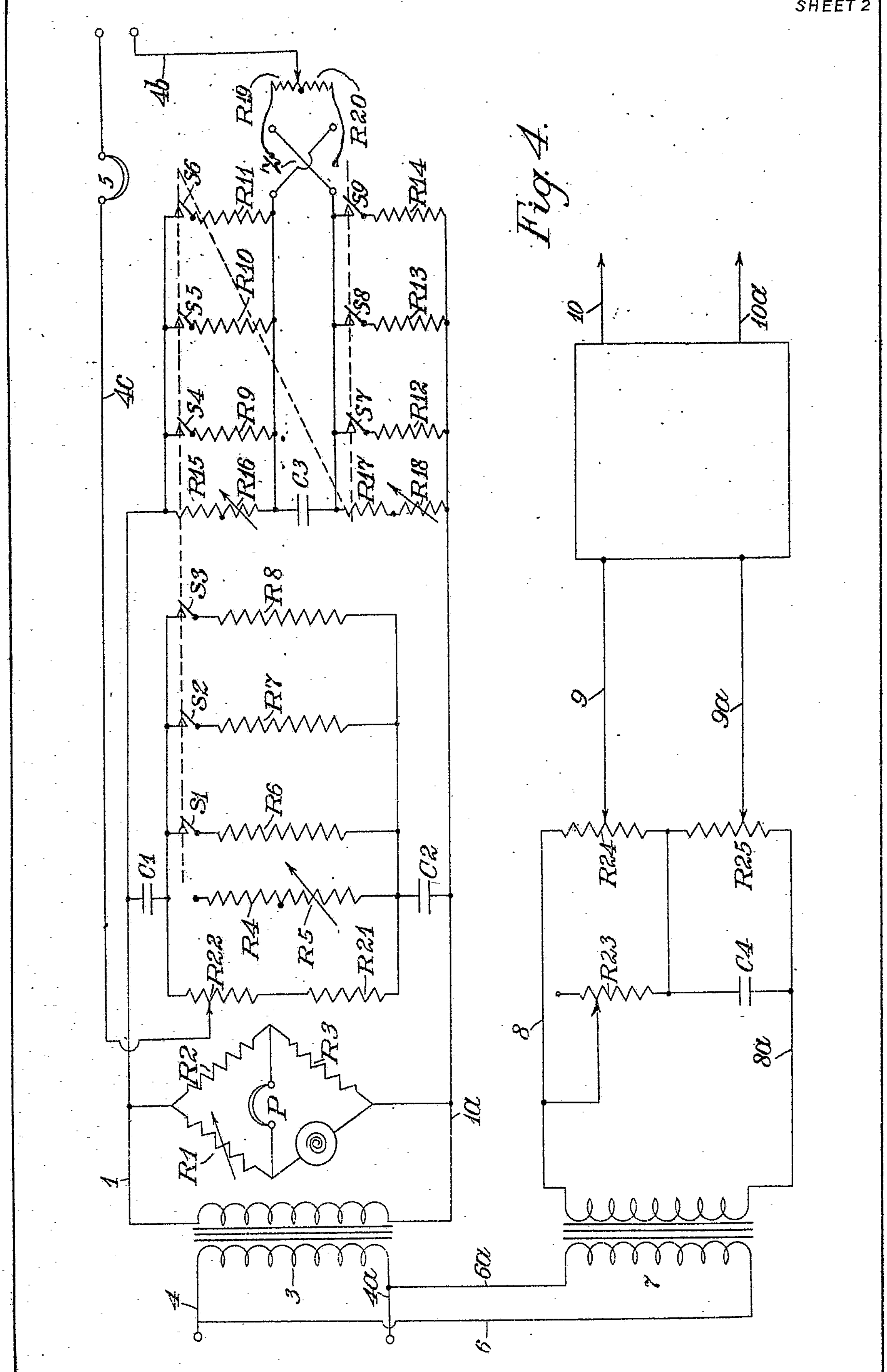

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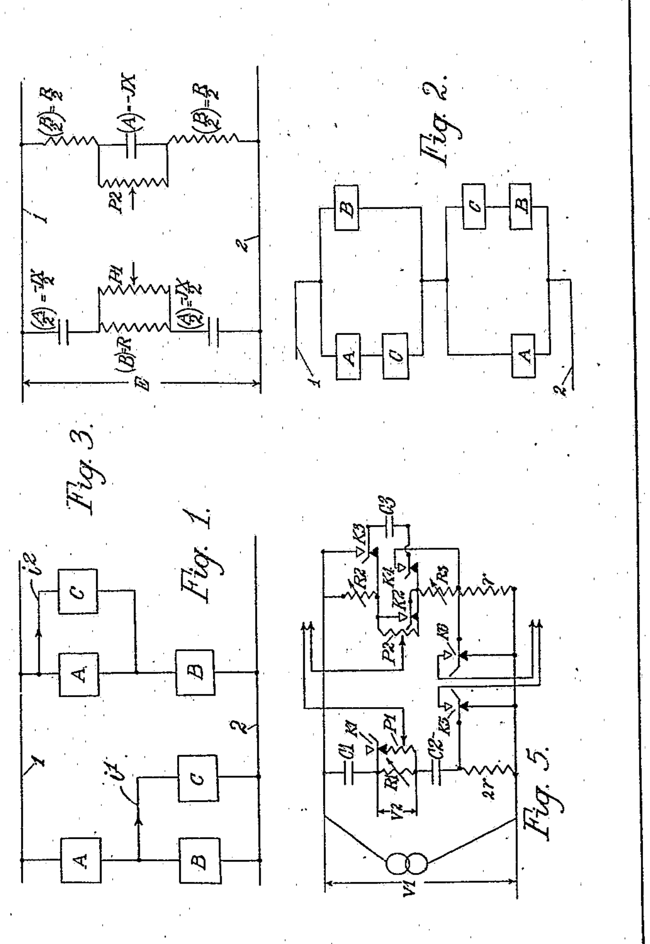

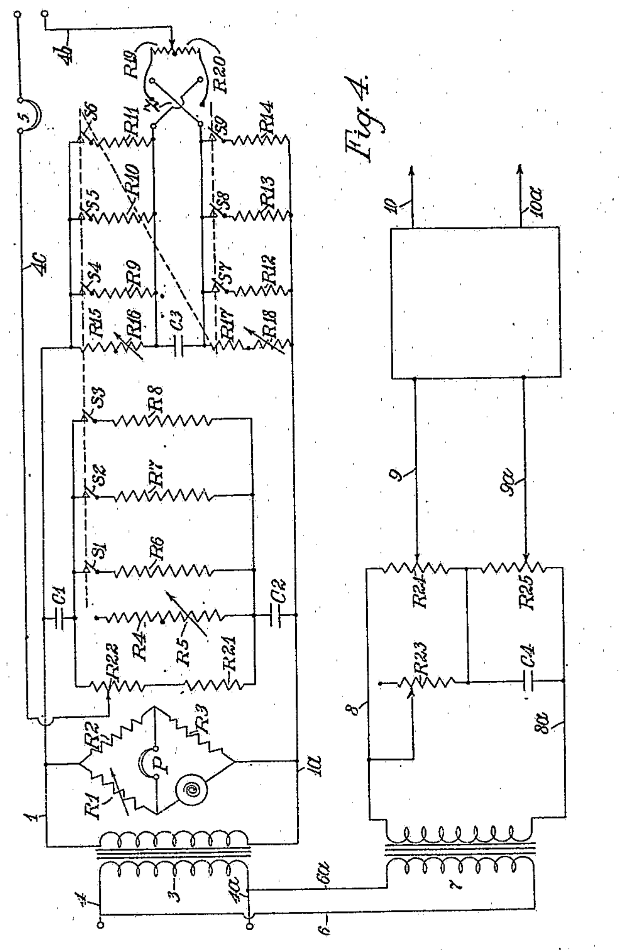

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