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H. GOLDBERG ET AL

2,497,166

PARALLEL CIRCUIT ARRANGEMENT FOR POWER TUBES

Filed June 6, 1944

2 Sheets-Sheet 1

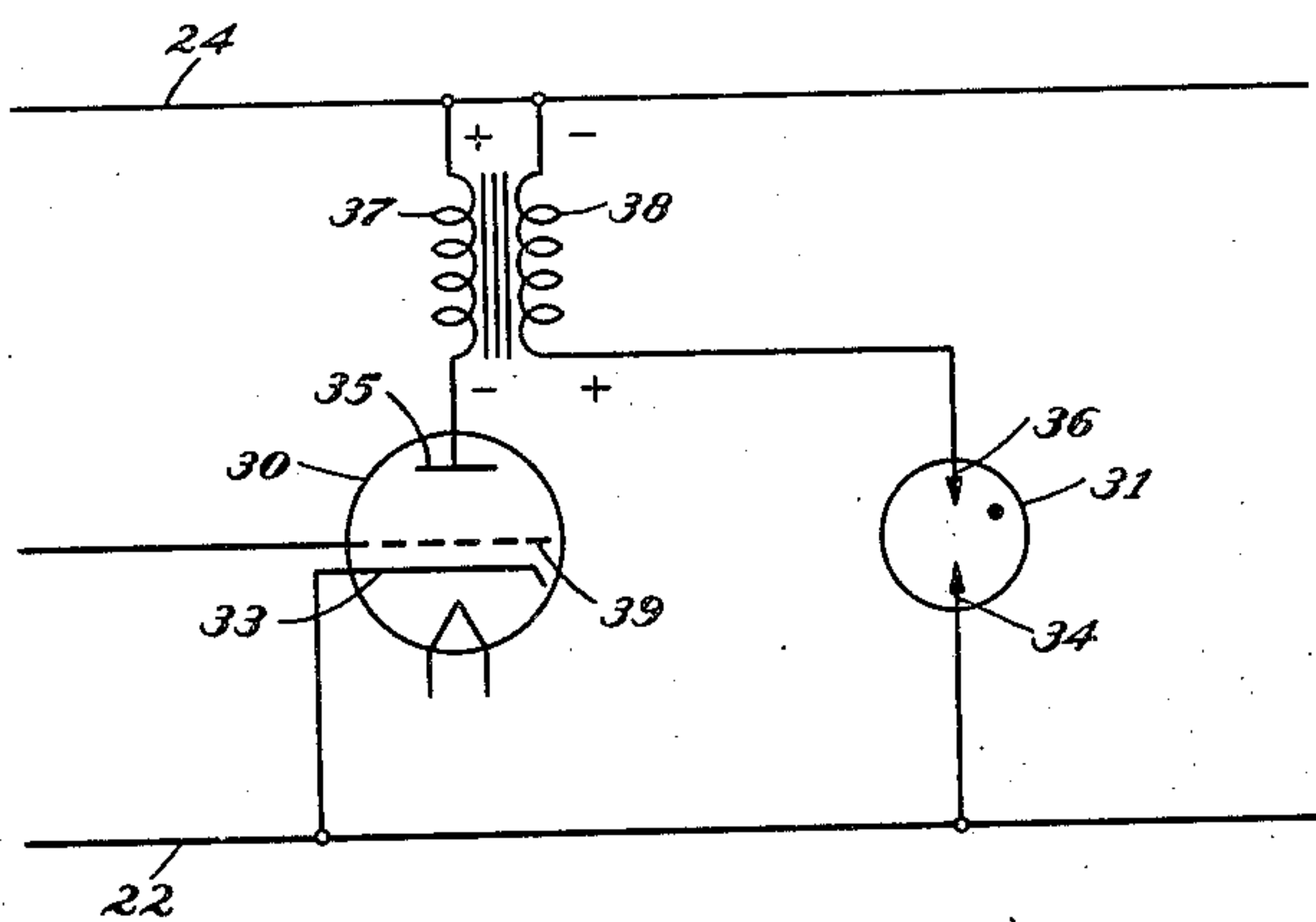


Fig. 2

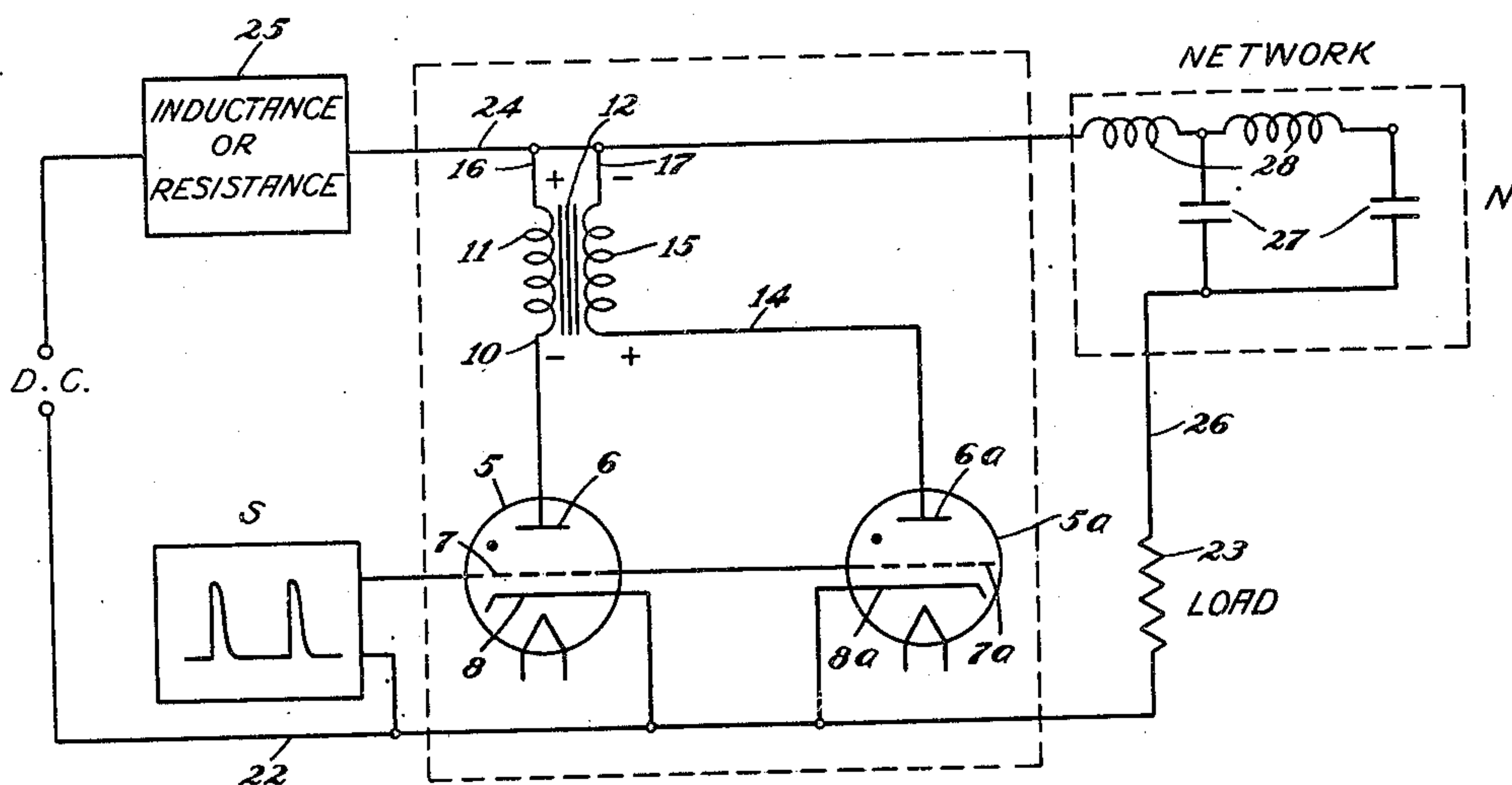


Fig. 1

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2 Sheets-Sheet 2

Fig. 7

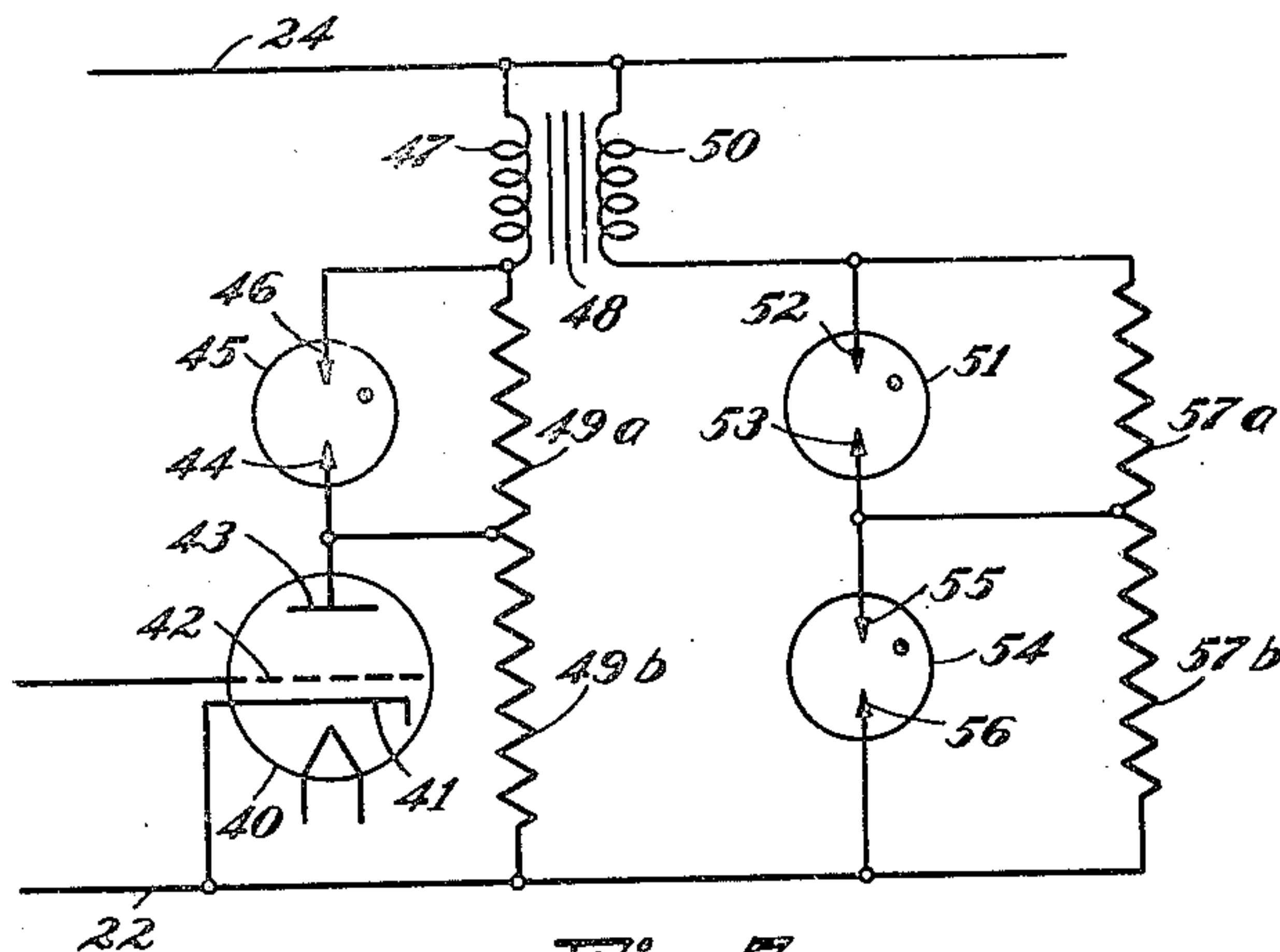
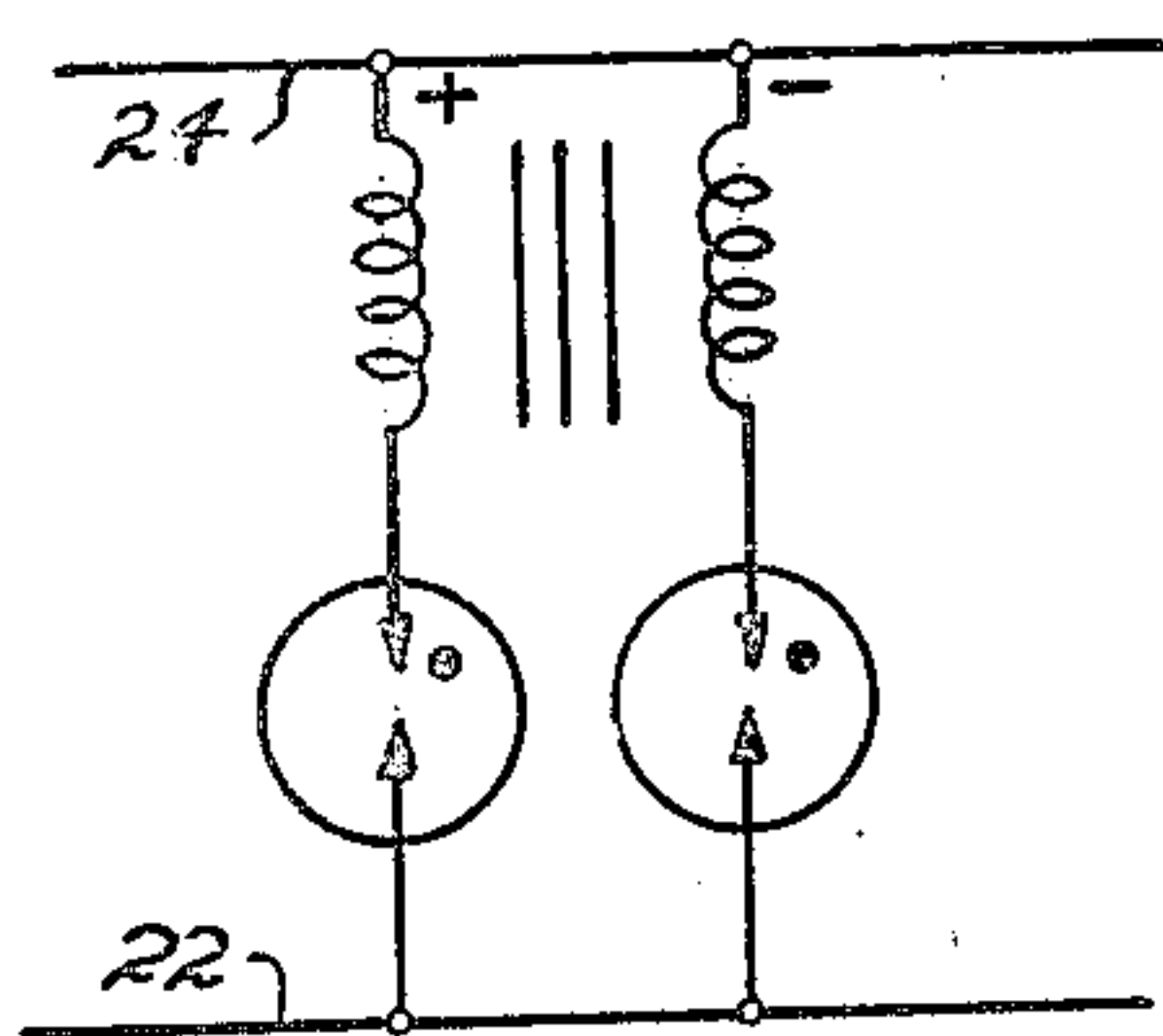


Fig. 3

Fig. 5

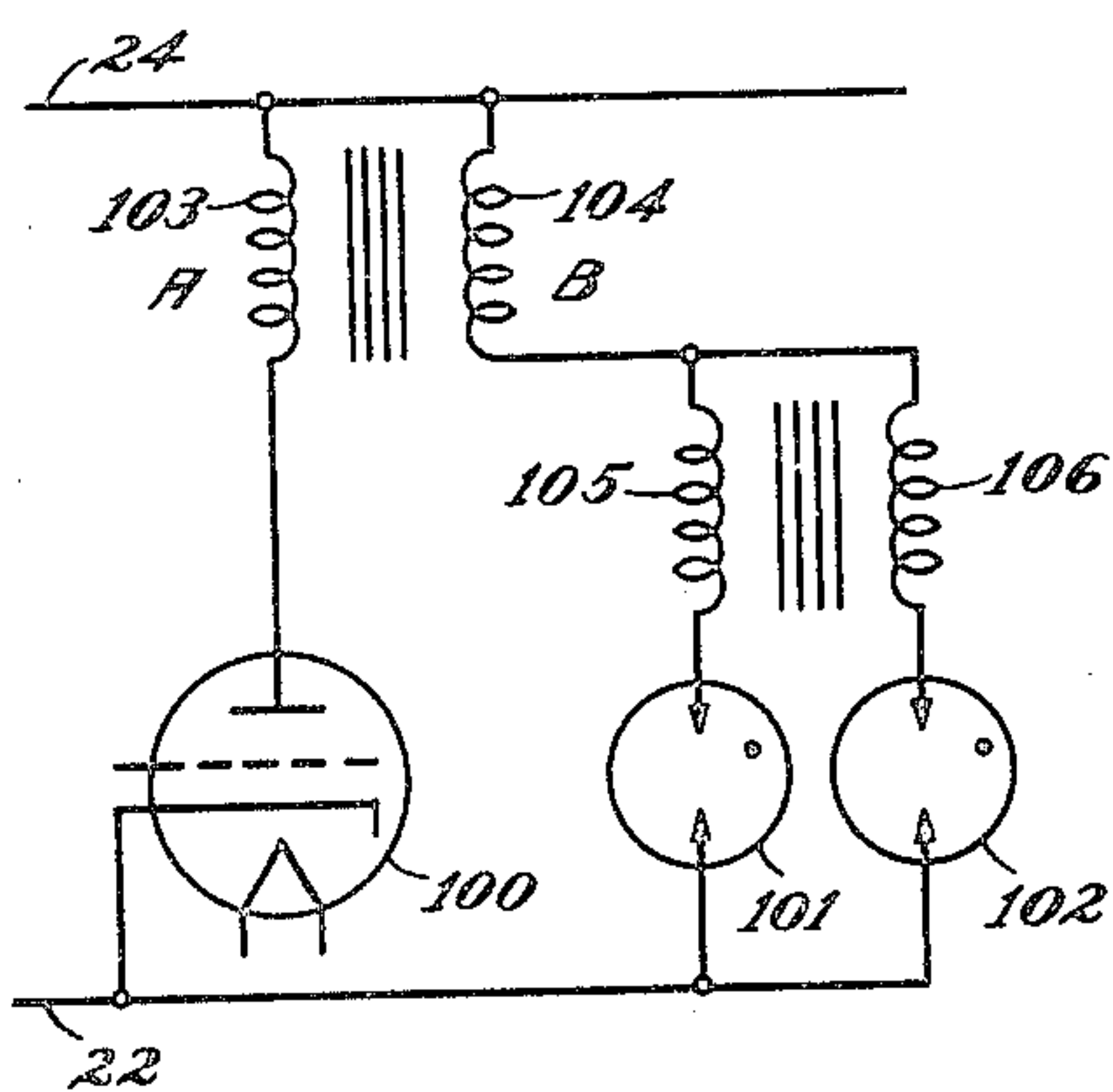
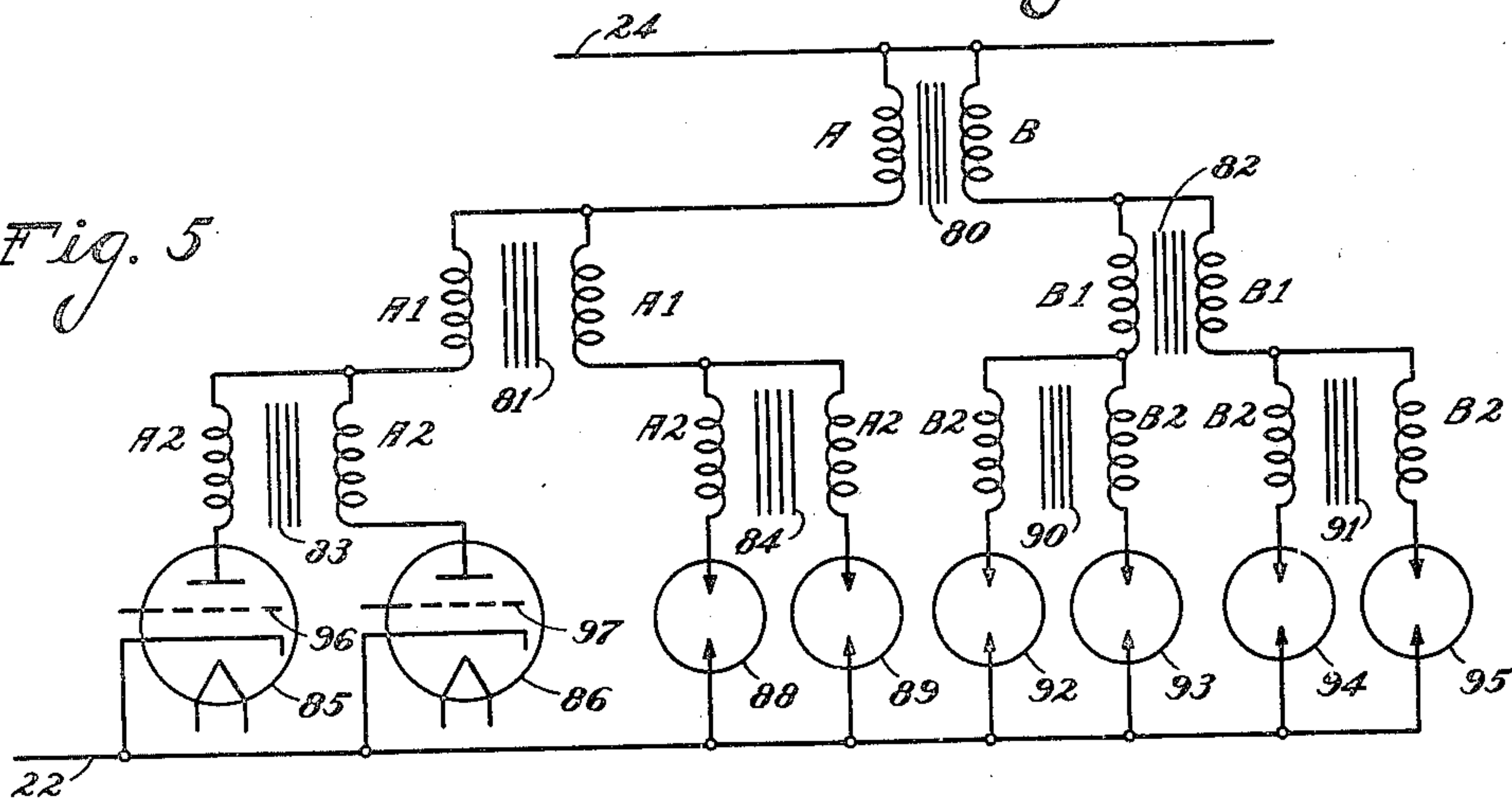


Fig. 6

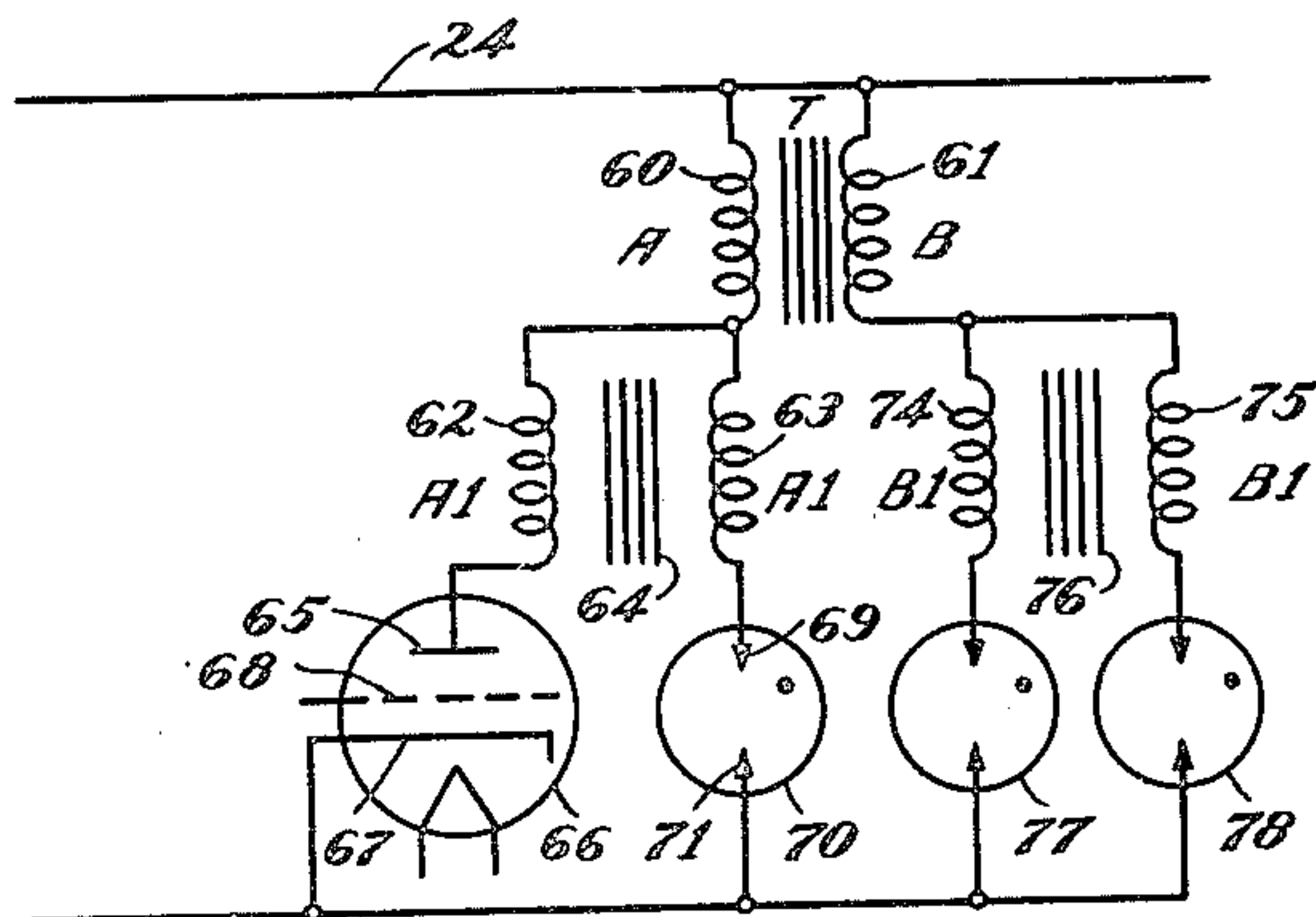


Fig. 4

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2,497,166

PARALLEL CIRCUIT ARRANGEMENT
FOR POWER TUBES

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Application June 6, 1944, Serial No. 538,920

7 Claims. (Cl. 315—195)

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This invention relates to circuit networks in which arc discharge devices are operated in parallel, multi-parallel or series-parallel relation in pulse generators.

In certain cases, it is desirable to develop a greater power output than can be provided by a single arc discharge device. However, it has been necessary in the past to use equalizing resistors with their attendant power losses where such arc discharge devices were operated in parallel. Such equalizing resistors have been required since supposedly identical devices have slightly different breakdown characteristics. Consequently, when one of the devices became conducting the anode potential of the second device would never be sufficient to establish current flow therethrough in the absence of some equalizing means.

In accordance with the main feature of the present invention, there are provided circuit networks for operating two or more arc discharge devices in parallel, in multi-parallel or in series-parallel in a pair of simple or complex branches without the need for equalizing resistors or other material power-dissipating control units. In the circuit arrangement of the present invention means common to a given pair of branches of such parallel-connected devices, is effective when one branch is conducting, for raising the voltages in the other branch thereof until it also becomes conducting. After both branches become conducting, the current division between them may be apportioned according to any desired ratio.

Another feature of this invention relates to a circuit arrangement in which dissimilar types of arc discharge devices can be operated in parallel.

A further feature of the invention relates to the pyramiding of parallel circuits for operating arc discharge devices in multiple. By this pyramiding of the parallel circuits, a theoretically large number of circuit combinations can be made, the limit on this number being determined by the complexity of the resulting networks which may render them impracticable for use.

In the drawings—

Fig. 1 is a diagrammatic showing for the parallel operation of similar arc discharge devices from a direct current source in a pulse generator;

Fig. 2 is a portion of a modified parallel circuit arrangement wherein a Thyatron is utilized in one parallel branch and a spark gap is used in the other parallel branch;

Fig. 3 is a fragmentary showing of a modified series-parallel arrangement wherein two arc dis-

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charge devices are connected in series in each parallel branch;

Fig. 4 is a diagrammatic showing of a portion of a modified parallel circuit arrangement in which the parallel circuits are pyramided;

Fig. 5 is a diagrammatic showing of a portion of a modified form of the invention in which the parallel circuits are further pyramided; and

Fig. 6 is a diagrammatic showing of a portion of a circuit arrangement in which a single arc discharge device is connected in parallel with a branch consisting of two parallel branches, in each of which there is included an arc discharge device.

Fig. 7 is a diagrammatic showing of a modified form of the invention in which the Thyratrons are replaced by spark gaps.

In Fig. 1 of the drawings there is illustrated a circuit arrangement of this invention wherein there are utilized two electrostatically controlled arc discharge devices 5 and 5a commonly referred to as grid glow tubes or "Thyratrons." The device 5 comprises an anode 6, at least one grid 7 and a cathode 8 enclosed in an envelope containing ionizable gas. The device 5a is identical in construction with device 5 and the corresponding parts of the two devices are identified by the same numerals, with the suffix "a" added in the case of the parts of device 5a. The cathodes 8 and 8a are connected in parallel by the conductor 22 to one side of the direct current source D. C. These cathodes are also connected by conductor 22 to one terminal of the load 23. This load may be a resistance or a transformer coupled load. The terminals 16 and 17 of the transformer 12 are also connected by the conductor 24 and the impedance 25 in series therewith, which may be a resistance or an inductance, to the second terminal of the direct current source. The conductor 24 also leads to one terminal of the network N, the other terminal of which is connected by lead 26 to the remaining terminal of the load 23. The network N, which may have various forms, is herein shown as comprising capacitors 27 and inductors 28. The input circuit of the tubes comprising the cathodes 8, 8a and the control grids 7 and 7a, has connected therein, a source of triggering potential of the character indicated by the graph enclosed within the rectangle S.

During operation, the capacitors 27 of the network N are charged through the impedance 25, from the source D. C. When, however, a positive triggering pulse from the source S is applied to the grids 7 and 7a to render the tubes 5 and 5a

conducting, the network N will discharge through these tubes into the load 23. The windings 11 and 15 of the transformer 12 respectively connected in the anode circuits of these tubes insure simultaneous operation of the tubes in the following manner.

The transformer 12 must have the following characteristics. First, the coupling between both of its windings must be extremely good, as good, in fact, as the state of the art will permit. The degree of coupling required will of course depend on the time duration of the pulse to be generated but in general it should be made as good as possible taking into account other required characteristics of the transformer. In general, the coupling requirements necessitate the use of iron cores of the very best characteristics. Second, the polarity of the windings should be as indicated in Fig. 1. Third, the transformer should be designed so that saturation does not take place under conditions of operation. Fourth, the self-inductance of the windings should be made as small as possible consistent with the above conditions. Fifth, the turns ratio between the two windings should be set according to the ratio of current division desired between the two branches. The manner in which the current is divided will be described.

Let it be assumed that the triggering pulse has been applied to the tubes 5 and 5a but that due to some dissimilarity in these tubes, only tube 5 is caused to conduct. In the ordinary case, where the two devices have their plates in parallel, the drop in potential due to one tube firing insures that the tube in parallel therewith will never fire. In accordance with the present invention, however, the effect of one tube firing is to place the voltage E to which the network has been charged, across winding 11. A transient response will occur which will cause a voltage to appear on winding 15 with the polarity indicated. If the turns ratio of the transformer is unity, this voltage will rise to a value of roughly E with the polarity shown and in conjunction with the network, will result in a momentary voltage 2E being applied to the tube 5a. The time for this to take place depends primarily on the self-inductance of the transformer windings, the coupling, and the stray capacitance of the circuit. With very tight coupling, it can be made to occur, in certain embodiments of the invention, in a fraction of a microsecond. Under this condition, tube 5a must also fire. Thus, the firing of both of these tubes is assured.

With respect to current division, very slight differences in the characteristics of two arc discharge tubes connected in parallel, will ordinarily cause gross differences in the current carried by the two. The devices are usually placed in parallel because the safe current handling capacity of one tube may be insufficient for the purpose at hand. If, however, the current division in parallel is so poor that one tube has its current handling capacity exceeded, nothing is gained by paralleling them. In accordance with this invention, the transformer 12, in addition to insuring firing of both tubes, also insures the proper current division. This is best explained by considering again the case in which the turns ratio of transformer 12 is unity. There are two cases: first, where both tubes fire simultaneously in which case both initial currents are equal and small and second, where the tubes fire consecutively in which case both initial currents are small but the initial current in the initially fired

tube is very slightly larger than current in the later fired tube. In the latter case, the current cannot rise to an appreciable value in the tube first to fire because in the absence of the conduction of the second tube the self-inductance of the transformer winding will limit this current. Therefore, in either case, at the instant of firing, the two tubes are conducting negligible current. The current will now build up to its peak value in the two tubes. If one tries to rise faster than the other, the transformer 12 will prevent this since voltages will be induced which slow the rise in the tube attempting to take more of the current and increase the rise in the tube which is lagging. Since it takes very little voltage to change the current in a discharge tube, the result is that the buildup of current in the tubes is practically identical. Furthermore, after the current has built up to its maximum value, the transformer will prevent, in essence, the departure of the current values from the values obtained just after buildup. Therefore, the current is equally divided in the case of a turns ratio of unity. The tight coupling in the transformer and the practically identical buildup time prevents the transformer from presenting too much inductance to the discharge of the pulse network. This is necessary. The inductive effect will be least when the coupling is the tightest and the self-inductances of the windings are reduced to their minimum value consistent with proper circuit performance.

Sometimes, it is desirable to operate in parallel two tubes of unequal current handling capabilities and to provide means for dividing the currents according to their ratings. This may be done by making the turns ratio of the transformer 12, equal to the desired current ratio. All other characteristics of the transformer such as tight coupling, etc., must also be preserved. The tube which is to carry the greater current must be connected to the winding having the smaller number of turns. In the case of starting, if one tube only fires, the following maximum voltages may be presented to the unfired tube. If the low current tube fires, the voltage possibly presented to the unfired tube is E plus $2E/n$ where n is the turns ratio of T. If the high current tube fires first, then the voltage may rise to E plus $2En$ on the unfired tube. Finally, if the current buildup is such that the time rate of change of the currents in the two windings is in the ratio n, then the final peak currents are in the ratio n.

In the form of the invention just described, electrostatically controlled arc discharge devices or "Thyratrons" have been used. However, dissimilar types of discharge devices, such as a "Thyratron" 30, in one parallel branch and a gas-filled spark gap 31 in the other parallel branch, can be used when the portion of the circuit illustrated in Fig. 2 is substituted for that portion of the diagram of Fig. 1 which is enclosed by the dotted rectangle. In the resulting circuit arrangement, the cathode 33 of the Thyratron 30 and the electrode 34 of the spark gap 31 are connected by conductor 22 to one side of the current source. Likewise, the anode 35 of the Thyratron and the electrode 36 of the spark gap are respectively connected through the windings 37 and 38 of an iron core transformer and conductor 24, to the other side of the current source.

Fig. 3 when substituted for that portion of the circuit arrangement of Fig. 1 which is enclosed

within the broken line rectangle, indicates how two arc discharge devices can be connected and operated in series in each of the parallel branches of the network to provide a series-parallel arrangement. In this arrangement, the Thyatron 40 has its cathode 41 connected to the conductor 22 while its anode 43 is directly connected to the electrode 44 of the gas-filled spark gap or arc discharge device 45. The other electrode 46 of this gap is connected in series with the winding 47 of the transformer 48 to the conductor 24. A resistor comprising sections 49a and 49b, has one of its ends connected to the conductor 22 and its other end connected to the lower terminal of the transformer winding 47. An intermediate point on the conductor between the anode of the Thyatron and the electrode of the gap is connected to the common terminal of said resistor section, thereby serving as a voltage divider. The voltage of the network normally applied across the Thyatron and the spark gap is insufficient to cause these devices to break down. However, when positive voltage is applied to the grid 41 or the Thyatron, the Thyatron becomes conducting. Under this condition, the cathode-anode drop of the Thyatron is reduced to a very low value, with the result that the voltage applied across the electrodes of the spark gap 45 is increased to the value where the spark gap breaks down and becomes conducting in series with Thyatron.

The current flowing through the Thyatron and spark gap in series, as well as through the transformer winding 47, will induce a voltage in the transformer winding 50 sufficient to cause current to flow in the other parallel branch. This parallel branch has a gas-filled spark gap 51 with its electrodes 52 and 53 connected in series with the gas-filled spark gap 54 which is provided with electrodes 55 and 56. Electrode 56 is connected to conductor 22. A resistor comprising sections 57a and 57b, is connected from the conductor 22 to the lower terminal of the transformer winding 50, an intermediate tap on this resistor being connected to the electrodes 53 and 55. The resistor sections serve to divide the voltage applied across the spark gaps 51 and 54 to render them conducting in response to the mentioned voltage induced in transformer winding 50. The manner in which a Thyatron, such as 40, and a spark gap, such as 45, connected in series, are rendered conducting, is more fully disclosed in the application of Goldberg et al., Serial No. 521,462, filed February 7, 1944, now abandoned.

The arrangements thus far described, disclose simple parallel arrangements and a series arrangement. However, the invention is applicable to a so-called multi-parallel arrangement, which results when the circuit starting network of Fig. 4 is substituted for that portion of the diagram of Fig. 1 which is enclosed within the broken line rectangle. In this modification, there are provided two parallel branches respectively designated A and B and connected across the conductors 22 and 24 connected to the respective sides of the current source. An iron-core transformer T has one of its windings 60 connected in series with branch A and its other winding 61 connected in series in branch B. Branch A is divided into two branches A1, A1 respectively including the windings 62 and 63 of an iron core transformer 64. The winding 62 is connected in series with anode 65 of a Thyatron or other arc discharge device 66. The cathode 67 of this

device is connected to conductor 22. The other winding 63 of this transformer is connected to one of the electrodes 69 of a spark gap 70, which has its other electrode 71 connected to conductor 22.

Similarly, the branch B is divided into two parallel branches B1, B1 which respectively include the windings 74 and 75 of transformer 76. Spark gap 77 is connected to conductor 22 and is also connected in series with the transformer winding 74 while a second spark gap 78 is likewise connected to conductor 22 and connected in series with the transformer winding 75.

In this arrangement, when the grid 68 of the Thyatron 66 has positive voltage applied thereto, the Thyatron will become conducting and as current flows therethrough, and through its related transformer winding 62, voltage is induced in the other winding 63 of the transformer which causes the spark gap 70 to break down. Current now flowing in the main branch A and its transformer winding 60 induces voltage in the transformer winding 61 included in the main branch B. This voltage is sufficient to cause one or both of the gas-filled spark gaps 77 and 78 to break down and become conducting. In the event that only one of these spark gaps becomes conducting current flowing through its related winding of transformer 76 will induce voltage in the other transformer winding sufficient to cause its related spark gap to become conducting.

For convenience in description, the arrangement shown in Fig. 4 is herein referred to as the pyramiding of parallel circuits for operating arc discharge devices in multiple.

The portion of the circuit arrangement illustrated in Fig. 5 may be substituted for that portion of the diagram of Fig. 1, which is enclosed within the dotted line rectangle. The network disclosed in Fig. 5 when substituted for that portion of Fig. 1 within the broken line rectangle provides an arrangement wherein the parallel circuits for operating arc discharge devices, are further pyramided. In this showing, the main branches A and B are inductively coupled together by a transformer 80 and are respectively provided with intermediate branches A1, A1 and B1, B1, as in Fig. 5. The intermediate branches A1, A1 are coupled together by a transformer 81 and the intermediate branches B1, B1 are coupled together by a transformer 82. However, each branch A1 is provided with a pair of sub-branches A2, A2, the respective pairs of sub-branches being coupled by the transformers 83 and 84. The windings of the transformer 83 are respectively connected to the anodes of Thyatrons 85 and 86 which have their cathodes connected to conductor 22. The windings of the transformer 84 are respectively connected in series with the spark gaps 88 and 89 to conductors 22.

Likewise, the main branch B is provided with intermediate branches B1, B1 coupled together by transformer 82. Each branch B1, in turn, is provided with a pair of sub-branches B2, B2, each pair being coupled together by transformers such as those designated 90 and 91. The winding of the transformers 90 and 91 are respectively connected in series with spark gaps 92, 93, 94 and 95 to the conductor 22.

In the operation of this arrangement, as in the case of those described above, positive voltage is applied to the grids 96 and 97 of the Thyatron

devices. One of these will become conducting, and it will insure operation of the Thyatron in its related branch. This results in the breakdown of all arc discharge devices in the remaining sub-branches in a manner similar to that set forth in the description of Fig. 4.

A further modified form of the invention results when the network of Fig. 6 is substituted for that portion of Fig. 1 included within the broken line rectangle. In this modification, the branch A includes a single arc discharge device such as a Thyatron 100 which is parallel with the branch B. Branch B has parallel sub-branches including the arc discharge devices. The branches A and B are coupled together by the iron core transformer having the windings 103 and 104. The sub-branches are likewise coupled together by the windings 105 and 106 of an iron core transformer. The operation of this modification is similar to that of the modifications already described. Where one parallel branch is formed of two gaps in parallel, as disclosed in Fig. 6, it will be understood that if only one gap breaks down at the overvoltage due to the Thyatron, the second gap will break down due to the overvoltage produced by the gap that has already fired. This embodiment of the invention is especially important in that the triggering of a spark gap or gaps may be controlled by the triggering of a Thyatron, a tube which is relatively easy to trigger. Thus, the spark gaps may be employed to handle most of the power and the Thyatron may be used principally to trigger the system. The spark gaps involved in any system may be triggered, or caused to conduct, only by overvoltageing them, that is, by applying, at least momentarily, a voltage in excess of the voltage that the gap can stand off. Likewise, in any pulse generator where the spark gaps are utilized, as herein disclosed, these gaps are used in such a manner that the breakdown voltage of the gap (or gaps) is always somewhat greater than the voltage to which the network is charged. Accordingly, the gaps must be overvoltageed to be fired. When being used in conjunction with a Thyatron, two results must be obtained. First, the firing or triggering of the Thyatron must result in the firing of the gap. Second, the current must be made to divide between the gap and the Thyatron in the desired fashion. Let it be assumed that the ratio of turns of winding 37 to turns of winding 38 is n (Fig. 2). Under this assumption, when the Thyatron is fired, as already described, the voltage of the network appears across winding 37, and a voltage $2E/n$ is generated in winding 38 with the polarity as shown. This occurs in a fraction of a microsecond. Therefore, a voltage E plus $2E/n$ is placed on the gap 31. As long as this voltage E plus $2E/n$ is sufficient to fire the gap, it will fire and conduct and the Thyatron and gap will divide the current in the manner already described for two Thyatrons. The only limitation on n is that E plus $2E/n$ must be sufficient to break down the gap.

All of the arrangements herein disclosed, have included at least one Thyatron for ease in initiating conduction throughout a given network. However, the invention is not limited in this manner since the Thyatrons can be replaced by spark gaps, as shown in Fig. 7. Of course, when a spark gap device is used, conduction there-through is initiated by increasing the difference of potential applied across its electrodes. The

principles of my invention include the use of discharge devices having two or more electrodes, one serving as an anode and another serving as a cathode, the "anode" being that electrode which is connected to the more positive side of the starting circuit. Hence, when one device is rendered conducting, the voltage at the electrode serving as the anode of any other device paralleled with the conducting device is made more positive. No matter how many electrodes are employed, the non-firing or non-conducting discharge devices are fired or rendered conducting only by reason of the increase in anode potential.

It should be emphasized that only a few of the typical modifications have been illustrated, but the invention includes various permutation, combinations and pyramiding of the several networks disclosed.

While the grid-glow tubes or "Thyatron" are herein illustrated as being of the single grid construction, the invention is not so limited, since known multi-grid tubes of this type may also be used instead. It will also be understood that there can be many other variations and changes in the present disclosure without departing from the spirit.

What we claim is:

1. In a circuit arrangement of the class described, a source of direct current, a pair of arc-discharge devices of unequal current handling ratings, each of said devices including a plurality of electrodes, and having certain corresponding electrodes thereof connected in parallel to said source, means for applying a control voltage to one of said devices for initiating the flow of current therethrough, and means responsive to the flow of current through said one device for increasing the voltage applied to the more positive electrode of the other device for insuring the flow of current through said other device, said last mentioned means comprising a transformer having one of its windings connected in series with one device and another winding connected in series with the other device, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having the smaller number of turns being connected in series with the anode of the device that conducts the greater current, and the winding having the larger number of turns being connected in series with the anode of the device that conducts the smaller current whereby current flow through one device will initiate the operation of the other device and whereby currents through said devices are divided in accordance with their ratings.

2. In a circuit arrangement of the class described, a source of direct current, a pair of different types of arc-discharge devices having certain corresponding electrodes thereof connected in parallel to said source, means for applying a control voltage to one of said devices for initiating the flow of current therethrough, and means responsive to the flow of current through said one device for increasing the voltage applied to the more positive electrode of the other device for insuring the flow of current through the other device, said last-mentioned means comprising a transformer having one of its windings connected in series with one device and another winding connected in series with the other device, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having the smaller number of turns being connected in series with the anode of the device that conducts the greater current, and the winding

having the larger number of turns being connected in series with the anode of the device that conducts the smaller current whereby current flow through one device initiates the operation of the other device and whereby currents through said devices are divided in accordance with their ratings.

3. In a circuit arrangement of the class described, a source of current, parallel branches connected across said source, each branch having arc-discharge devices of unequal current handling ratings connected in series therein, means for initiating current flow through the devices in one of said branches, and means responsive to current flow through the devices in said one branch for insuring current flow through the devices in the other branch, said last-mentioned means comprising a transformer having one of its windings connected in series with one device and another winding connected in series with the other device, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having the smaller number of turns being connected in series with the anode of the device that conducts the greater current, and the winding having the larger number of turns being connected in series with the anode of the device that conducts the smaller current whereby current flow through one device initiates the operation of the other device and whereby currents through said devices are divided in accordance with their ratings

4. In a circuit arrangement of the class described, a source of current, parallel branches connected across said source, each branch having arc-discharge devices of unequal current handling ratings connected in series therein, means for initiating in succession the current flow through the respective arc-discharge devices in one of said branches, and means responsive to current flow in said one branch for insuring current flow through the arc-discharge devices in the other branches, said last-mentioned means comprising a transformer having one of its windings connected in series with one device and another winding connected in series with the other device, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having the smaller number of turns being connected in series with the anode of the device that conducts the greater current, and the winding having the larger number of turns being connected in series with the anode of the device that conducts the smaller current whereby current flow through one device initiates the operation of the other device and whereby currents through said devices are divided in accordance with their ratings.

5. In a circuit arrangement of the class described, a source of current, a pair of main branches connected in parallel across said source, each main branch comprising sub-branches connected in parallel, each sub-branch having included therein an arc discharge device, said arc discharge device having unequal current handling ratings, means for starting current flow from said source through an arc discharge device of one sub-branch, means responsive to said current flow for effecting current flow in all of the sub-branches of the main branch associated therewith, said effecting means comprising a transformer having one of its windings connected in series with one device and another winding connected in series with the other device, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having

the smaller number of turns being connected in series with the anode of the device that conducts the greater current, and the winding having the larger number of turns being connected in series with the anode of the device that conducts the smaller current whereby current flow through one device initiates the operation of the other device and whereby currents through said devices are divided in accordance with their ratings and means responsive to the current flow in said last-mentioned main branch for insuring current flow through the arc discharge devices in all of the sub-branches of the other main branch said insuring means comprising a transformer and having one of its windings connected in series with one device and another winding connected in series with the other device, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having the smaller number of turns being connected in series with the anode of the device that conducts the greater current, and the winding having the larger number of turns being connected in series with the anode of the device that conducts the smaller current whereby current flow through one device initiates the operation of the other device and whereby currents through said devices are divided in accordance with their ratings.

6. In a circuit arrangement of the class described, a source of direct current, a pair of arc-discharge devices of unequal current handling ratings, each device comprising at least a primary electrode and a secondary electrode surrounded by an ionizable atmosphere, a primary electrode of each device being connected in multiple to one terminal of said source and the secondary electrode of each device being connected in multiple to the other terminal of said source, means for applying a control voltage for initiating the operation of at least one of said devices, and a closely coupled transformer having a pair of windings, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having the smaller number of turns being connected in series with the secondary electrode of the device that conducts the greater current, and the winding having the larger number of turns, being connected in series with the secondary electrode of the device that conducts the smaller current, and the windings being properly poled, whereby current flow through one device will initiate the operation of the other device, and whereby the currents through said devices are divided in accordance with their ratings.

7. In a circuit arrangement of the class described, a source of direct current, a pair of electrostatically controlled arc-discharge devices of unequal current handling ratings, each device comprising a cathode, an anode and a grid surrounded by an ionizable atmosphere, the anodes and the cathodes being respectively connected in multiple to the terminals of said source, means for applying control voltages to said devices for initiating the operation of at least one device, and a closely coupled transformer having a pair of windings, the turns ratio of said windings being equal to the desired current ratio of said devices, the winding having the smaller number of turns being connected in series with the anode of the device that conducts the greater current, and the winding having the larger number of turns being connected in series with the anode of the device that conducts the smaller current whereby current flow through one device will initiate the operation of the other device, and whereby the

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currents through said devices are divided in accordance with their ratings.

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