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2,434,259

CIRCUIT ARRANGEMENT UTILIZING A PLURALITY OF ELECTRON DISCHARGE DEVICES

Filed June 22, 1943

4 Sheets-Sheet 1

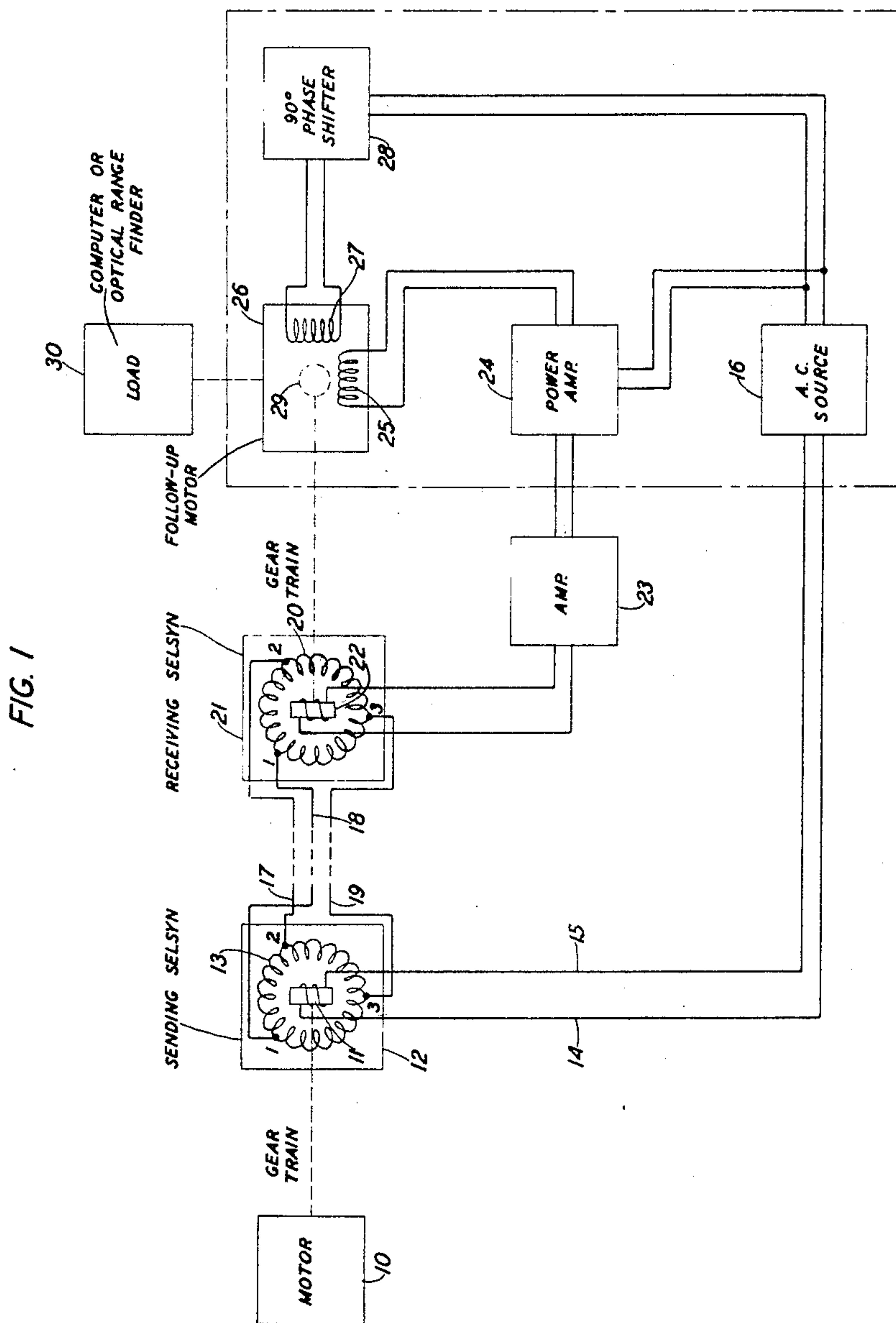


FIG. 1

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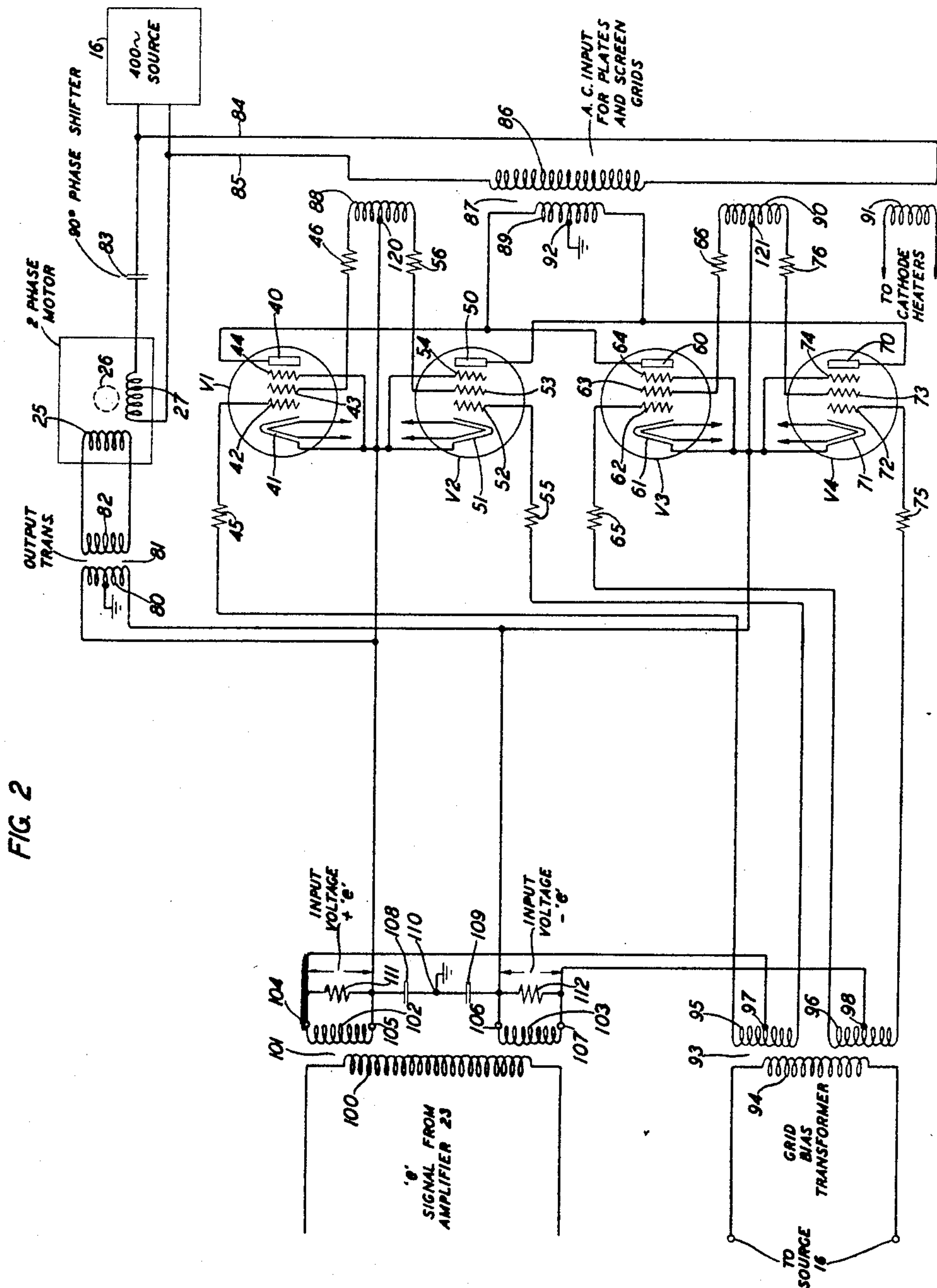
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FIG. 3

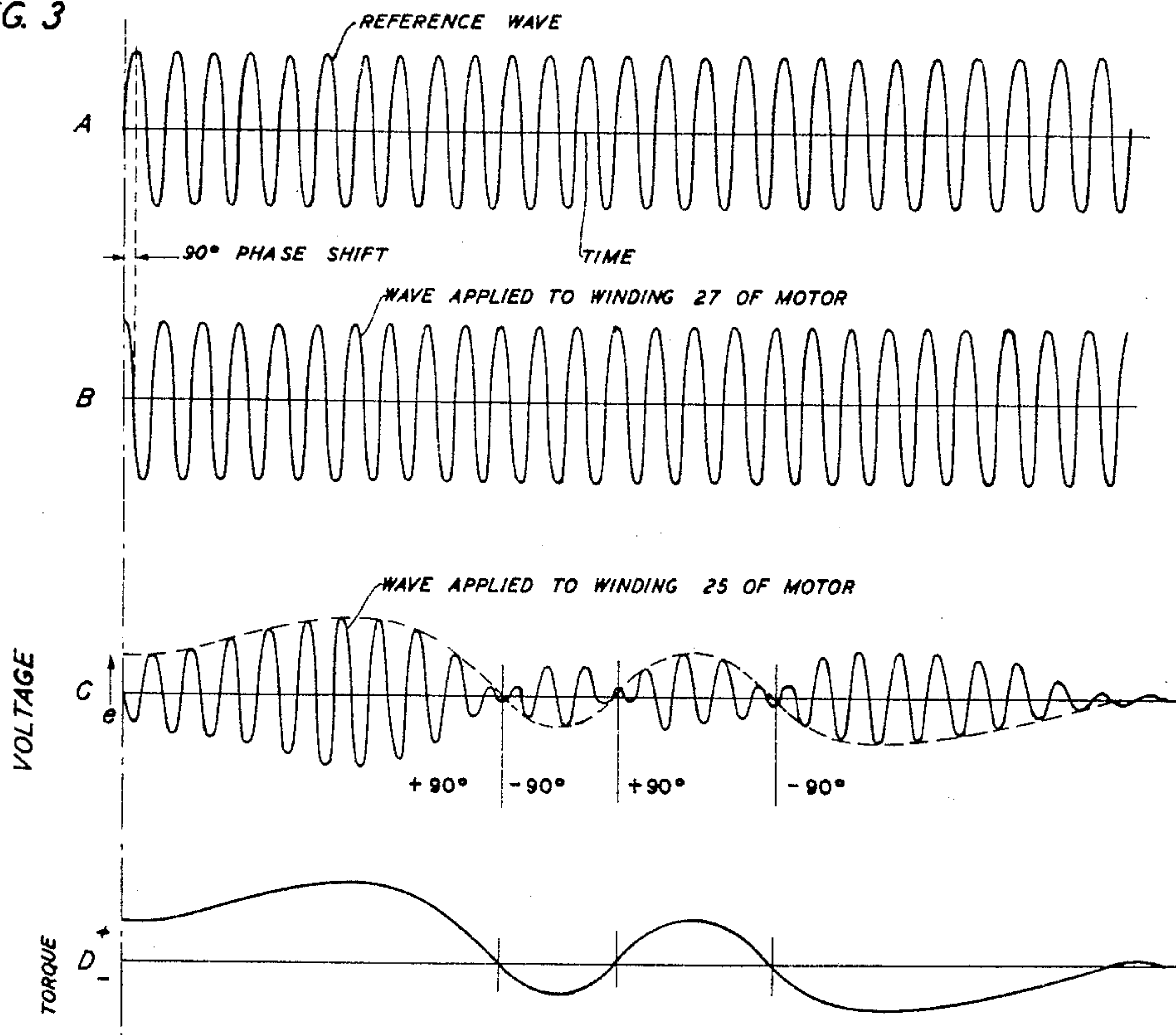
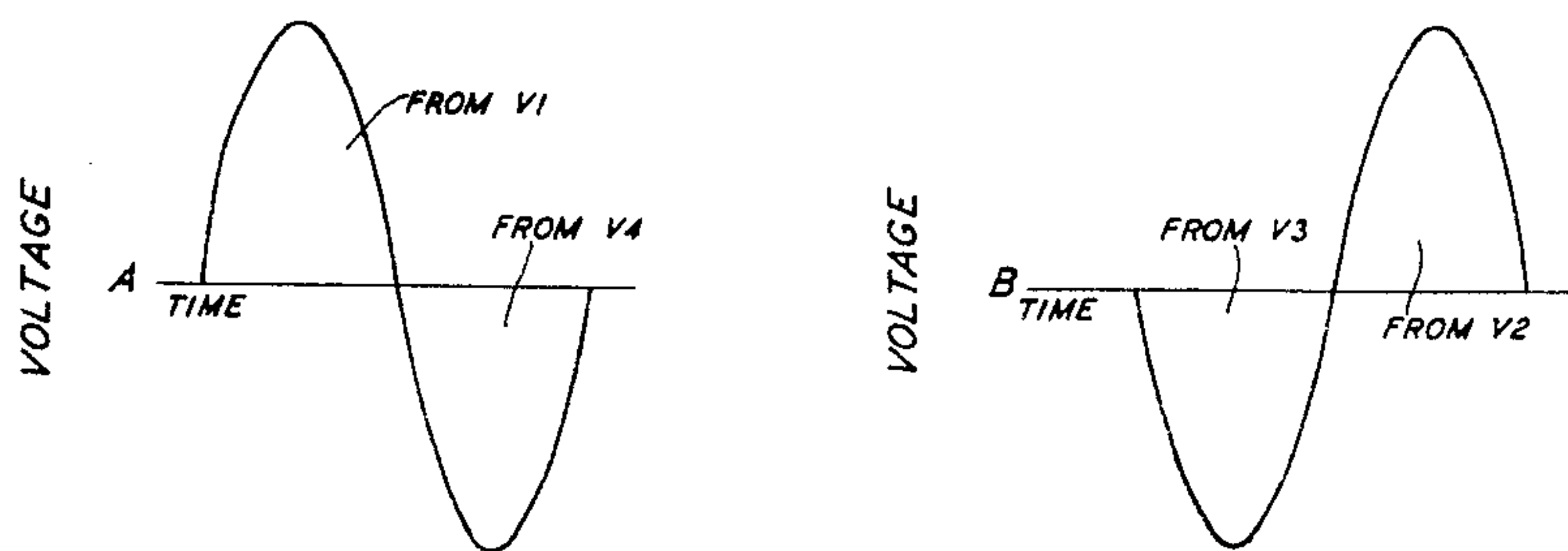


FIG. 5



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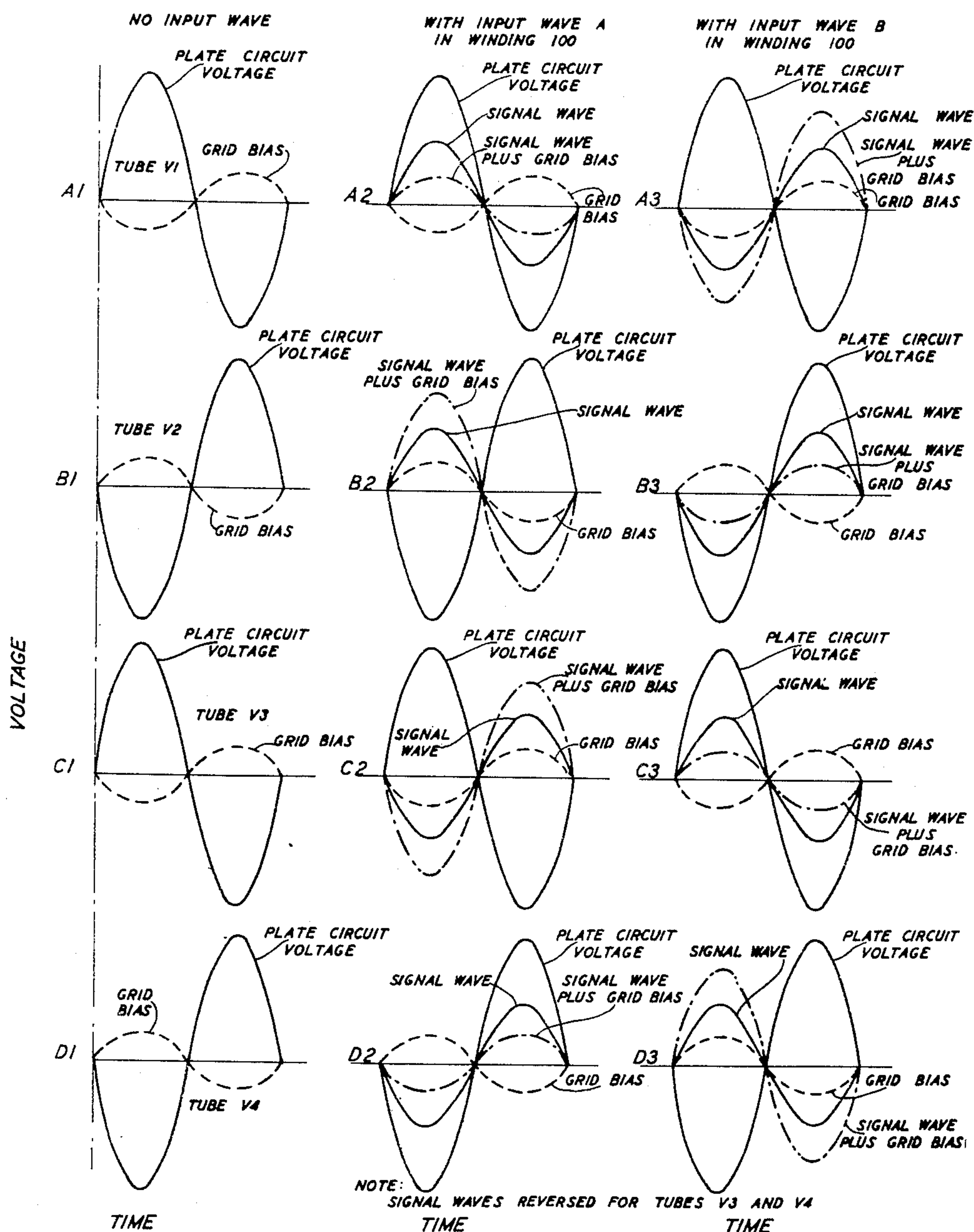
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CIRCUIT ARRANGEMENT UTILIZING A PLURALITY OF ELECTRON DISCHARGE DEVICES

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4 Sheets-Sheet 4

FIG. 4



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CIRCUIT ARRANGEMENT UTILIZING A PLURALITY OF ELECTRON DISCHARGE DEVICES

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13 Claims. (Cl. 250—27)

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This invention relates to circuit arrangements utilizing unilaterally conducting devices of the type commonly used as amplifiers and more specifically to arrangements using a plurality of such devices to which are applied in both the input and the output circuits thereof alternating potentials.

A principal object of the invention is to provide a novel amplifier arrangement which is highly efficient from the power output standpoint.

This arrangement, however, involves novel operation of the tubes, or equivalent elements used for amplifying, which is not limited in use to amplifying signals or other current or voltage variations, but may find a wide variety of uses. For example, it permits selective operation of a plurality of elements by utilizing changes in phase relationships between a control wave and alternating potentials applied to both the input and output terminals of the amplifying devices, which, in fact, do not then need to operate as amplifiers, their function being primarily that of circuit closers. From this point of view the invention provides a novel circuit arrangement utilizing at least two such devices, one of which is conducting, or conducts better, when an input alternating voltage has a certain phase condition, and the other of which is conducting, or conducts better, when the input voltage has a reverse phase condition.

It is still another object of this invention to provide a novel amplifier arrangement for a follow-up circuit, that is, a circuit for causing one shaft to follow the rotation of another shaft located at a distant point, and more specifically for a follow-up circuit utilizing a two-phase alternating current follow-up motor. Such a follow-up circuit can be utilized, by way of example, in a radar system having a rotary element associated with a range dial if it is desired to cause a rotary element at a distant station, or at another point at the same station too remote for a direct connection to the first rotary element, to follow the rotation of the first rotary element. The second rotary element can be used to impart a component of motion to a computer or director or to an optical sight or range finder.

Other features and aspects of the invention will be apparent from the following description.

In accordance with a specific embodiment of the invention, shown by way of example for illustrative purposes, there is provided a novel four-tube amplifier used in a follow-up arrangement in which one shaft is adapted to rotate

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in accordance with the rotations of another shaft at a distant point, that is, too distant to make a mechanical connection practical. For convenience in description the four-tube amplifier can be considered as two groups of two tubes each. An alternating potential wave is applied between the anode members of the tubes of the first group and the same alternating potential wave, or one similar to it in amplitude and phase, is applied between the anodes of the tubes of the second group. The mid-point of the transformer winding applying each of these potential waves is connected to the cathode of each tube through ground and the primary winding of an output transformer, there being one such primary winding (or half of a winding) for each group of two tubes and the cathodes of each group being connected together. An alternate grid bias voltage of the same frequency as the anode voltage wave is applied between the control grids of the tubes of the first group and the same wave, or one similar in amplitude and phase, is applied between the control grids of the tubes of the second group, the phase of the bias wave or waves being such that the grid voltage wave of each tube (in the absence of input signal voltage) is opposite in phase to that of the plate or anode voltage wave of the same tube. The mid-point of the transformer winding supplying the grid bias voltage for each group of tubes is connected through the secondary winding of an input transformer to the cathodes of the tubes of the corresponding group, these being two such secondary windings so wound that the voltages induced therein are opposite in phase. There is substantially zero output current from the amplifier when no voltages are induced in the input transformer windings because, when the plate voltage of each tube is positive with respect to its cathode, its grid is negative with respect thereto, and vice versa. The signal input voltage to the amplifier is an alternating voltage wave which may at times have its phase changed by 180 degrees, or, in other words, it may have two phase conditions, when compared with a reference wave, which are 180 degrees apart. The signal voltage applied in each grid-cathode circuit is the same frequency as the anode voltage and grid biasing waves. The phase of the signal applied to the control grids of the first group of tubes, because of the arrangement of the input transformer secondary windings, is opposite to that of the signal voltage wave applied to the control grids of the tubes in the second group. If the signal voltage has its first

phase condition, that is, for example, if it is in phase with the anode voltage, one pair of tubes (that is one tube of the first group and one tube of the second group, the two tubes of the pair acting in alternate half cycles of the wave) conducts current and an amplified signal current appears in the secondary winding of the output transformer which is magnetically coupled to both output transformer primary windings. Now if the signal voltage is of opposite phase to the first-mentioned condition, that is, if it has its second phase condition, the other of the pairs of tubes connects current, that is, the two tubes which were not conducting current when the signal voltage had its first phase condition act to conduct current in alternate half cycles. In this latter situation the first-mentioned pair of tubes is not conducting. The screen grid of each tube is caused to have an alternating potential applied thereto of the same frequency and phase as the alternating potential applied to the anode of the same tube. Alternating voltage can also be used to pass current through the cathode heaters.

The four-tube amplifier arrangement of this invention is particularly adapted for use in a follow-up system which utilizes a two-phase alternating current motor, one field winding of which has applied thereto an alternating voltage wave of fixed frequency and phase and the other field winding of which has applied thereto a voltage wave which has the same frequency as the wave applied to the first winding but the phase of which is either +90 degrees or -90 degrees with respect to it. In other words, the voltage wave applied to the second winding may have either of two phase conditions with respect to a reference wave, these two phase conditions being 180 degrees apart. It will be apparent from the description above that one pair of tubes in the four-tube amplifier arrangement acts to amplify the voltage wave if it has its first phase condition while the other pair of tubes acts to amplify the wave if it has its second phase condition. Because of the intermittent operation of the tubes and because of the fact that maximum current in each tube occurs at the same time that the plate supply voltage is at a maximum, each tube can give an instantaneous power output which is much above the rating of the tube when used in a conventional circuit with direct current plate supply. The power output efficiency of the arrangement is therefore high.

The follow-up system comprises, by way of example, a rotating shaft whose rotation it is required to reproduce at a remote station (or at a remote point at the same station) by the rotation of a second rotating shaft, a transmitting Selsyn or similar device, a receiving Selsyn or similar device, a three-stage amplifier of conventional type, the four-tube amplifier briefly described above, and a two-phase motor, preferably of the low inertia type having one field winding connected to the output circuit of the four-tube amplifier arrangement and its other field winding connected to a source of alternating potential, as described above. The two-phase motor is geared or otherwise mechanically connected to the rotary armature of the receiving Selsyn which, in turn, is geared or otherwise mechanically connected to a computer, optical range finder or other device. In general, the voltage induced in the receiving Selsyn is not sufficient to produce a torque large enough to drive the computer or other device so the am-

plifier and motor serve as a "torque amplifier" for the receiving Selsyn.

While the invention in its primary aspects relates to a novel power amplifier or to a follow-up system including such an amplifier, in another of its aspects it is not so limited. For example, one of the groups of two tubes described above can be utilized independently of the other group as a switching device or as a device to indicate which of two possible phase conditions 180 degrees apart that an input voltage may have is present. When the input voltage has one of the two phase conditions, one of the tubes is conducting during one half cycle and neither tube is conducting during the second half cycle. but when the input voltage has the second of its two phase conditions, 180 degrees removed from the first condition, the other one of the two tubes is conducting during the first half cycle and neither tube is conducting during the second half cycle. Thus, if load elements are placed in the output circuits of the two tubes, the arrangement functions to switch power from one load element to the other when the input voltage changes from one of its two possible phase conditions to the other. By making the load elements lights, buzzers or other indicators, a visible or audible indication of the phase condition is produced.

The invention will be more readily understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof in which:

Fig. 1 is a block diagram of a follow-up system in accordance with the invention;

Fig. 2 is a circuit diagram of a portion of the apparatus of Fig. 1, including a four-tube amplifier arrangement; and

Figs. 3 to 5, inclusive, are various graphical and diagrammatic representations to aid in understanding the invention.

Referring more specifically to the drawings, Fig. 1 shows by way of example to illustrate the principles of the invention, a follow-up system which is used to reproduce at a remote station, or at a distant point at the same station, by the rotation of a second shaft, the rotation of a first rotatable shaft. The first shaft can be, for example, that of a motor associated with a range dial in a distance indicating system of the pulse reflection type. The first rotatable shaft is shown as a portion of the motor 10 which is geared or otherwise mechanically connected to the motor 11 of the sending Selsyn 12 which has a stator member 13 provided with a distributed poly-circuit winding which may be similar to the usual three-phase winding of an alternating current dynamoelectric machine. The winding may be either Y- or delta-connected. The single circuit rotor winding 11 is connected by means of the conductors 14 and 15 to a source of alternating current 16. The stator 13 is connected by means of the conductors 17, 18 and 19, which can be of considerable length, to the stator 20 of the receiving Selsyn 21, which has a rotor member 22 provided with a single circuit winding. The receiving Selsyn 21 is in all respects similar to the transmitting Selsyn 12 but the rotor winding 22 of the receiving Selsyn is connected to the input circuit of the amplifier 23 instead of to the alternating source 16. The term "Selsyn" is being used in a broad sense to include all devices of the general character of the members 12 and 21.

At this point the operation of the sending and

receiving Selsyns 12 and 21 will be explained. The rotor winding 11 of the sending Selsyn 12, when energized with current from the alternating current source 16, produces an alternating magnetic field by means of which a voltage is induced in the stator winding 13, thereby causing current to flow in the stator winding 20 of the receiving Selsyn 21. These currents in the stator winding 20 produce an alternating magnetic field by means of which a voltage is induced in the rotor winding 22, when the relationship between the axis of the rotor winding and the axis of the magnetic field is other than 90 degrees. When this 90-degree relationship obtains, no voltage is induced in the rotor winding and consequently no component voltage is supplied to the input circuit of the amplifier 23 with the result that the system is deenergized and at rest. However, when the rotor 11 of the sending Selsyn is rotated, a magnetic field is set up which induces a voltage in the rotor winding 22 which is either in phase with the voltage wave from the alternating current source 16 (which latter wave will hereinafter be designated the reference wave (see Fig. 3A)), or have a phase 180 degrees with respect thereto. This voltage induced in the rotor winding 22 is insufficient to produce a torque large enough to turn the armature of the Selsyn 21 (particularly if any load 30 such as a computer or optical range finder is applied thereto). The amplifier 23, which is of any suitable form, the amplifier 24, and the motor 26 serve as a "torque amplifier" for the receiving Selsyn 21. The voltage output of the amplifier 23 is applied to the power amplifier 24 which preferably comprises the four-tube arrangement shown in Fig. 2 and which will be described in detail below. The device 24 produces an amplified version of the output wave of the amplifier 23. The output wave of the device 24 is either in phase with the reference wave from the source 16 or 180 degrees out of phase with respect thereto. This output wave is applied to the field winding 25 of the follow-up motor 26, the other field winding 27 of which is connected through a 90-degree phase shifter 28 to the alternating current source 16. The motor 26 has an armature 29 which is geared or otherwise mechanically connected to drive the rotary member 22 in such a direction that the voltage in the input circuit of the amplifier 23 is reduced to zero. The load 30, which may be a computer or optical range finder or any other mechanical device which it is desired to have follow the motion of the device 10, is geared or otherwise mechanically connected to the armature 29 of the motor 26 or to the armature 22 of the receiving Selsyn 21. The follow-up motor 26 can be of any suitable two-phase type, preferably one which has a low inertia. Such a motor operates by having two alternating voltages applied to its two field windings, these voltages being substantially 90 degrees apart in phase. It will be appreciated that as the voltage applied to the winding 27 (see Fig. 3B) is 90 degrees out of phase with respect to the reference potential from the alternating current source 16, and as the winding 25 has applied thereto a voltage wave (see Fig. 3C) which may be at one particular time in phase with the voltage wave from the alternating current source 16 and at another particular time 180 degrees out of phase with respect to the reference wave from the source 16 (the particular condition depending on which direction the rotary armature 11 of the sending Selsyn 12 is driven and hence the direction that

the induced voltage in the rotary member 22 takes), then the phase of the voltage wave applied to the winding 25 is either plus or minus 90 degrees with respect to the voltage wave applied to the winding 27, as indicated in Fig. 3C. Thus the armature 29 of the motor 26 will be actuated in one direction or the other to reduce to zero the voltage applied to the input of the amplifier 23, at which time the position of the rotor 22 of the receiving Selsyn 21 will correspond to the position of the rotor of the sending Selsyn 12.

Reference will now be made to Fig. 2 which is a circuit diagram of the portion of the apparatus shown within dot-and-dash lines in Fig. 1. The circuit arrangement of Fig. 2 includes a first tube V1, a second tube V2, a third tube V3 and a fourth tube V4. These tubes can be of any suitable type but are preferably high vacuum tubes. Tube V1 comprises an anode 40, a cathode 41, a control grid 42, a screen grid 43, and a suppressor grid 44. Tube V2 has corresponding elements 50 to 54, inclusive, tube V3 has corresponding elements 60 to 64, inclusive, and tube V4 has corresponding elements 70 to 74, inclusive. Each of the suppressor grids is connected to its corresponding cathode. The cathodes 41 and 51 are connected together and their common terminal is connected to one terminal of the primary winding 80 of an output transformer 81, the secondary winding of which is connected to the field winding 25 of the motor 26. The opposite terminal of the winding 80 of the transformer 81 is connected to the common terminal of the cathodes 61 and 71, while the mid-point of the winding 80 is connected through ground to the mid-point 92 of the transformer winding supplying plate voltage. The two halves of the primary winding 80 can be, of course, separate windings if desired. The source 16 which, for example, generates or supplies oscillations of 400 cycles frequency, is connected through a 90-degree phase shifter, shown as a condenser 83, to the second field winding 27 of the motor 26. Oscillations from the source 16 are also applied by means of conductors 84 and 85 to the primary winding 86 of a transformer 87 which has four secondary windings 88, 89, 90 and 91. The secondary winding 89 is connected between the common terminal of the anodes 40 and 60 and the common terminal of the anodes 50 and 70. The plate circuit voltage is, for example, 500 volts peak. The connections of the other three secondary windings will be described below.

An alternating grid bias wave of, for example, 20 volts peak, is applied between the control grids of the tubes V1 and V2 and between the control grids of the tubes V3 and V4 by means of the grid bias transformer 93 having a primary winding 94 which is connected to the source 16 and two secondary windings 95 and 96 which are so wound, by way of example, that the voltage wave across each of them is opposite in phase to the voltage across the winding 89 of the transformer 86. The outer terminals of the secondary winding 95 of the transformer 93 are connected through "anti-sing" resistors 45 and 55 to the control grids 42 and 52, respectively, while the outer terminals of the secondary winding 96 are connected through "anti-sing" resistors 65 and 75 to the control grids 62 and 72, respectively. Some economy of space and equipment can be realized by combining on a single core the various secondary windings of the transformer 87 and of the transformer 93 and replacing the primary wind-

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ings of these two transformers by a single winding. This modification does not alter the performance of the circuit.

The signal or input wave from the amplifier 23 is applied to the primary winding 100 of the transformer 101 which has two secondary windings 102 and 103. The signal can have any value from zero to a peak of 20 volts or even somewhat higher if the grids are to be driven positive with respect to their cathodes. The outer terminal 104 of the secondary winding 102 is connected to the mid-point 97 of the secondary winding 95 while the outer terminal 107 of the secondary winding 103 is connected to the mid-point 98 of the secondary winding 96. Two condensers 108 and 109 are connected in series between the terminals 105 and 106 of the secondary windings 102 and 103, respectively, the common terminal 110 of these condensers being connected to ground. The condensers 108 and 109 are of very small capacity such as, for example, .005 microfarad each. Resistors 111 and 112 are connected across the secondary windings 102 and 103, respectively, these resistors being, for example, of 22,000 ohms each. The resistors 111 and 112 are used to provide correct impedance termination for the transformer secondaries. The condensers 108 and 109 are high frequency by-pass capacitors, required to reduce a tendency of the vacuum tubes to oscillate at high frequency. The terminal 105 of the secondary winding 102 is connected to the common terminal of the cathodes 41 and 51 while the terminal 106 of the secondary winding 103 is connected to the common terminal of the cathodes 61 and 71.

The secondary winding 88 of the transformer 87 provides screen grid voltage for the tubes V1 and V2. This winding is connected through "anti-sing" resistors 46 and 56 to the screen grids 43 and 53, respectively. The mid-tap 120 of the winding 88 is connected to the common terminals of the cathodes 41 and 51. Similarly, the transformer winding 90 supplies screen grid voltage through the "anti-sing" resistors 66 and 76 to the screen grids 63 and 73 of the tubes V3 and V4, respectively, the mid-terminal 121 of the winding 90 being connected to the common terminal of the cathodes 61 and 71. The transformer winding 91 supplies current for the cathode heaters (by connections not shown in the drawings).

A considerable improvement from the standpoint of tube power loss is realized when alternating voltage is applied to the plates and to the screen grids of the tubes. The limit of power output is in part dependent on the heat dissipating capabilities of the tube elements involved. By varying the plate and screen voltages between zero and maximum during one-fourth of the alternating current supply cycle, the tube dissipation is materially reduced for given plate and screen voltages. Since a tube supplied with alternating voltage to the plate and screen grid shows lower loss for a given voltage, it follows that for a given size of tube a higher alternating voltage supply can be used than is permissible with direct voltage supply, without exceeding the rating of the tube.

The operation of the arrangement shown in Figs. 1 and 2 will now be described. If the shaft of the motor member 10 is turned, a rotation of the rotary armature 11 of the sending Selsyn 12 is produced which, in the manner pointed out above, causes a voltage to be induced in the armature 22 of the receiving Selsyn 21. The voltage

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induced in the winding 22 may be, for example, of the form shown in Fig. 3C, the notation +90 degrees indicating that this portion of the wave leads by 90 degrees the wave shown in Fig. 3B (which is the wave applied to the winding 27 of the motor 26) and the notation -90 degrees indicating that this portion of the wave is lagging the wave shown in Fig. 3B by 90 degrees. The wave shown in Fig. 3B is displaced 90 degrees with respect to the reference wave shown in Fig. 3A, the wave produced by the source 16. The torque of the motor 26 for a signal wave of the type shown in Fig. 3C is indicated in Fig. 3D. It will be noted that it is in one direction (positive) for certain periods and in an opposite direction (negative) for other periods, these periods being determined by the direction of rotation of the shaft of the motor 10 and hence by the direction of the voltage induced in the winding 22.

The operation of the four-tube amplifier arrangement 24 will be more readily appreciated by considering the various curves shown in Fig. 4. Fig. 4A1 shows in full line the plate circuit voltage curve for the tube V1 and in dotted line the grid bias voltage of the same tube. The same two curves are shown in Figs. 4B1, 4C1 and 4D1 for tubes V2, V3 and V4, respectively. It will be noted that in the absence of a signal wave the grid voltage wave is maintained 180 degrees out of phase with the plate circuit voltage wave so that no current flows in any of the tubes when no input wave appears in the primary winding 100 of the transformer 101. Now assume that the input wave in the primary winding 100 (for at least a cycle of the wave shown in Fig. 3C) has one of its two possible phase conditions, which one condition is called "Input wave A" and is so designated at the top of the second column of the various diagrams collectively designated Fig. 4. Because of the manner of connection of the transformer windings 102 and 103, it will be appreciated that the input wave applied to the grids of the tubes V1 and V2 is 180 degrees out of phase with respect to the wave applied to the control grids of the tubes V3 and V4. In Figs. 4A2, 4B2, 4C2 and 4D2 the plate circuit voltage and the input voltage wave have been shown in full line, the grid bias wave has been shown in dashed lines, and the algebraic sum of the input wave and the grid bias wave has been shown in dot-dash line. These curves are for the tubes V1, V2, V3 and V4, respectively. As indicated in these figures, the input signal wave is of somewhat larger magnitude than the grid bias wave although it will be appreciated that this is not always necessary. Obviously, the magnitude of the plate circuit voltage wave is much larger in relation to that of the signal or grid bias waves than has been indicated in the drawing. In the condition shown in the second column of Fig. 4, this being indicated "Input wave A," tube V1 conducts current during the first half cycle of signal wave input because both the control grid and the anode of this tube are positive. During this half wave, tube V2 does not conduct current because the plate voltage is negative even though the grid voltage is positive. In the tube V3 during the first half cycle the anode voltage is positive and the grid voltage is negative so that the tube is not conducting. In the tube V4, both grid voltage and anode voltage waves are negative. Thus for the first half cycle of the input wave A, only the tube V1 is conducting, as indicated in Fig. 5A. In the second half cycle of

the input wave A, only the tube V4 is conducting, as will be appreciated from the diagrams 4A2, 4B2, 4C2 and 4D2. Now if the input wave in the primary winding 100 has the second of its two conditions, which condition will be called "Input wave B" and is so designated at the top of the third column of the diagrams comprising Fig. 4, it will be appreciated from a study of Figs. 4A3, 4B3, 4C3 and 4D3 that during the first half cycle, tubes V1, V2 and V4 are not conducting because either one or the other or both of the grid and anode voltages are negative during this half cycle. Tube V3 is, however, conducting during this first half cycle and produces the first half cycle of the wave shown in Fig. 5B. During the second half cycle of the input wave B, the tube V2 is conducting, while tubes V1, V3 and V4 are not. Thus the tube V2 produces the second half cycle of the wave indicated in Fig. 5B. Due to the fact that output currents of the tubes V1 and V2 flow in one direction through the upper half of the transformer winding 80 while those of the tubes V3 and V4 flow in the opposite direction through the lower half of this winding, the output currents of the tubes V1 and V2 have been shown in the positive direction in Fig. 5 while those of tubes V3 and V4 have been shown in the negative direction.

It should be noted that the output waves shown in Figs. 5A and 5B are amplified replicas of the input waves "A" and "B." These amplified waves are applied to the winding 25 of the motor 26 and produce torque in one direction or the other to drive the rotor member 22 in a direction to reduce the voltage induced in the winding 22 to zero, as indicated in the middle portion of the curve of Fig. 3C. The computer or optical range finder 30 is also driven by the motor 26 (or by the rotor member 22) through a gear train or other suitable mechanical means so that a shaft or other movable member therein tends to follow the movement of the rotary member in the motor 10. As examples of suitable computers (directors) utilizing range information imparted as a rotary movement, reference is made to the book "Elements of Ordnance" by Hayes, Chapter XIV. An optical range finder having rotatable optical ridges is also described in this book, on page 546.

It will be apparent that various features of the invention can be utilized in circuits other than those of the type shown in Figs. 1 and 2. For example, two of the tubes in the arrangement of Fig. 2 (V1 and V2 or V3 and V4) can be utilized as a switching or phase indicating arrangement. Thus if the input wave e in the transformer winding 100 has one of its two phase conditions with respect to reference wave, one of the two tubes is conducting for one half cycle and both tubes are non-conducting for the other half cycle, while if the input wave e has the second of its two phase conditions, the other of the two tubes becomes conducting during one half cycle and both tubes are non-conducting during the other half cycle. By having indicating instruments such as bells, buzzers or lights in the respective output circuits of the two tubes (instead of one half of the transformer winding 80 common to the two) a visible or audible indication is given of the phase condition of e with respect to the reference wave. If load elements are connected in the respective output circuits, the circuit arrangement affords means for switching from one load element to the other when the phase condition of the input voltage wave e with

respect to the reference wave changes. Obviously, moreover, the four tube arrangement shown in Fig. 2 can be readily adapted for switching and indicating purposes.

Various other modifications can be made in the circuit arrangements described above without departing from the spirit of the invention in its various aspects.

The term "signal" as used in the claims is intended to apply to waves of the kind utilized in electrical control systems, electric power systems, etc., as well as the kind employed strictly for conveying intelligence.

What is claimed is:

1. In combination, four unilaterally conducting discharge devices each including an anode, a cathode and a control element, means for simultaneously applying to both the control element and anode of any selected one of said devices such potentials respectively with respect to the cathode as to permit current to flow through said device and at the same time to apply to the control elements and anodes of the remaining devices such potentials with respect to the respective cathodes that no current flows through said devices, said means comprising means for applying the same alternating voltage between the cathode and anode of each of said devices, the phase thereof being the same in two of said devices and opposite thereto in the other two of said devices, means for applying simultaneously with the application of said alternating voltage a second alternating voltage between the respective cathodes and control elements of all of said devices, said second alternating voltage being of the same frequency as said first-mentioned voltage and opposite in phase thereto in each of said devices, and means for applying a third alternating voltage between said cathodes and control elements which at times is more nearly in phase with said second voltage in two of said devices than in the other two and at other times more nearly in phase with said second voltage in the other two of said devices than in said first two, and means for producing a combined effect from all the currents flowing through said devices.
2. In combination, four discharge devices each including an anode, a cathode and a control element, means for simultaneously applying to both the control element and anode of any selected one of said devices such potentials respectively with respect to the cathode as to permit current to flow through said device and at the same time to apply to the control elements and anodes of the remaining devices such potentials with respect to the respective cathodes that no current flows through said devices, said means comprising means for applying the same alternating voltage between the cathode and anode of each of said devices, the phase thereof being the same in two of the devices and opposite thereto in the other two of said devices, means for applying a second alternating voltage between the respective cathodes and control elements of all of said devices, said second alternating voltage being of the same frequency as said first-mentioned voltage and opposite in phase thereto in each of said devices, and means for applying a third alternating voltage between said cathodes and control elements which at times is in phase with said second voltage in two of said devices and in phase with said second voltage in the other two devices at other times, and means for producing a combined effect from all the currents flowing through said devices.

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3. In combination, two electron discharge devices, means for applying to each of said devices an input voltage wave which may have one of the other of two phase conditions substantially 180 degrees apart, means for applying anode voltage waves to the anodes of said two devices in opposite phase, and circuit means associated with said devices for rendering one of said devices effective to pass current during one half cycle of the input wave and for rendering non-conducting both of said devices during the other half cycle of the input wave when the input wave has one of said two phase conditions, and also for rendering the other of said devices effective to pass current during one half cycle of the input wave and for rendering non-conducting both of said devices during the other half cycle of the input wave when the input wave has the other of its two phase conditions.

4. In combination, two discharge devices each comprising an anode, a cathode and a control element, means for applying an alternating voltage wave between the cathode and anode of each of said devices in such a manner that the potential of one anode is maintained in opposite phase to the potential of the other, means for applying between the control element and cathode of each of said devices an alternating voltage wave of the same frequency as the voltage wave applied between the corresponding anode and cathode but of opposite phase, whereby the control element of each tube, in the absence of other voltage, is always negative with respect to the corresponding cathode when the corresponding anode is positive with respect to said cathode, and vice versa, means for applying an alternating input voltage wave in circuit with the control element and cathode of each device, the input voltage wave being of the same frequency as the voltage wave applied between the corresponding anode and cathode and substantially either in phase or 180 degrees out of phase therewith, and means for producing a combined effect from the currents flowing through said devices.

5. In combination, a first group of two discharge devices each comprising an anode, a cathode and a control element, means for applying an alternating voltage wave between the cathode and anode of each of the devices in said group and in such a manner that the potential of one anode is maintained in opposite phase to the potential of the other, means for applying between the control element and cathode of each of said devices a biasing alternating voltage wave of the same frequency as the voltage wave applied between the corresponding anode and cathode but of opposite phase, whereby the control element of each tube, in the absence of other voltage, is always negative with respect to the corresponding cathode when the corresponding anode is positive with respect to said cathode, and vice versa, means for applying an alternating signal voltage in circuit with the control element and cathode of each device of the group and at least equal in magnitude to the biasing alternating voltage wave applied between said control element and cathode, the input voltage wave being of the same frequency as the voltage wave applied between the corresponding anode and cathode, a second group of discharge devices similar to those of the first group, means for applying anode and grid bias voltage waves to the devices of the second group which are similar in frequency and phase to corresponding waves applied to those of the first group,

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means for applying an alternating input voltage to the grid-cathode circuit of each device of the second group, and means for producing a combined effect from all the currents flowing through said devices.

6. The combination of elements as in claim 5 in which the input voltage wave for each group is either in phase or 180 degrees out of phase with the wave applied between the anode and cathode of one of the devices of that group.

7. The combination of elements as in claim 5 in which said devices are further characterized in that each has a screen grid, and in further combination with means for applying a voltage wave between each screen grid and its corresponding cathode which has the same frequency and phase as the voltage wave applied to the anode of the same tube.

8. The combination of elements as in claim 5 in which each of said devices is a high vacuum electron discharge tube.

9. The combination of elements as in claim 5 in which said last-mentioned means includes means for connecting the cathodes of the first group together, means for connecting the cathodes of the second group together, an impedance element, and means for connecting said impedance element between the common terminal of the cathodes of said first group and between the common terminal of the cathodes of said second group.

10. In combination, four electron discharge devices each comprising an anode, a cathode and a control element, means for applying alternating potentials to each of said anodes with respect to the corresponding cathode, means for applying alternating grid biasing potentials to each of said control elements with respect to the corresponding cathode, the phase of the wave applied to each of the control elements being substantially 180 degrees displaced with respect to the potential wave applied to the corresponding anode so that each device is substantially non-conducting at all times in the absence of other input voltage, means for applying to each of the control elements with respect to its corresponding cathode an alternating input voltage wave which is either in one phase condition with respect to the anode voltage wave of said tube or in a second phase condition which is 180 degrees removed from the first phase condition, whereby two of said tubes are caused to be conducting in alternate half cycles of the input wave when the input signal wave is in one of said two phase conditions and the other two tubes are caused to be conducting in alternate half cycles when said input wave is in the other phase condition.

11. The combination of elements as in claim 5 in which the phase of the input voltages in the control element-cathode circuits of the devices of the first group is opposite that of those in the control element-cathode circuits of the devices of the second group.

12. The combination with a unilaterally conducting device of the type having a cathode, an anode, and current control means, of means for applying an alternating voltage between said anode and cathode and a second alternating voltage of the same frequency and of opposite phase between said cathode and control means, means for applying between said cathode and said control means a third alternating voltage of the same frequency and greater amplitude than said second voltage, and means for shifting the phase of said third voltage, whereby the phase changes in said

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third voltage are translated into current amplitude changes in the anode circuit of said device.

13. The combination with four conducting devices of the type having an anode, a cathode, and a current control electrode, of means for applying alternating potential waves of the same frequency simultaneously to the anode terminals of each device and to the control electrode terminals of each device, those of said waves applied to control electrodes of a pair of said devices being in opposite phase with respect to each other, those of said waves applied to the control electrodes of the remaining pair of said devices being in opposite phase with respect to each other, the waves applied to the control electrodes of a third pair consisting of one of each of said two first-mentioned pairs being in phase with each other and the waves applied to the control electrodes of a fourth pair consisting of the other one of each of said two first-mentioned pairs being likewise in phase with each other, said alternating potentials applied to said anodes being 180 degrees out of phase at each anode with that applied to the corresponding control electrode, means for at times applying control voltage waves to the control electrodes of two of said devices which are opposite to and at least equal to said

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alternating potential waves applied thereto and at other times applying control voltage waves to the control electrodes of the other two of said devices which are in phase with each other and at least equal to said alternating potential applied thereto, and means for utilizing the resulting anode currents of said devices.

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