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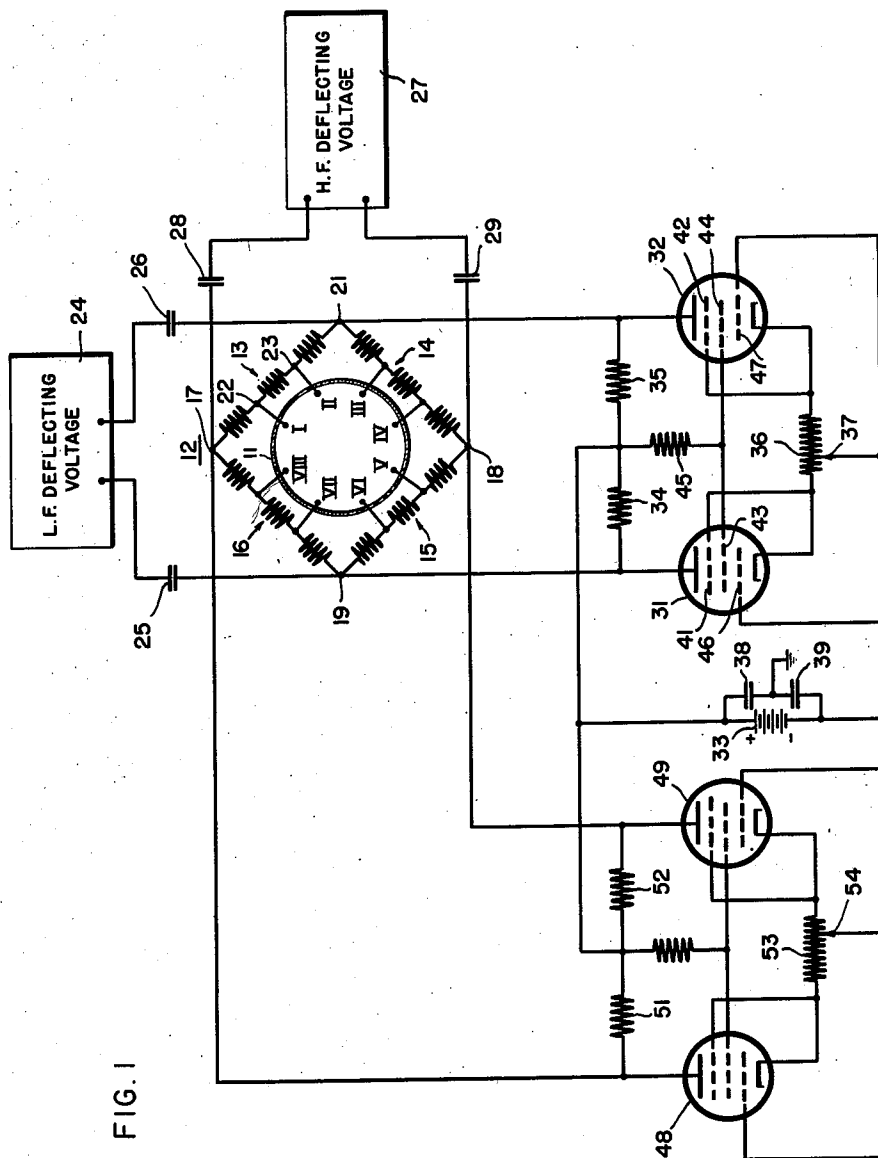
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2,472,727

VOLTAGE DISTRIBUTION SYSTEM

Filed Nov. 27, 1946

2 Sheets-Sheet 1



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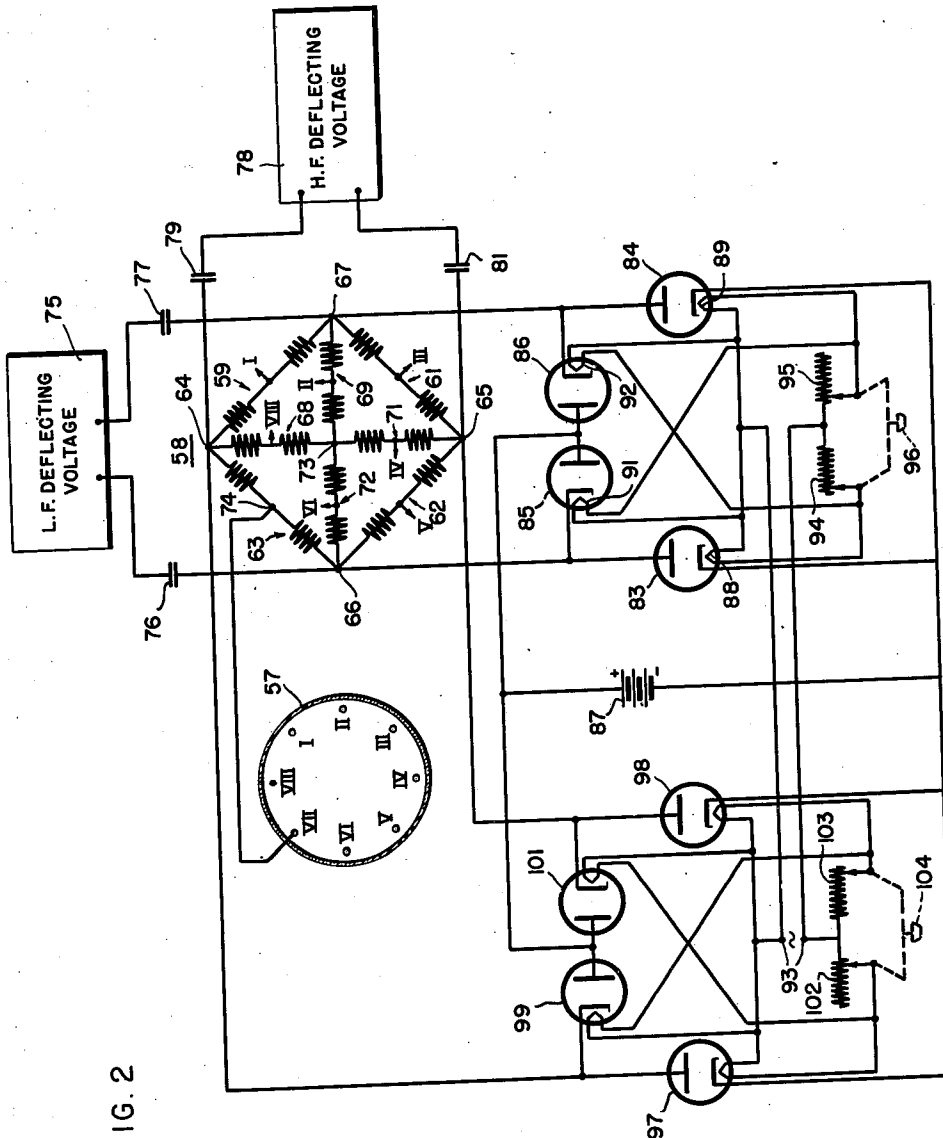


FIG. 2

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VOLTAGE DISTRIBUTION SYSTEM

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8 Claims. (Cl. 315-24)

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This invention relates to systems for controlling the direction of the electron beam in a cathode ray device, and particularly to such systems employing a voltage-distributing network in conjunction with a plurality of beam-deflecting electrodes.

In one type of deflection system for use with a cathode ray tube a plurality of field-producing electrodes is provided in such a manner that the electrodes are uniformly spaced around the path of the electron beam. In order for these electrodes to produce the desired field it is necessary to impress respective voltages thereon having magnitudes dependent upon the location of the electrodes relative to one another. One voltage-distributing network which has been successfully employed consists of a balanced bridge arrangement of a plurality of impedance devices. Voltage sources connected to conjugate corner points of the network and the field-producing electrodes are coupled to intermediate network points.

Usually, in order to completely control the direction of the electron beam it is necessary to impress two types of voltages upon the field-producing electrodes. A substantially constant unidirectional voltage is employed to orient the beam properly relative to a target electrode. Systematic deflection of the beam relative to the target electrode is accomplished by impressing an alternating voltage of predetermined wave form upon the field-producing electrodes. In one form of device which has been used, a voltage-distributing network for the unidirectional voltage and another voltage-distributing network for the alternating voltage have been employed. Such an arrangement operates satisfactorily and is quite economical with respect to power consumption from the various voltage sources. Systems of this type, however, require a great number of circuit components which are costly, occupy considerable space in the equipment and require extensive labor in assembly.

Consequently, a modified form of such a system has also been used. In this modification a single voltage-distributing network is employed both for the unidirectional and for the alternating voltages. The number of circuit components required is materially reduced, but such systems have been found to operate at a lower efficiency from the standpoint of power consumption. In order to minimize the dissipation of the unidirectional power in the apparatus for furnishing the alternating deflecting voltages, direct current blocking condensers are required in the coupling be-

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tween the alternating voltage source and voltage-distributing network. Such components do not add to the power consumption in such a system. However, in order to minimize the dissipation of the power developed for deflecting the electron beam in the apparatus for supplying the unidirectional voltage, it has been found necessary to employ isolating resistors in the coupling between the unidirectional voltage source and the voltage-distributing network. Apparatus of this character does consume power without contributing to the control of the electron beam and, therefore, adversely affects the efficiency of the system.

It is an object of the present invention, therefore, to provide a system employing a single voltage-distributing network for the control of an electron beam to which may be coupled both unidirectional and alternating voltage sources and which is capable of operating with a minimum of power loss.

Another object of the invention is to provide a novel system for impressing electron beam-controlling voltages upon a plurality of field-producing electrodes wherein a single voltage-distributing network is used for both unidirectional and alternating voltages and in which the magnitude and polarity of the unidirectional voltage may be controlled by electron discharge devices.

In accordance with this invention, there is provided a system for controlling the direction of an electron beam which comprises a plurality of field-producing electrodes uniformly spaced around the path of the beam. In order to suitably energize these electrodes to produce the desired field, there also is provided a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices. The network is so formed that it has two pairs of corner points and a plurality of intermediate tap points, the latter of which are coupled respectively to the field-producing electrodes. The unidirectional voltages are impressed upon the network corner points through the space discharge paths of two pairs of electron discharge devices. The source of space current for the two pairs of electron devices serves as the source of unidirectional voltage for the field-producing electrodes. In addition there are provided facilities for varying the conductivity of the two electron devices of each pair in a manner, whereby the polarity and magnitude of the unidirectional voltages impressed upon the corner points of the network may be varied as desired.

More specifically in accordance with one illustrative embodiment of the present invention, the electron discharge devices may be pentodes operated in a manner to present a relatively high impedance to alternating currents. The space current for each pair of tubes is derived from a source of unidirectional voltage and is impressed upon the space discharge paths of the tubes through two impedance devices which are effectively connected across a pair of network corner points. Space current conduction in the two pentodes of each pair is varied by suitably changing the control grid-to-cathode voltages of the tubes.

In accordance with another illustrative embodiment of the invention, the electron discharge devices are diodes provided with thermionic cathodes. The space current for the diodes is derived from a source of unidirectional voltage and is conducted to the tubes through another pair of diodes which also have thermionic cathodes. The heater elements of the four diodes are interconnected and the current supply thereto is suitably controlled to vary the conductivity of the tubes and, therefore, the magnitude and polarity of the unidirectional voltage impressed upon the voltage-distributing network.

By using electron discharge devices to couple the unidirectional voltage to the network, they may be so operated as to have a high impedance for alternating voltages. Consequently, the alternating deflecting voltages may also be coupled to the network corner points by condensers. In such an arrangement substantially none of the power of either of the two types of voltage sources is dissipated in the other type of source.

For a better understanding of the invention, together with other and further objects thereof, reference is made to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 is a circuit diagram of an embodiment of the invention employing pentodes for regulating the unidirectional voltage impressed upon the network; and,

Fig. 2 is a circuit diagram illustrating another embodiment of the invention using diodes for the impression of the unidirectional voltages upon the network.

Reference will now be made to Fig. 1 of the drawings. The invention is disclosed herein for supplying the necessary voltages to the field-producing electrodes of a cathode ray tube such as an image dissector type of television tube. Such a tube is shown herein fragmentarily. An image dissector tube 11 is shown in transverse section. On the inside of the tube envelope there is provided a plurality of elongated field producing electrodes I to VIII. These electrodes surround the path of the electron beam from the cathode source of the electrons to a target electrode which in the case of the dissector is an apertured anode (not shown). Preferably these electrodes extend along the path of the beam from the plane of the cathode to the plane of the anode. In the form of device shown in this figure the electrodes are located symmetrically with respect to the vertical and horizontal axes of the tube in such a manner that none of the electrodes lie on either of these axes. This arrangement, however, is not material, particularly as regards the present invention.

A voltage-distributing network 12 is provided for impressing the proper voltages upon the tube

electrodes so as to produce the desired electron beam-controlling field. The network comprises four substantially identical impedance branches 13, 14, 15 and 16. These branches are arranged as shown in a series connection forming a closed loop. Corner points of the network are formed at the junctions of two branches. The corner points 17—18 and 19—21 are used for the connection of the beam-controlling voltage sources to the network in a manner to be described. Each branch of the network is provided with a plurality of intermediate tap points for connection to the field-producing electrodes. For example, the branch 13 is provided with tap points 22 and 23 which are connected respectively to the electrodes I and II. The impedance values of each of the components of the network branches are chosen so as to properly proportion the voltages applied to the field-producing electrodes for the production of a homogeneous, substantially constant intensity field in the path of the electron beam.

A source 24 of low frequency deflecting voltage is coupled by condensers 25 and 26 to the network corner points 19 and 21. Similarly a source 27 of high frequency deflecting voltage is coupled by condensers 28 and 29 to the network corner points 17 and 18 respectively.

The unidirectional voltage for impression upon the corner points 19—21 is controlled by a pair of vacuum tubes 31 and 32, the anodes of which are directly coupled to these corner points. Preferably these tubes are pentodes such as RCA type 6SJ7 or equivalent tubes having relatively high impedances for alternating currents. The tubes should be chosen for substantially identical operating characteristics. Space current for the tubes is supplied by a source of unidirectional voltage such as a battery 33. The positive terminal of this battery is connected through substantially identical resistors 34 and 35 to the anodes of the tubes 31 and 32, respectively. The negative terminal of the battery 33 is connected through a potentiometer 36 and its sliding contact 37 to the cathodes of the tubes 31 and 32, respectively. The positive and the negative terminals of the battery 33 are by-passed to ground through condensers 38 and 39, respectively. The suppressor grids 41 and 42 respectively of the tubes 31 and 32 are connected to their associated cathodes. The screen grids 43 and 44 respectively of the tubes 31 and 32 are coupled together through a resistor 45 to the positive terminal of the battery 33. The control grids 46 and 47 respectively of tubes 31 and 32 are connected to the negative terminal of the battery 33.

Another pair of vacuum tubes 48 and 49 is provided for impressing a unidirectional voltage upon the corner points 17—18. The respective anodes of these tubes are connected to these corner points. In all other respects the connections of the tubes 48 and 49 are identical to those for the tubes 31 and 32 and, therefore, will not be described in detail. Space current for the tubes 48 and 49 may also be derived from the battery 33 through substantially identical resistors 51 and 52. This space current is also caused to traverse a potentiometer 53 and its sliding contact 54 connecting the cathodes of the tubes 48 and 49 to the negative terminal of the battery 33.

The conductivity of each pair of vacuum tubes may be independently controlled by suitable manipulation of the sliding contacts 37 and 54, respectively, of the potentiometer 36 and 53 in a

manner to be described whereby to vary the unidirectional voltages impressed upon the respective pairs of corner points of the network 12.

Referring now to the operation of the embodiment of the invention shown in Fig. 1, there will be briefly considered first the function of the voltage-distributing network 12. The character of this network is such that a voltage impressed upon any pair of corner points is distributed and impressed upon the tube electrodes in such a manner that they all contribute to the production of a homogeneous field of substantially uniform intensity in the path of electron beam. Inasmuch as the network is a balanced bridge arrangement, a voltage impressed upon one pair of corner points is entirely decoupled from the voltage impressed upon the other pair of corner points. Consequently, components of these two voltages may be impressed simultaneously upon all of the tube electrodes to produce a composite field of the character required to effect the desired control of the electron beam.

Considering only the cyclically varying deflecting voltages impressed upon the network 12 from the voltage sources 24 and 27, the component of the field produced by the electrodes under the control of the high frequency deflecting voltage impressed upon the corner points 17—18 varies in intensity according to a saw-tooth function at a relatively rapid rate, whereby to effect line scansion by the electron beam. At the same time, the low frequency deflecting voltage impressed upon the corner points 19—21 effects a variation in one of the field components at a relatively slow rate, whereby to effect field or frame scansion by the electron beam.

In order to suitably orient the beam relative to a target electrode to produce suitable deflection of the beam, unidirectional voltages are impressed upon the respective pairs of network corner points. The resistors 34 and 35 are effectively connected across the source of low frequency deflecting voltage so that they additionally load this voltage source. However, by using as resistors 34 and 35, components each having a value of 100,000 ohms the total impedance of this additional load circuit is of the order of 200,000 ohms. Inasmuch as the effective impedance of the network 12 between the corner points of 19 and 21 is of the order of 10,000 ohms, the additional drain placed upon the voltage source 24 by the resistors 34 and 35 is negligible.

In addition, the space discharge paths of the tubes 31 and 32 are effectively connected across the voltage source 24 as previously described. However, since these tubes are pentodes operated in a conventional manner, the total impedance represented by the tubes for the alternating current derived from the source 24 is relatively high. It may be seen, therefore, that these tubes do not place any substantial power drain on the deflecting voltage source 24.

Unidirectional current conduction in the tubes 31 and 32 is controlled by the potentiometer 36 and its sliding contact 37. The voltages of the control grids relative to the associated cathodes are controlled by the position of the sliding contact on the potentiometer, whereby to control the magnitude of the unidirectional space current conducted by the tubes. The connections of the potentiometer 36 and its contact 37 are such that, when the contact, is manipulated to increase the control grid voltage of one tube, the control grid voltage of the other tube is decreased. For example, the potentiometer contact may be adjusted

to effect the conduction of space current in the tube 31 in greater magnitude than the space current conduction in the tube 32. In this case unidirectional current will flow from the battery 33 through the network 12 from the corner point 21 to the corner point 19. The magnitude of this current will depend upon the adjustment of the potentiometer 36. If it is desired to increase this current flow, the contact 37 may be manipulated to increase the flow of space current in the tube 31 and at the same time to decrease the flow of space current in the tube 32.

If it is desired to reverse the polarity of the unidirectional voltage impressed upon the network corner points 19—21 so that the point 19 will be positive and the point 21 will be negative, the contact 37 is manipulated to so adjust the potentiometer 36 that more space current will flow in the tube 32 than in the tube 31.

The unidirectional voltage which is impressed upon the network corner points 17—18 under the control of the tubes 48 and 49 is dependent upon the space current conduction in these tubes. In substantially the same manner as that described, space current conduction in the tubes 48 and 49 is controlled by suitable manipulation of the sliding contact 54 relative to the potentiometer 53.

Referring now to Fig. 2, there is shown another embodiment of the invention. In this case a cathode ray tube 57 is provided with eight field-producing electrodes I to VIII arranged around the path of the electron beam so that two pairs of diametrically opposite electrodes lie respectively on the vertical and horizontal axes of the tube. About the only significance of this electrode arrangement is that it requires a somewhat more elaborate voltage-distributing network. Otherwise the operation of the deflecting system is the same as in the previous instance.

There is provided a voltage-distributing network 58 which comprises a balanced bridge arrangement of a plurality of impedance devices. In this case the network consists of four exterior branches 59, 61, 62 and 63 connected in series to form a closed loop having two pairs of conjugate corner points 64—65 and 66—67. The network also includes four interior branches 68, 69, 71 and 72 which are connected in pairs between respective pairs of corner points. More specifically, interior branches 68 and 71 are connected in series between the corner points 64 and 65, and interior branches 69 and 72 are connected in series between corner points 66 and 67. The junction point 73 between the interior branches may be connected (in a manner not shown) to a wall coating of the tube 57 if desired. Intermediate points on the network branches such as the point 74 on the exterior branch 63 are connected to the field-producing electrodes of the tube as indicated. The point 74, for example, is connected to the tube electrode VII. Other connections are as indicated by the Roman numerals.

A low frequency deflecting voltage source 75 is coupled by condensers 76 and 77 to the network corner points 66—67. In like manner, a high frequency deflecting voltage source is coupled by condensers 79 and 81 to the network corner points 64—65.

In this case the unidirectional voltages are impressed upon the corner points of the network by means of a bridge arrangement of four diodes 83, 84, 85 and 86 all of which are provided with thermionic cathodes. As shown and described

herein, the cathodes of all diodes are provided with indirect heating elements. However, it is contemplated to be within the scope of the invention to employ diodes provided with filamentary cathodes, particularly for tubes such as 83 and 84. The diodes 83 and 84 are connected with their anodes to the network corner points 66—67. Space current for these diodes is provided by a source of unidirectional voltage such as a battery 87. The positive terminal of this battery is connected through diode 85 to the anode of the diode 83 and also through diode 86 to the anode of the diode 84. The cathodes of diodes 83 and 84 are connected to the negative terminal of the battery.

The diodes 83, 84, 85 and 86 are provided with cathode heaters 88, 89, 91 and 92, respectively. Heating current for the cathode heaters is supplied from an alternating current source 93 which may be a commercial source of 60 cycle energy, for example. The magnitude of the heating current is varied by two potentiometers 94 and 95 which may be mechanically linked for simultaneous adjustment by means of a single control knob 96. The heaters 88 and 92, respectively, of the diodes 83 and 86 are connected in parallel through the potentiometer 94 to the source 93. Similarly, the heaters 89 and 91, respectively, of the diodes 84 and 85 are connected in parallel through the potentiometer 95 to the heating current source 93.

Unidirectional voltage is impressed upon the network corner points 64—65 by means of an identical bridge connection of four diodes 97, 98, 99 and 101, all of which may be provided with indirectly heated cathodes as shown. The cathode heaters for the tubes 97 and 101 are connected through a potentiometer 102, while the cathode heaters for the tubes 98 and 99 are connected through a potentiometer 103 to the current source 93. A single control knob 104 may be linked to both of these potentiometers in a manner to simultaneously effect an adjustment thereof.

It is seen that, inasmuch as the diodes 85 and 86 are connected in opposite polarity between the network corner points 66—67 there is substantially no power drain placed thereby upon the low frequency deflecting voltage source 75. Also all of the diodes are operated in a temperature-saturated manner so that the diodes 83 and 84 have a relatively high impedance for the alternating current derived from the source 75. In like manner the diodes 97, 98, 99 and 101 connected to the network corner point 64—65 do not appreciably load the high frequency deflecting voltage source 78.

Referring now to the operation of the embodiment of the invention shown in Fig. 2, the deflecting voltage sources 75 and 78 in cooperation with the network 58 produce a continuously varying field in the cathode ray tube 57 in substantially the same manner as in the previously described embodiment. In order to suitably orient the electron beam relative to the target electrode the control knobs 96 and 104 are manipulated to suitably vary the magnitude and polarity of the unidirectional voltages impressed upon the network corner points.

With respect to the unidirectional voltage impressed upon the corner points 66—67, assume that the potentiometers 94 and 95 are adjusted so as to supply relatively large heating currents to the cathode heaters 88 and 92 of the diodes 83 and 86, respectively, and that the potenti-

ometer 95 is so adjusted to supply a relatively small heating current to the cathode heaters 89 and 91 of the diodes 84 and 85, respectively. The current flow from the battery 87 in this case is predominantly through the diode 86, through the network 58 from the corner point 67 to the corner point 66 and through the diode 83. This is accomplished by so conditioning the tubes that the diodes 83 and 86 conduct a current of greater magnitude than that which can be conducted by the diodes 84 and 85. The magnitude of the current flow from the corner 67 to the corner point 66 of the network determines the magnitude of the unidirectional voltage impressed upon these two points. In order to increase the magnitude of the unidirectional voltage, the current flow through the network is increased by still further increasing the current conduction through the diodes 83 and 86, and at the same time, still further decreasing the current conduction through the diodes 84 and 85. These current changes are made under the control of the potentiometers 94 and 95.

If it is desired to reverse the polarity of the unidirectional voltage impressed upon the network corner points 66—67, the control knob 96 is manipulated so as to adjust the potentiometers 94 and 95 to supply greater heating current to the cathode heaters 89 and 91 of the diodes 84 and 85, respectively, than to the heaters 88 and 92 of the diodes 83 and 86, respectively. In such a case, the predominant current flow from the battery 87 is through the diode 85, through the network 58 from the corner point 66 to the corner point 67 and finally through the diode 84. A variation in the magnitude of this reversed polarity unidirectional voltage is effected by an appropriate adjustment of the potentiometers 94 and 95.

The unidirectional voltages which are impressed upon the network corner points 64—65 are controlled both as to polarity and as to magnitude by suitable manipulation of the control knob 104, whereby to condition the diodes 97, 98, 99 and 101 to conduct current through the network in the proper direction and in the desired magnitude. The operation of these diodes to effect the voltage variation at the corner points 64—65 is substantially identical to that described for the group of diodes associated with the corner points 66—67.

While there has been described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A system for controlling the direction of an electron beam comprising, a plurality of field-producing electrodes uniformly spaced around the path of said beam, a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices having two pairs of corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, two pairs of electron discharge devices having relatively high impedance space discharge paths, means for coupling the space discharge paths of each pair of electron discharge devices to respective pairs of said corner points, a source of space current for each pair of electron discharge de-

vices, and means for oppositely varying the conductivity of each pair of electron discharge devices, whereby to vary the voltages derived from said space current source and impressed upon said network corner points.

2. A system for orienting an electron beam relative to a target electrode comprising, a plurality of elongated field-producing electrodes spaced uniformly around the path of said beam, a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices having two pairs of conjugate corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, two pairs of electron discharge devices having relatively high impedance space discharge paths coupled to respective pairs of said corner points, a source of unidirectional voltage, means for coupling the space discharge paths of said electron discharge devices to said voltage source, and means for oppositely varying the conductivity of the electron discharge devices of each pair of said devices, whereby to vary the unidirectional voltages impressed by said electron discharge devices upon said network corner points.

3. A system for orienting an electron beam relative to a target electrode comprising, a plurality of elongated field-producing electrodes spaced uniformly around the path of said beam, a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices having two pairs of conjugate corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, two pairs of electron discharge devices, each having a relatively high impedance output circuit and an input circuit, each pair of output circuits being coupled to respective pairs of said corner points, a source of unidirectional voltage, means for coupling said output circuits to said voltage source, and means including said input circuits for oppositely varying the conductivity of the electron discharge devices of each pair of said devices, whereby to vary the unidirectional voltages impressed by said electron discharge devices upon said network corner points.

4. A system for orienting an electron beam relative to a target electrode comprising, a plurality of elongated field-producing electrodes spaced uniformly around the path of said beam, a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices having two pairs of conjugate corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, two pairs of electron discharge devices, each having at least an anode, a cathode, a control grid and a relatively high impedance space discharge path between said anode and said cathode, each pair of anodes being coupled to respective pairs of said corner points, a source of unidirectional voltage, means including individual impedance devices for coupling said anodes to said voltage source, and means including said control grids for oppositely varying the conductivity of the electron discharge devices of each pair of said devices, whereby to vary the unidirectional voltages impressed by said anodes upon said network corner points.

5. A system for orienting an electron beam relative to a target electrode comprising, a plurality of elongated field-producing electrodes spaced uniformly around the path of said beam,

a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices having two pairs of conjugate corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, two pairs of pentode electron discharge devices, each having an anode, a cathode, a control grid, a screen grid and a suppressor grid each pair of anodes being coupled to respective pairs of said corner points, a source of unidirectional voltage, means including individual substantially identical impedance devices for coupling said anodes to said voltage source, means including impedance devices for coupling said screen grids to said voltage source, each of said suppressor grids being connected to its associated cathode, and means including said control grids for independently and oppositely varying the conductivity of the electron discharge devices of each pair of said devices, whereby to vary the polarity and magnitude of the unidirectional voltages impressed by said anodes upon said network corner points.

6. A system for orienting an electron beam relative to a target electrode comprising, a plurality of elongated field-producing electrodes spaced uniformly around the path of said beam, a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices having two pairs of conjugate corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, a first pair of diode electron discharge devices coupled to each pair of said corner points, a source of unidirectional voltage, a second pair of diode electron discharge devices for coupling each of said first pair of diodes to said voltage source, all of said diodes having thermionic cathodes, and means for oppositely varying the temperatures of the cathodes of each pair of diodes to correspondingly vary the conductivity of said diodes, whereby to vary the unidirectional voltages impressed upon said network corner points.

7. A system for orienting an electron beam relative to a target electrode comprising, a plurality of elongated field-producing electrodes spaced uniformly around the path of said beam, a voltage-distributing network comprising a balanced bridge arrangement of a plurality of impedance devices having two pairs of conjugate corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, two first pairs of diode electron discharge devices, each diode having an anode, a cathode and a cathode heating element, each pair of diodes being coupled to respective pairs of said corner points, a source of unidirectional voltage, means including two second pairs of diode electron discharge devices for coupling said anodes to said voltage source, each diode of said two second pairs of diodes having a cathode heating element, and means for variably energizing the heating elements of all of said diodes so as to oppositely vary the conductivity of said electron discharge devices, whereby to vary the unidirectional voltages impressed by said two first pairs of diodes upon said network corner points.

8. A system for orienting an electron beam relative to a target electrode comprising, a plurality of elongated field-producing electrodes spaced uniformly around the path of said beam, a voltage-distributing network comprising a balanced bridge arrangement of a plurality of im-

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pedance devices having two pairs of conjugate corner points and a plurality of intermediate tap points, said tap points being coupled respectively to said field-producing electrodes, two pairs of electron discharge devices, each of said electron discharge devices having an anode, a cathode and a cathode heating element, each pair of anodes being coupled to respective pairs of said corner points, a source of unidirectional voltage, means including individual substantially identical diode electron discharge devices for coupling said anodes to said voltage source, said diodes each having a cathode heating element, a source of heating current connected to the heating elements of all of said electron discharge devices, and current varying means coupled between said cathode heating elements and said current source

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for oppositely varying the conductivity of the electron discharge devices of each of said two pairs of said devices and the conductivity of said diode electron discharge devices, whereby to vary the unidirectional voltages impressed by said anodes upon said network corner points.

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