

June 28, 1960

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2,943,237

MULTI-ELECTRODE TUBE CIRCUIT

Filed Feb. 27, 1956

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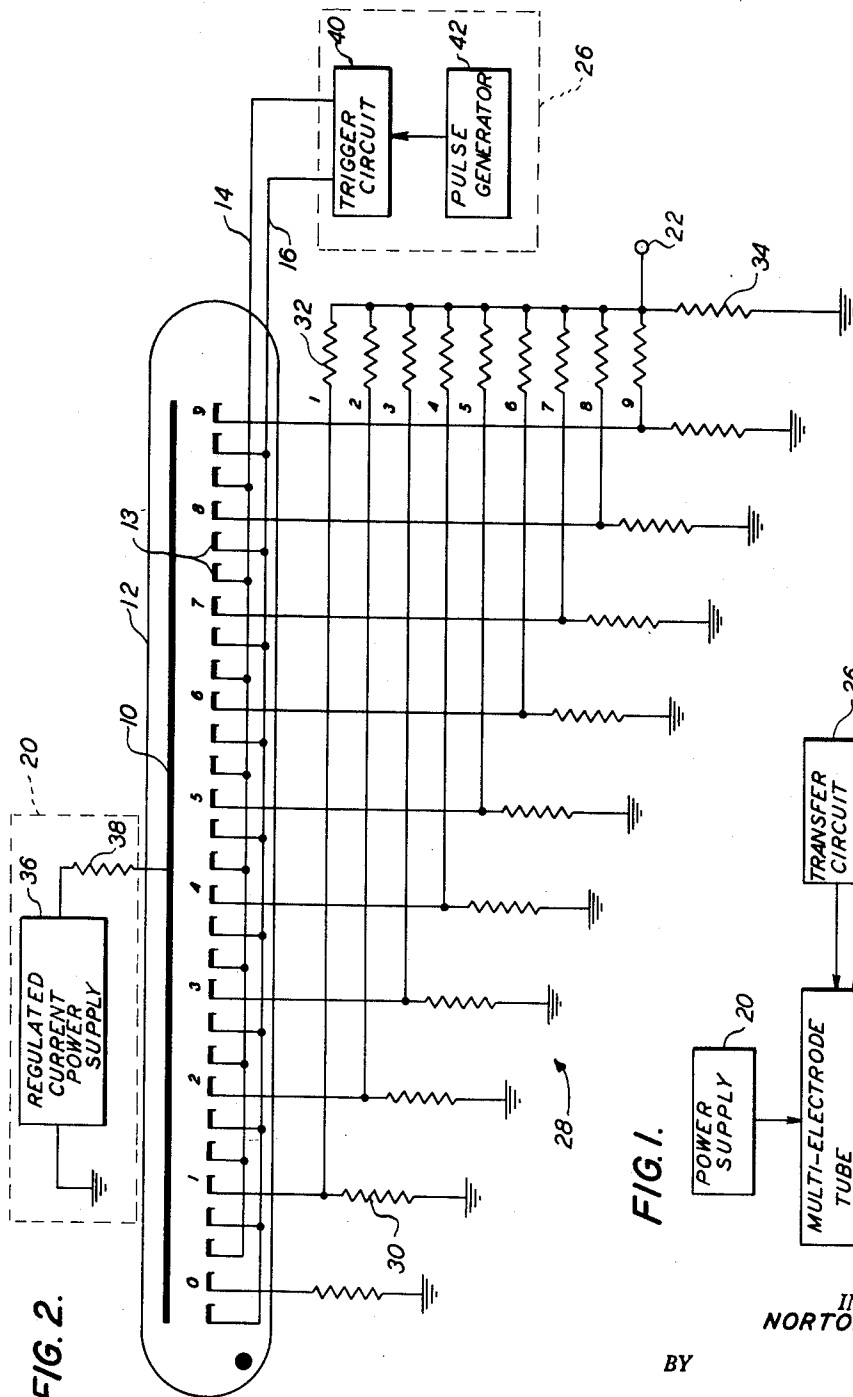
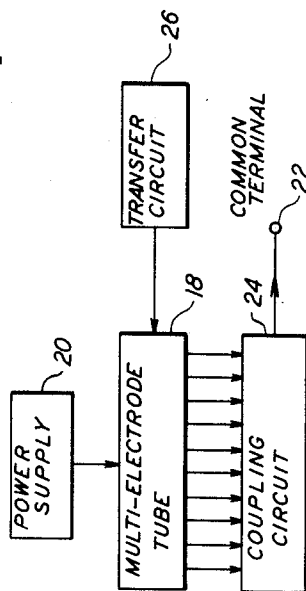


FIG. 2.

FIG. 1.



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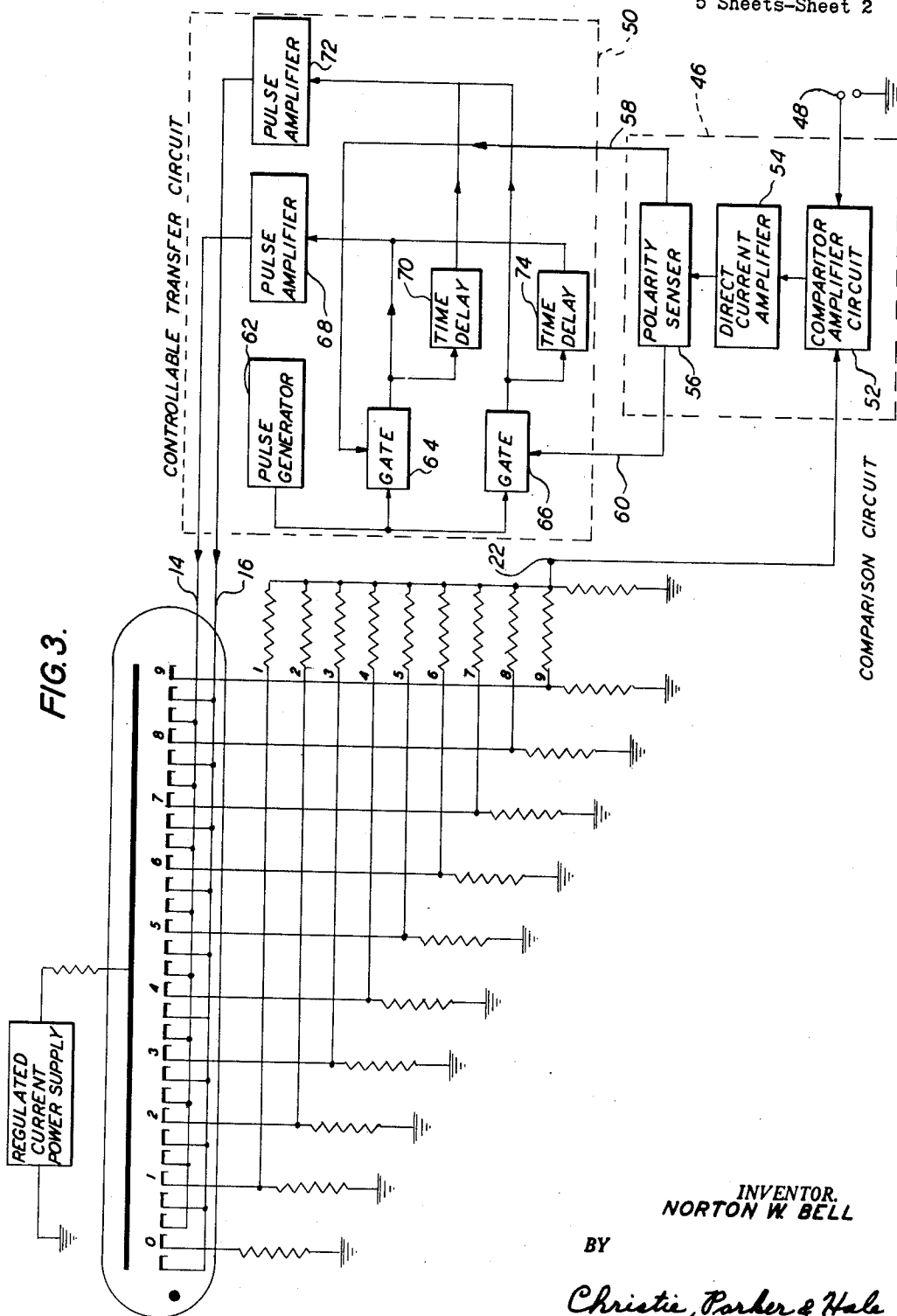
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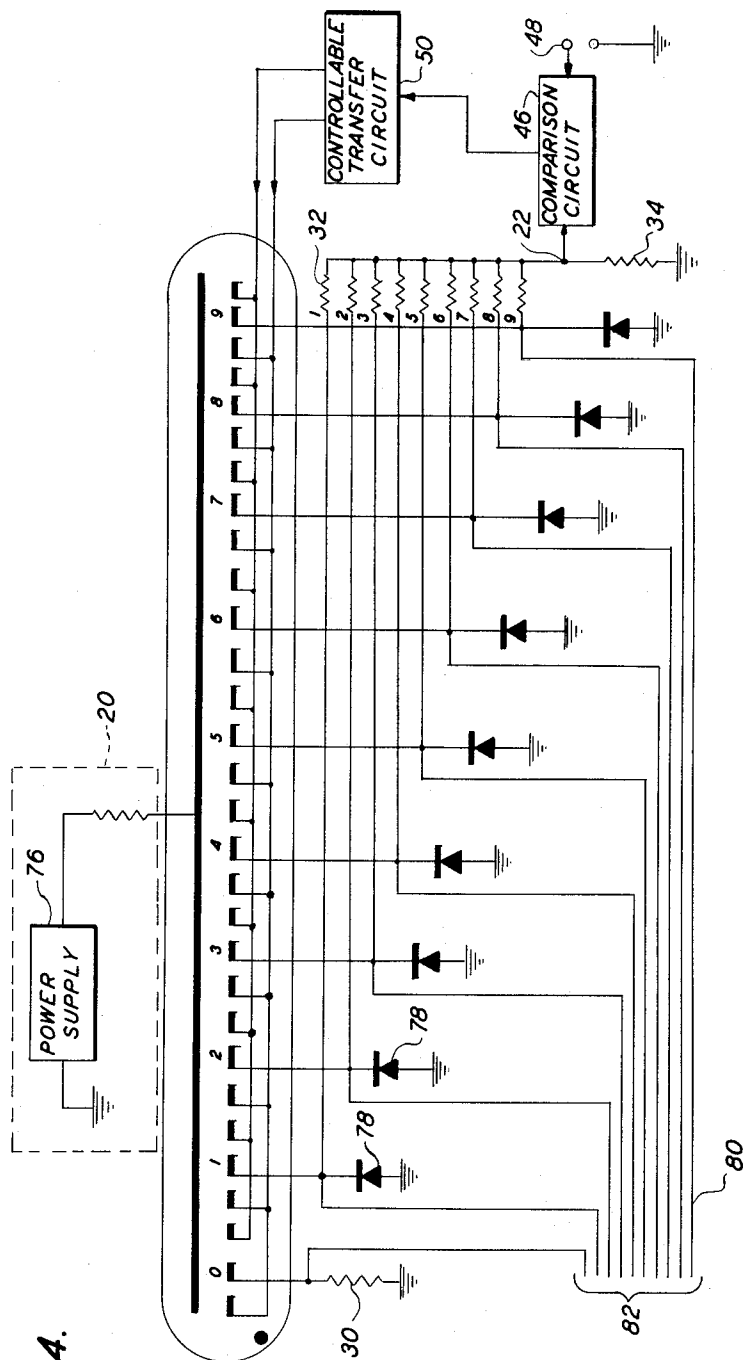


FIG. 4.

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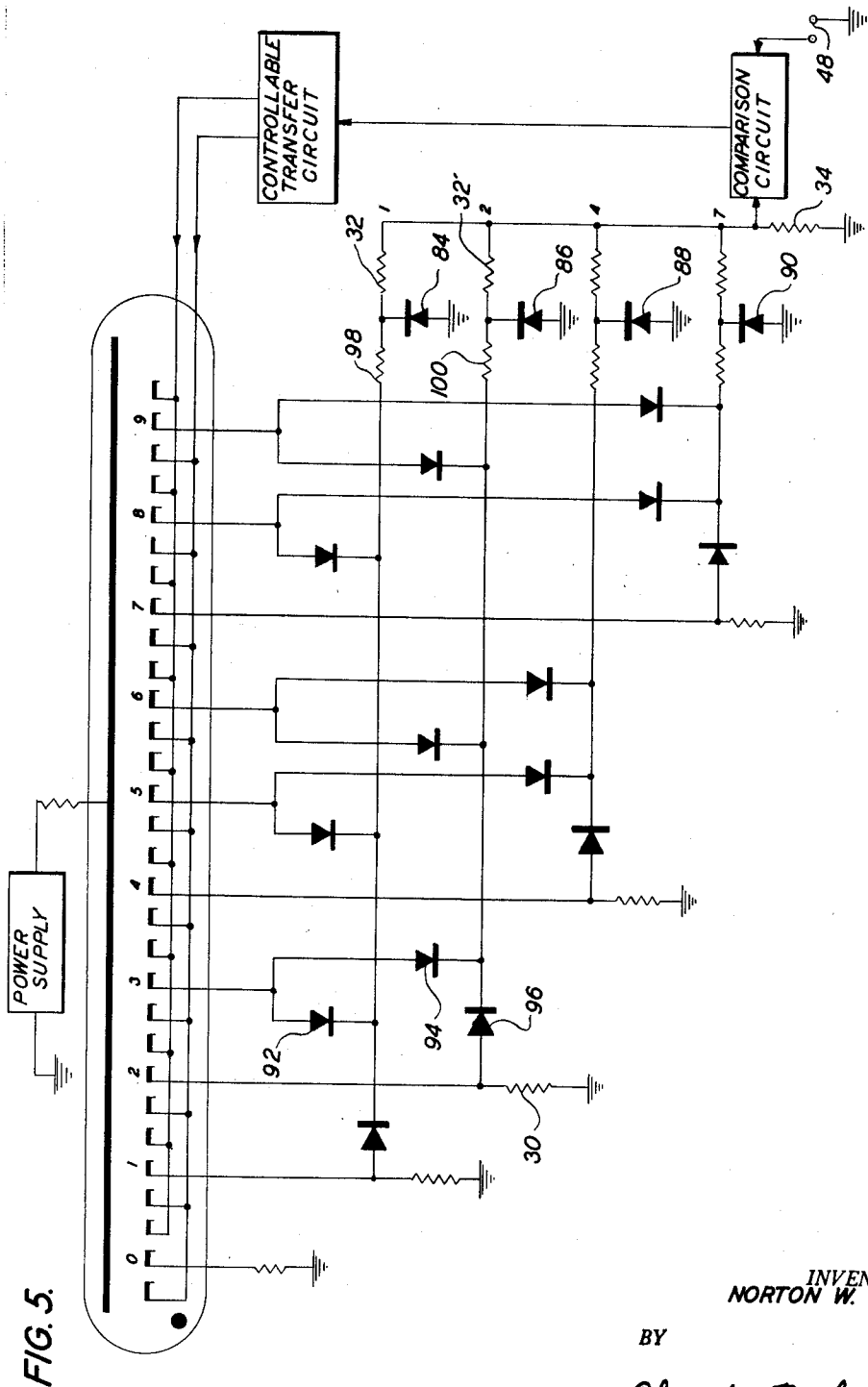
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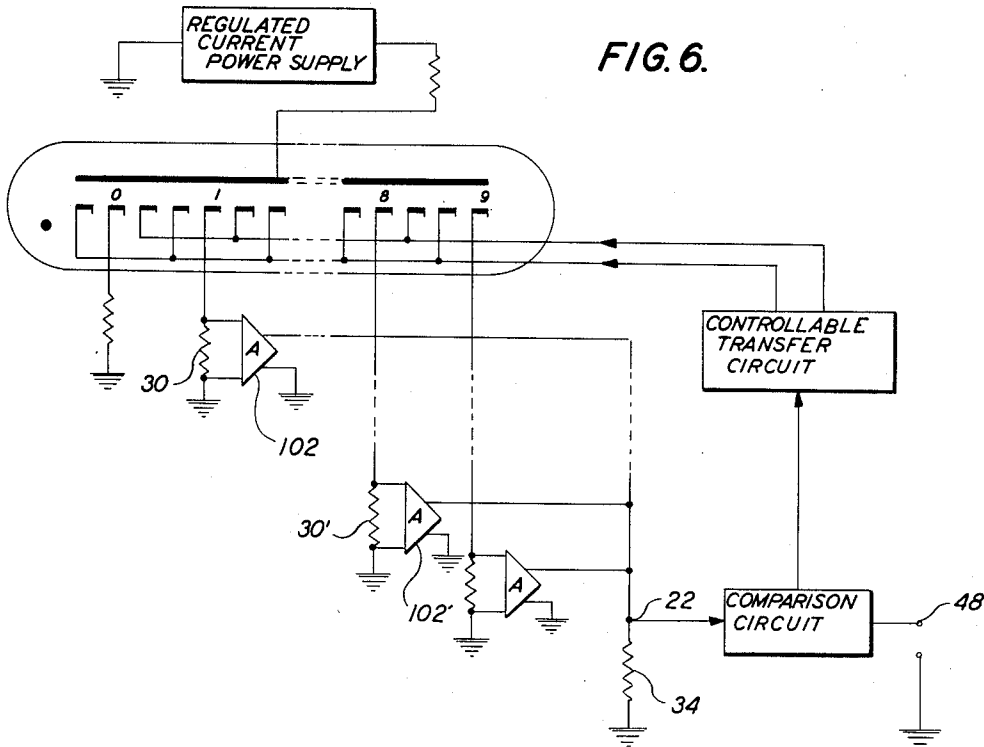
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MULTI-ELECTRODE TUBE CIRCUIT

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5 Sheets-Sheet 5



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MULTI-ELECTRODE TUBE CIRCUIT

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Filed Feb. 27, 1956, Ser. No. 567,789

7 Claims. (Cl. 315—84.6)

This invention relates to electrical circuits that employ multi-electrode tubes, and it has particular reference to multi-electrode tube circuits that provide a reference voltage which can be varied rapidly in accurate steps. The invention is also concerned with improved analog-to-digital conversion devices which incorporate such multi-electrode tube circuits.

For purposes of this disclosure, the term "multi-electrode tube" refers to a tube having a common electrode and a plurality of separate electrodes spaced proximate the common electrode, the tube being designed to conduct electric current between the common electrode and one of the separate electrodes at a time. The Sylvania type 6476 is a typical example of a tube which meets these requirements. It is a multiple cold-cathode gas discharge tube having ten separate cathodes spaced radially around a common anode, with auxiliary electrodes dispersed among the separate cathodes in the tube for assisting in the transfer of the conductive condition from one separate cathode to another. While the teachings of this disclosure will apply to other types of multi-electrode tubes as well, the Sylvania type 6476 seems adequate to illustrate the invention so that the application of the teachings of this disclosure to other types of multi-electrode tubes will be apparent to those skilled in the art.

The circuit of the invention provides a reference voltage which can be varied rapidly in accurate steps. This is accomplished by employing a multi-electrode tube of the general nature described, means coupled to the tube for transferring the conductive condition in the tube from one separate electrode to another, and by employing circuit means coupled between the separate electrodes of the tube and a common terminal, the circuit means having different transmission characteristics between the various separate electrodes and the terminal so that different voltage levels appear at the terminal in accordance with transfers of the conductive condition from one separate electrode to another.

The conductive characteristics of a multi-electrode tube will differ slightly from one separate electrode to another, and will change with the age of the tube as well as other factors. To prevent such variations in the conductive characteristics of the tube from affecting the accuracy of the voltage levels provided at the common terminal, where high accuracy is required, means are coupled externally of the tube between the separate electrodes and the common electrode for regulating the voltage level on the conductive separate electrodes to predetermined values. This may be accomplished by employing a current regulating power supply in conjunction with the tube. However, what is considered to be a better way of accomplishing this is by providing means for causing the voltage level of each separate electrode when it is in the conductive condition to be substantially independent of variations in the amount of current being conducted through the separate electrode. Such means may comprise a plurality of diodes coupled

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to the separate electrodes, each diode having a reverse breakdown region in which the voltage across the diode is substantially fixed and independent of the amount of current being conducted by the diode over a wide range of current. For example, silicon junction diodes available from Texas Instruments, Incorporated, Dallas, Texas, will work for this purpose.

The multi-electrode tube circuit of the invention may be used for a variety of purposes. For example, it may be used to provide various voltage wave forms with high precision; also it may be used as a high speed replacement for various forms of stepping switch circuits and the like. What is considered to be an excellent adaptation of the multi-electrode tube circuit of the invention is as an improved analog-to-digital conversion device.

In general, the normal operation of an analog-to-digital converter is to provide a digital evaluation of an analog function at successive intervals. The analog function is usually in the form of a direct current voltage, or it is readily reducible to this form. If this analog voltage is plotted with respect to time, then it can be seen that the analog-to-digital converter provides a digital evaluation of the ordinate of the voltage curve at successive instants of time. Naturally, the more points on the curve that the analog-to-digital converter is capable of identifying per unit of time, the better the device is for defining the exact variations in the analog function.

The analog-to-digital converter of the invention has the advantages of being relatively simple and inexpensive, and of being capable of operating accurately at very high speeds. These advantages are at least partly due to the incorporation into the analog-to-digital converter of the multi-electrode tube circuit of the invention. To adapt the multi-electrode tube circuit as an analog-to-digital converter, controllable means is coupled to the multi-electrode tube for transferring the conductive condition from one separate electrode to another, and comparison means is coupled to the common terminal for comparing the voltage levels appearing thereon with an analog voltage applied to the comparison means. The comparison means is coupled to the controllable transfer means for causing the transfer means to transfer the conductive condition along the plurality of separate electrodes of the tube until a voltage level is reached on the common terminal which most nearly approximates the voltage level of said analog voltage applied to the comparison means.

If the multi-electrode tube employed is a glow discharge tube, then the digital value of analog voltage may be visually determined by noticing the corresponding separate electrode of the tube upon which the glow discharge is presently settled. If a different form of digital indication is required or preferred, a digital indicating circuit may be coupled to the tube circuit for this purpose.

A more detailed discussion of the various aspects of the circuits of the invention is taken up with reference to the drawings, in which:

Fig. 1 is a generalized schematic drawing of the multi-electrode tube circuit of the invention;

Fig. 2 shows one embodiment of the apparatus of Fig. 1;

Fig. 3 is a schematic drawing of an analog-to-digital converter which incorporates most of the apparatus of Fig. 2;

Fig. 4 is a second embodiment of the apparatus of Fig. 1, adapted as an analog-to-digital converter in accordance with the teachings of Fig. 3;

Fig. 5 is a third embodiment of the apparatus of Fig. 1, also adapted as an analog-to-digital converter in accordance with the teachings of Fig. 3; and

Fig. 6 is a fourth embodiment of the apparatus of Fig.

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1, also adapted as an analog-to-digital converter in accordance with the teachings of Fig. 3.

As previously stated, a particular type of multi-element tube has been chosen for purposes of illustrating the invention; namely, the Sylvania type 6476 multiple-cold cathode gas discharge tube. This tube has a common electrode (anode) disposed centrally with a plurality of separate electrodes (cathodes) spaced radially about the anode. Figs. 2-6 show this tube schematically. It should be noted that while the actual configuration of this tube is circular as described, the drawings are simplified by showing the electrodes of the tube spread out in linear fashion.

It can be seen in Fig. 2 that this tube has a plurality of separate cathodes 0-9 respectively, which are spaced proximate to a common anode 10, all inside an envelope 12. A plurality of auxiliary electrodes 13 (guide cathodes) are dispersed among the separate cathodes in the tube, these auxiliary electrodes being broken down into a first group commonly coupled to a lead 14 and into a second group commonly coupled to a lead 16. The tube is designed to conduct electric current as a glow discharge between the common anode 10 and one of the separate cathodes 0-9 at a time. The purpose of the auxiliary electrodes is to facilitate the transfer of this conductive condition from one separate cathode to another.

As can be seen, two auxiliary electrodes, one from each group, are disposed between each successive pair of separate cathodes. The auxiliary electrodes operate as follows: Assuming that a glow is present on cathode No. 2, a negative pulse on the lead 14 will cause the glow to move to the right onto the adjacent auxiliary electrode which is one of the group of auxiliary electrodes connected to the lead 14. At the end of this pulse, a negative pulse is applied to the lead 16 moving the glow to the right and onto the next adjacent auxiliary electrode which is a member of the group of auxiliary electrodes connected to the lead 16. Then, since the auxiliary electrodes are normally biased above the separate cathodes, at the end of this second pulse the glow will go to the right by itself and onto the adjacent separate cathode No. 3. The reason that the glow goes to cathode No. 3 instead of back to cathode No. 2 is because of the preferential influence of the ionization of gas near cathode No. 3. The glow will remain on cathode No. 2 until the pulsing sequence is repeated. Thus, to move the glow to the right a negative pulse is first applied to lead 14, then later in time a negative pulse is applied to lead 16. Conversely, the glow may be transferred to the left by applying a negative pulse to the lead 16 first, then later in time applying a negative pulse to the lead 14. This will transfer the conductive condition from cathode No. 2 to cathode No. 1.

Referring now to Fig. 1, a multi-electrode tube 18 is energized by a power supply circuit 20. The multi-electrode tube is coupled to a common terminal 22 by a coupling circuit 24. A transfer circuit 26 is coupled to the multi-electrode tube for causing the conductive condition in the tube to be transferred from one separate electrode to another. The coupling circuit 24 provides different transmission characteristics between the various electrodes of the tube and the terminal 22 so that different voltage levels appear at the terminal in accordance with transfers of the conductive condition in the tube. This will be more apparent from a consideration of a particular embodiment of the circuit which is shown in Fig. 2.

Referring now to Fig. 2, the separate cathodes 1-9 are all coupled to the common terminal 22 by a resistor network 28. Each separate cathode has a first resistor 30 coupling it directly to ground, with a second resistor 32 coupling it to the common terminal 22. The common terminal 22 is coupled to ground by way of a summing resistor 34. Cathode No. 0 of the tube is coupled di-

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rectly to ground by a first resistor. However, it is not coupled to the common terminal 22 by a second resistor and therefore a voltage value of 0 may be used as one of the voltage levels to appear on the terminal. A regulated current power supply 36 and a resistor 38 are coupled to the common anode 10 so that power is supplied to the tube. A trigger circuit 40 has its two stages coupled to the respective leads 14 and 16 for supplying the negative pulses to these leads. The trigger circuit is driven by a pulse generator 42, and the resulting operation is to transfer the conductive condition in the tube along the plurality of separate cathodes 0-9 respectively in continuous cycles. Actually the cathode No. 0 is disposed adjacent the cathode No. 9 as previously explained, although it is not shown this way in the drawing.

In typical operation with this particular tube, the regulated current power supply and the various resistors are chosen so that the total anode current is about 0.5×10^{-3} amperes. To achieve this operation the voltage from the power supply 36 should range around 400 volts with the anode resistor 38 having a value of approximately 0.4 megohm and with the total resistance coupling each cathode to ground being about 68,000 ohms. Under these conditions the nominal tube voltage drop is about 190 volts with the voltage developed across cathode to ground being about 28 volts.

The object of the resistor network 28 is to provide different amounts of transmission between the various separate cathodes and the common terminal so that different voltage levels appear at the common terminal in accordance with transfers of the conductive condition from one separate cathode to another.

Since each cathode has a first resistor 30 coupled to it in parallel with a second resistor 32 and the summing resistor 34 (excepting cathode No. 0), then we may choose the total equivalent series resistance of each of these combinations as 68,000 ohms. A 68,000 ohm first resistor can be coupled to the cathode No. 0, and a 1000 ohm value may be used for the summing resistor 34. In each of these parallel resistor combinations, the resistance of the first resistor 30 and the second resistor 32 can be chosen so that the total series resistance between cathode and ground remains constant for each cathode but the resistance between cathode and common terminal differs.

Accordingly, the resistance values may be chosen so that the voltage levels appearing at the common terminal 22 are 0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4 and 0.45 volt respectively going from cathode Nos. 0 to 9 in order. Of course, these voltage levels may be amplified, if desired.

No doubt there are countless arrangements of resistors which may be worked out according to the teachings of Fig. 2 to accomplish the same purpose. However, the particular resistor network shown gives excellent results and it is preferred because it maintains the total resistance between each cathode and ground substantially constant, which results in the potential on each cathode in the conductive condition being substantially the same predetermined constant value. This is not a necessary condition for operation of the tube but it does insure that the tube is operated within certain limits. For example, when the potentials on different cathodes in the conductive state are allowed to be at different predetermined values, one must be careful that the potential on any cathode does not become so positive as to exceed the potential on any of the auxiliary electrodes, because if this should happen the glow settled on any particular cathode might transfer off of this cathode of its own accord.

In the resistor network shown in Fig. 2, it should be observed that each cathode is not strictly coupled to ground by the parallel resistor arrangement previously described. That is, in the parallel arm of the resistor arrangement which includes the second resistor 32 and the summing resistor 34, there is also included in that

same arm a parallel combination of paths going back through all the other second resistors and first resistors to ground. As previously stated, the value of the summing resistor 34 is relatively small compared with the value of the first and second resistors. Therefore, these added circuit paths will have little effect upon the voltage levels appearing at the common terminal and upon the total resistance coupling each cathode to ground. These extra circuit paths can be taken into consideration in the design of the circuit, and by the conventional procedure of solving simultaneous equations the circuit may be designed substantially exact to include the effect of these extra circuit paths to ground. Therefore, this is not considered to be a disadvantage of the resistor circuit shown in Fig. 2.

The power supply 36 is of the current regulating type. This insures that the current conducted between the anode and any of the cathodes is always the same constant amount and therefore, it insures that any variations in the characteristics of the tube from one cathode to another and with the age of the tube will not affect the voltage levels produced at the common terminal. Where accurate voltage levels are desired this provision in the multi-electrode tube circuit is valuable.

Referring now to Fig. 3, an improved analog-to-digital converter is shown which incorporates the multi-electrode tube circuit shown in Fig. 2 excepting for the transfer circuit 26 thereof.

Thus, in Fig. 3, a voltage level will appear at the common terminal 22 in accordance with which one of the cathodes of the multi-electrode tube is in its conductive condition. A comparison circuit 46 is coupled to the terminal 22 for comparing the voltage level on the terminal with an analog voltage, the analog voltage being applied to the comparison means by way of an input circuit 48. A controllable transfer circuit 50 is coupled to the respective leads 14 and 16 which run to the auxiliary electrodes of the tube, the transfer circuit being designed to supply the necessary pulses to the auxiliary electrodes for transferring the conductive condition in the tube. The comparison circuit is coupled to the transfer circuit and, in accordance with the details of each of these circuits, the comparison circuit causes the transfer circuit to transfer the conductive condition along the plurality of cathodes in the tube until a reference voltage level is reached on the terminal 22 which most nearly approximates the voltage level of the analog voltage applied to the comparison circuit. The direction of transfer along the plurality of cathodes is determined by the comparison means in accordance with whether the present reference voltage level on the terminal 22 is greater or less than the present voltage level of the analog voltage. The result is that with every small change in the analog voltage (as determined by the design of the comparison circuit) the conductive condition in the tube will be transferred right or left to the cathode whose associated voltage output at the terminal 22 most nearly approximates the new value assumed by the analog voltage.

It can be appreciated, that the tube shown in Fig. 3 and other types of multi-electrode tubes can be made to operate at extremely high speeds, so that the digital evaluation of the analog voltage as represented by the cathode in the conductive condition follows the variations in the analog voltage closely, and is an accurate portrayal of rapid variations in the analog voltage.

In more detail, the comparison circuit 48 includes a comparator amplifier circuit 52 which is coupled to the common terminal 22 and to the analog voltage input circuit 48. The comparator amplifier circuit is of a conventional nature. It amplifies and compares the reference voltage levels with the analog voltage, and provides an output signal whose magnitude is determined by the scaled difference between these voltages and whose polarity is determined by which of the scaled voltages is greater. The output of the comparator amplifier circuit

is applied through a direct current amplifier 54 to a conventional circuit for sensing the polarity of the signal which may be called a polarity sensor 56.

The polarity sensor 56 provides a voltage on one of two output leads 58, 60 in accordance with the polarity of the comparator output. For example, a voltage on the output lead 58 may be said to represent the condition when the analog voltage exceeds the reference voltage by a predetermined amount. The voltage on the lead 58 then is used to tell the controllable transfer circuit to transfer the conductive condition in the tube to the next adjacent cathode having a higher reference voltage output.

Accordingly, the controllable transfer circuit includes a pulse generator 62 which is constantly attempting to supply pulses through each of a pair of gates 64, 66. The pulse path after passing through the gate 64 divides into two paths, one going directly through a pulse amplifier 68 onto the lead 14, and the other going through a time delay circuit 70 and through a different pulse amplifier 72 to the lead 16. The pulse path leaving the gate 66 is connected up in the opposite manner. That is, this path divides into two paths, one going through a time delay circuit 74 and through the pulse amplifier 68 to the lead 14, and the other going directly through the pulse amplifier 72 to the lead 16. The output leads 58, 60 from the polarity sensor are coupled to open the respective gates 64, 66 when a voltage is provided on the leads, the lead 58 being coupled to gate 64 and the lead 60 being coupled to gate 66 for this purpose.

Thus, for example, when the analog voltage supplied at the input circuit 48 exceeds the reference voltage by a predetermined amount on the scaled comparison in the comparator amplifier circuit, the comparator amplifier circuit provides an output signal to the polarity sensor. The polarity sensor senses the positive polarity and provides a voltage on the lead 58 to open the gate 64. A single pulse from the pulse generator 62 is then able to get through the gate 64. This pulse first appears as a negative pulse on lead 14 through the pulse amplifier 68 and later appears as a negative pulse on lead 16 through the time delay circuit 70 and pulse amplifier 72. This sequence of negative pulses causes the conductive condition in the tube to be transferred to the right onto the next adjacent higher order cathode. It can be seen that where the analog voltage is less by a predetermined amount than the reference voltage in accordance with the scaled comparison, the gate 66 will be opened which will reverse the time sequence of appearance of the negative pulses to the respective leads 14 and 16 causing the negative pulse to first appear on lead 16 which causes the conductive condition in the tube to be transferred to the left or from a higher to a lower order cathode in the tube.

As soon as this transfer to the new cathode is completed, the reference voltage level changes and will more nearly approximate the analog voltage. If equalization is achieved at this instant, the output of the comparator amplifier circuit drops to 0 causing the gate which was open to close. If, on the other hand, this first transfer was not sufficient to bring about equality, then the new voltage level on the terminal 22 will still leave the comparator amplifier circuit with an output sufficient to keep the polarity sensor energized, and the particular gate will remain open allowing a second pulse from the pulse generator 62 to cause another transfer of the conductive condition in the tube in the same direction. Of course, the pulse generator is synchronized so that it generates pulses at the proper rate precluding the possibility of two pulses getting through one of the gates or of no pulses getting through as a result of a single comparison output by the comparator amplifier circuit.

It is a simple matter to arrange the comparator amplifier circuit so it has no output unless the scaled difference between the reference and analog voltages ex-

ceeds a predetermined amount. That is, as long as the scaled reference voltage level is within a certain tolerance of being equivalent to the analog input voltage, there is no purpose in attempting to effect a transfer in the tube. If larger variety and finer spacing of reference voltages is desired, then several circuits like that shown in Fig. 2 can be coupled together in accordance with conventional practice so that one tube circuit handles a units decade of reference voltages and other circuits handle a tens decade, thousands decade, and so forth. The voltage levels at the common terminal in each of these circuits could be the same, and the scale on which they are compared with the analog voltage could be varied so that the digital significance attached to the valuations in each circuit would be of relative value in the mentioned decimal order of 1:10:100, etc. However, our concern here is with the more general aspect of describing one such circuit.

Referring now to Fig. 4, a second embodiment of the multi-electrode tube circuit of the invention is shown adapted as an analog-to-digital conversion device. In this embodiment of the invention there is no need for a current regulating type power supply in the power supply circuit 20, and an ordinary direct current supply 76 is used. The comparison and controllable transfer circuits 46, 50 are hooked up the same as before.

In Fig. 4, a plurality of diodes 78 are used to couple the cathode of the multi-electrode tube directly to ground. The circuit of Fig. 4 is like the circuit of Figs. 2 and 3 except that these diodes replace the first resistors 30 thereof. Thus, a separate diode 78 couples each cathode directly to ground with a parallel path including one of the second resistors 32 and the summing resistor 34 also coupling each cathode to ground (except for cathode No. 0 which is coupled directly to ground by one first resistor 30 as before).

The diodes used are of the type having a reversed breakdown region in which the voltage across the diodes is substantially fixed and independent of the amount of current being conducted by the diode over a wide range of current. This causes the voltage level on each separate cathode when it is in the conductive condition to be substantially independent of variations in the amount of current being conducted through the cathode. Silicon junction diodes or Zener diodes are suitable for this purpose. These diodes are designed so that a predetermined reverse voltage value will force the diode into the reverse breakdown operation region, and the effect is that it will conduct over a wide range of currents while maintaining this predetermined voltage value. Thus, each diode in effect amounts to a voltage regulating device, eliminating the need for a current regulating power supply.

In accordance with the circuit of Fig. 4, the diodes can be chosen so that they all have the same reverse breakdown characteristics in order that the voltage level on any conducting cathode will be the same predetermined value. Different reference voltage levels will then appear at the common terminal 22 in accordance with the value assigned to each of the second resistors 32 and to the summing resistor 34. The current drawn off through any of the paths to the common terminal 22 will not affect the potential of any cathode. Of course, it is possible to vary both the values of the second resistors 32 and the breakdown potentials of the diodes to achieve different reference voltage levels.

The digital value of the analog voltage may be visually determined by noticing the corresponding separate cathode of the tube upon which the glow discharge is presently settled. If a different form of digital indication is required or preferred, a digital indicating circuit may be coupled to the tube circuit for this purpose. For example, a separate electrical lead 80 may be coupled to each cathode, and the voltage levels on a plurality of leads 82 so coupled will indicate which one of the sepa-

rate electrodes is presently in its conductive condition and thus the present digital value of the analog function. In accordance with conventional practices, a suitable network may be used to couple these leads to some kind of a printing mechanism or the like for recording a permanent digital record of the variations in the analog voltage. On the other hand, it would be a conventional practice to transfer the information from these leads in coded form into a computer arrangement or some other form of data handling system. In any event, it is desirable that these leads be hooked up so that they do not affect the operating characteristics of the tube and so that the design of the analog-to-digital converter network is thereby not unduly complicated.

Fig. 5 shows a further embodiment of the invention wherein only four diodes having the reverse breakdown characteristic are needed, these being diodes 84, 86, 88 and 90. The other diodes shown in Fig. 5 are the ordinary type diodes used for blocking purposes.

The circuit of Fig. 5 is arranged in accordance with a 1—2—4—7 code and operates in the following manner: When, for example, cathode No. 3 is conducting, the current divides through blocking diodes 92 and 94. The current through diode 92 further divides across second resistor 32 and the silicon junction diode 84. The current through diode 94 divides across another of the second resistors 32' and the silicon junction diode 86. Either the reverse breakdown potentials of the diodes 84 and 86, or the values of the second resistors 32, are chosen so that the current thereby developed through summing resistor 34 is contributed to by one part through resistor 32 and by two parts through resistor 32', the total current being representative of three parts. On the other hand, when cathode No. 2 is conducting, the current passes through diode 96, then divides across the silicon junction diode 86 and the second resistor 32', the current through the summing resistor 34 then being equivalent to two parts.

Thus, when the cathode No. 2 is conducting, the voltage developed across the summing resistor 34 is two-thirds of the voltage which is developed across the summing resistor 34 when cathode No. 3 is conducting. In order to keep the silicon junction diodes 84 and 86 properly within their reverse breakdown regions of conduction, cathode No. 2 has a first resistor 30 coupling it to ground and resistors 98 and 100 are coupled respectively in series with silicon junction diodes 84 and 86. By choosing the values of the resistors 30, 98 and 100, the amounts of current conducted by the respective diodes 84 and 86 will be properly within their reverse breakdown regions when either the No. 2 or No. 3 cathode is conducting. Otherwise, diode 84 would be conducting a substantially lesser amount of current when cathode No. 3 is conducting, than this same diode would be conducting when cathode No. 2 is conducting. The explanation of the circuitry for the Nos. 2 and 3 cathodes applies analogously to the rest of the circuit.

Thus, in Fig. 5 the various cathodes of the multi-electrode tube are hooked up to four silicon junction diodes through a plurality of resistors and blocking diodes in accordance with a 1—2—4—7 code, and substantially the same operation is achieved with this circuit as was achieved with the circuit shown in Fig. 4 with a savings of five silicon junction diodes.

Referring now to Fig. 6, an embodiment of the invention is shown wherein each of the cathodes 1—9 has a first resistor 30, 30', etc. coupling it directly to ground. The values of the resistors 30, 30', etc. may all be the same so that in conjunction with the regulated current power supply the voltage on any cathode in the conductive condition is always the same. As before stated, this is not a necessary condition and in some cases it may not even be desirable, for by varying the value of the resistors 30, 30', etc. in Fig. 6, or by doing the same thing to the analogous components in the other figures,

namely the silicon junction diodes 84, 86, 88 and 90 in Fig. 5, or the silicon junction diodes 78 in Fig. 4, or the various first resistors 30 in Fig. 2; a wider range of reference voltage is afforded at the common terminal 22.

The essential feature of Fig. 6 is to show that it is not at all impossible to obtain different voltage levels at the common terminal 22 without providing different amounts of resistance coupled between the various cathodes and the common terminal. Accordingly, in Fig. 6, separate amplifiers 102, 102', etc. are coupled across the respective separate first resistors 30, 30', etc. and the amplification of these amplifiers may then be set so that without drawing any appreciable current from the tube circuit they provide different voltage levels at the common terminal 22 in accordance with the transfers of the conductive condition in the tube. Otherwise the circuit of Fig. 6 has been previously explained in conjunction with the other figures.

It is to be noted that there are many possible circuits which in accordance with the teachings of this disclosure can be provided to achieve the same purpose. However, the best circuits known for this purpose have been demonstrated in general form. It is to be understood that the circuits shown in the figures represent only basic circuits and that these circuits may be refined in accordance with conventional practice in order to achieve more excellent operation.

It is also to be understood that silicon junction type diodes and other equivalent types are ordinarily supplied with a certain tolerance in their predetermined breakdown voltage. Therefore, it is to be expected that the resistors in the circuits therefore would be adjusted in order to compensate for this.

I claim:

1. In combination with a multi-electrode tube having a common electrode and having a plurality of separate electrodes spaced proximate the common electrode, the tube being adapted to conduct electric current between the common electrode and one of the separate electrodes at a time, and means for transferring said conductive condition from one separate electrode to another, the improvement which comprises a common output terminal, circuit means coupling the separate electrodes to the common output terminal, the circuit means having different transmission characteristics between the various separate electrodes and the terminal so that different reference voltage levels appear at the terminal in accordance with transfers of the conductive condition from one separate electrode to another, and comparison means coupled to the common output terminal for comparing said reference voltage levels with an input voltage applied to the comparison means, the comparison means being coupled to the transfer means for causing the transfer means to transfer the conductive condition along the plurality of separate electrodes until a reference voltage level is reached on said terminal which most nearly approximates the voltage level of said input voltage applied to the comparison means.

2. In combination with a multi-electrode tube having a common electrode and having a plurality of separate electrodes spaced proximate the common electrode, the tube being adapted to conduct electric current between the common electrode and one of the separate electrodes at a time, the improvement which comprises controllable means for transferring said conductive condition from one separate electrode to another, a common output terminal, circuit means coupling the separate electrodes to the common output terminal, the circuit means providing different amounts of resistance between the various separate electrodes and the terminal so that different reference voltage levels appear at the terminal in accordance with transfers of the conductive condition from one separate electrode to another, and comparison means coupled to the terminal for comparing said reference voltage levels with an input voltage applied to the comparison

means, the comparison means being coupled to the controllable transfer means for causing the transfer means to transfer the conductive condition along the plurality of separate electrodes until a reference voltage level is reached on said terminal which most nearly approximates the voltage level of said input voltage applied to the comparison means, the direction of transfer along the plurality of separate electrodes being determined by the comparison means in accordance with the polarity of the voltage difference between the present reference voltage level and the present voltage level of the input voltage applied to the comparison means in accordance with the scale of comparison in the comparison means.

3. An analog-to-digital converter comprising a multi-electrode tube having a common electrode and having a plurality of separate electrodes spaced proximate the common electrode, the tube being adapted to conduct electric current as a glow discharge between the common electrode and one of the separate electrodes at a time, transfer means including a plurality of auxiliary electrodes dispersed among the separate electrodes in the tube for transferring said conductive condition from one separate electrode to another, means coupled externally of the tube between the separate electrodes and the common electrode for regulating the voltage level on the conductive separate electrodes to predetermined values, a common output terminal, circuit means coupling the separate electrodes to the common output terminal, the circuit means providing different amounts of resistance between the various separate electrodes and the terminal so that different reference voltage levels appear at the terminal in accordance with transfers of the conductive condition from one separate electrode to another, each of the different reference voltage levels being representative of a different digital value which may be visually determined by noticing the corresponding separate electrode upon which the glow discharge is settled, and comparison means coupled to the terminal for comparing said reference voltage levels with an analog voltage applied to the comparison means, the comparison means being coupled to the transfer means for causing the transfer means to transfer the conductive condition along the plurality of separate electrodes until a reference voltage level is reached on said terminal which most nearly approximates the voltage level of said analog voltage applied to the comparison means, the direction of transfer along the plurality of separate electrodes being determined by the comparison means in accordance with the polarity of the voltage difference between the present reference voltage level and the present voltage level of the analog voltage, in accordance with the scale of comparison in the comparison means.

4. Apparatus of claim 3 wherein the comparison means comprises a comparator amplifier circuit for comparing the reference voltage levels with the analog voltage and producing an output voltage of polarity dependent upon whether the reference voltage level is greater or lesser than the voltage level of the analog voltage in accordance with the scale on which these voltages are compared, and a polarity sensing circuit coupled to the comparator amplifier for providing a voltage on one of two leads in accordance with the polarity of the comparator output, and wherein the controllable transfer means comprises a plurality of auxiliary electrodes dispersed among the separate electrodes in the tube, the plurality of auxiliary electrodes being broken down into two groups with the electrodes in the first group being commonly connected to one another and with the electrodes in the second group being commonly connected to one another, first gating means coupled to the first group of electrodes, time delay means coupled between first gating means and the second group of electrodes, second gating means coupled to the second group of electrodes, time delay means coupled between the second gating means and the first group of electrodes, and pulse generator means coupled to both

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gating means for providing transfer pulses through the gating means to the auxiliary electrodes, and wherein one lead from the polarity sensing means is coupled to the first gating means and the other lead from the polarity sensing means is coupled to the second gating means for opening one of the respective gating means in accordance with the polarity of the comparator output so that pulses are provided to the respective groups of auxiliary electrodes in the proper time sequence to transfer the conductive condition in the direction along the plurality of separate electrodes which causes the reference voltage level to approach the voltage level of the analog voltage applied to the comparator amplifier.

5. A step-voltage generating circuit comprising a multi-electrode tube having a common electrode and plurality of separate electrodes, the tube including means for initiating a current conductive condition between the common electrode and any one of the plurality of separate electrodes at a time, means for transferring the conductive condition from one separate electrode to another, a summing network including a common summing resistor across which an output voltage is derived and a plurality of series resistors of weighted values respectively connecting each of the separate electrodes to one end of the summing resistor, a voltage source connected between the other end of the summing resistor and the common elec-

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trode of the tube, and means for maintaining a fixed voltage drop between each of separate electrodes when in a conductive condition and said other end of the summing resistor.

6. Apparatus as defined in claim 5 wherein said last-named means includes a plurality of shunt resistors, each shunt resistor being connected between a respective one of the separate electrodes and said other end of the summing resistor, the value of each shunt resistor being such as to provide equal resistance current paths between each of the separate electrodes and the common electrode.

7. Apparatus as defined in claim 5 wherein said last-named means includes a plurality of constant voltage regulators, each of the voltage regulators being connected between a respective one of the electrodes and said other end of the summing resistor.

References Cited in the file of this patent

UNITED STATES PATENTS

2,427,533	Overbeck	Sept. 16, 1947
2,547,008	Hough	Apr. 3, 1951
2,553,263	Loughren	May 15, 1951
2,575,517	Hagen	Nov. 20, 1951
2,743,394	Ruhlig	Apr. 24, 1956