Nov. 25, 1952 E. O. JOHNSON 2,619,622

GASEOUS ELECTRON TUBE CIRCUITS

Filed Jan. 2, 1951

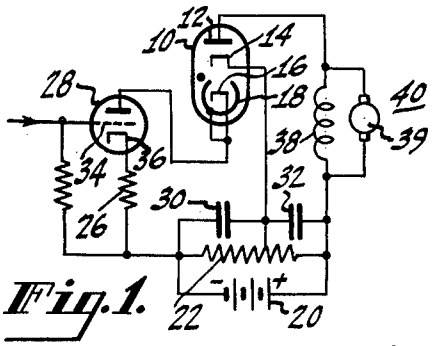


Fig. 1.

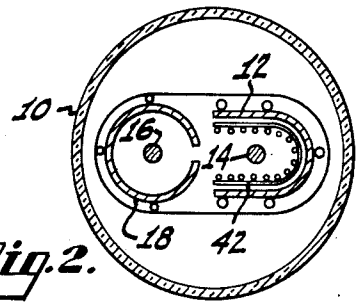


Fig. 2.

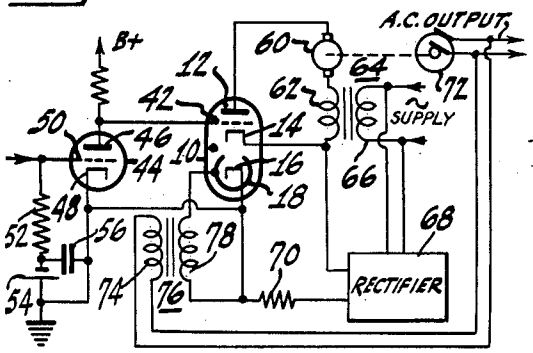


Fig. 3.

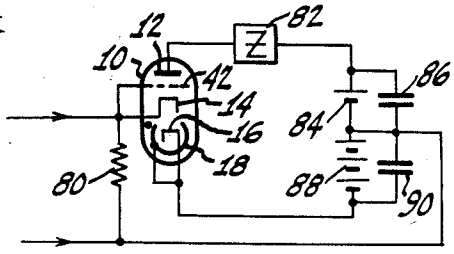


Fig. 4.

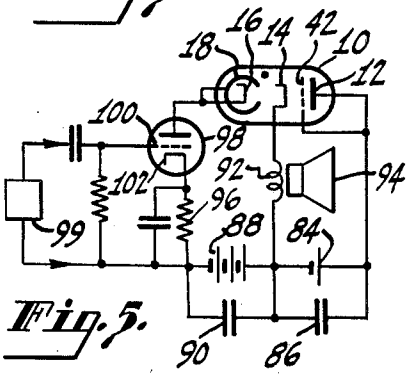


Fig. 5.

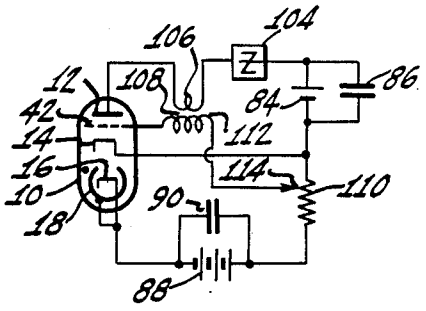


Fig. 6.

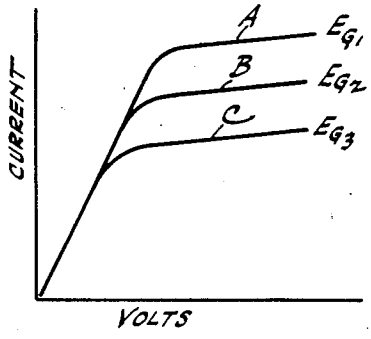


Fig. 7.

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GASEOUS ELECTRON TUBE CIRCUITS

Edward Oscar Johnson, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 2, 1951, Serial No. 203,948

15 Claims. (Cl. 318—345)

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This invention relates to electron tube circuits utilizing gaseous electron tubes, which provide continuous control of an operating characteristic, such as output current, through internal tube action. More particularly this invention relates to electron tube circuits utilizing gaseous electron tubes in which the current flowing in an ionization circuit is operative to control or to enable continuously variable control of the current in a work circuit connected with the tube.

It is well known in the electron tube art that the space charge limits the current that may flow in an evacuated electron tube and that this limitation can be overcome by providing a small quantity of gas in the tube envelope. If the potential between the electron emitting and collecting electrodes of the tube is sufficiently high, the gas becomes ionized by electron bombardment of the gas molecules, thereby developing positive ions which will neutralize the negative space charge formed by the electrons. The combined cloud of ions and electrons then act as an excellent current conductor, allowing the tube current to rise very rapidly until the full electron emitting capacity of the electron emitter electrode is attained.

While the phenomenon briefly described above has considerable utility, there are several characteristics of gas-filled tubes which heretofore have imposed limitations on their use.

In order to ionize the gas in the tube, a certain minimum voltage is required, as determined by the tube geometry and the type of gas used. Briefly, this is due to the fact that a certain amount of energy must be imparted to an atom or molecule in order to cause an electron to be liberated from the energy confines of the atom or molecule. In the case of a gas tube, this means that the bombarding electrons must be given a certain minimum velocity so as to provide sufficient energy to cause and sustain the electron liberation or ionization of the tube gas. To give these ionizing or bombarding electrons this minimum velocity, a corresponding minimum potential or "arc drop" must be maintained between an electron emitter electrode and an electron collector electrode immersed in the gas. In conventional gas tube systems, this arc drop is a minimum potential which is unproductive where a principal objective is to transfer potential from a source to a load with the least possible loss in the system.

The effective and efficient control of the gas tube current is another problem in conventional

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gas tubes. In a conventional vacuum tube, a control electrode placed between the electron emitting and electron collecting electrodes provides a very efficient and effective means for controlling the tube current. A very small change in the control electrode potential will have a relatively large effect on the output circuit of the tube, as is well known, it being possible to vary the tube current smoothly and continuously within relatively wide limits by varying the control electrode potential.

The above described mechanism of gas tubes has been under study for many years in an effort to provide a tube capable of a large work or output circuit current while enabling continuous variable control of the tube by internal tube action.

Various systems of control have been devised, among which is one providing for the use of velocity modulation of a plasma generating electron stream and having a temperature controlled cathode. This system is disclosed in U. S. Patent 2,213,551, issued to H. Nelson, September 3, 1940, for Electron Discharge Device. Nelson clearly discloses that the total current in his control circuit remains constant and that a temperature controlled cathode is used as a current limiting device. Such a system is linear for only small changes in voltage and is subject to distortion due to temperature variation.

U. S. Patent 2,034,571, issued March 17, 1936, to C. G. Found for Electrical Discharge Device and Method of Operating Same, provides another type of gaseous electron tube utilizing an additional pair of electrodes to provide a plasma generating circuit. However, here again due to the inherent limitations of the system the grid control usually attributed to vacuum tubes cannot be attained.

In a copending application of E. O. Johnson, Serial No. 185,745, filed September 20, 1950, and assigned to the assignee of the present invention, there is described and claimed a gaseous electron tube capable of continuous grid control action. As pointed out in greater detail in that application, the usual loss of grid control in a gaseous electron tube upon ionization is avoided by providing separate paths for the ionization currents and the load currents and by providing in the work circuit a potential lower than that required to produce ionization. Because the potential available in the load circuit is insufficient to produce ionization, an auxiliary source of ionization potential is provided to fill this need and since only this source is energized with a

sufficiently large potential to produce ions it is unaffected by signal variations in the form of either changes in the potential of the control grid or changes in the load currents which are produced thereby.

Accordingly, it is an object of this invention to provide circuit means for operating gaseous electron tubes of the type providing effective grid control action as shown, described and claimed in the aforesaid pending application.

It is another object of this invention to provide circuits capable of enabling maximum utilization of continuously variable grid controlled gaseous electron tubes of the type referred to for the control of electrical energy flowing in associated work circuits and the like.

It is a further object of this invention to provide circuit means in which small current variations in a control circuit are utilized to control continuously by means of gaseous electron tubes, relatively large amounts of current or power in a load circuit.

It is an ancillary object of this invention to provide means for applying control signals to a gaseous electron tube and for connecting a load circuit to the gaseous electron tube in such a manner as to enable multi-signal control of a single load circuit through the single gaseous electron tube means.

In accordance with the present invention, there is provided circuit means which may be connected between any two of several electrodes of a gaseous electron tube of the type capable of providing continuously variable control, by means of resistor-capacitor coupling, transformer coupling or other forms of coupling to provide in a load circuit of the tube, an output signal which is directly proportional to a control signal applied between any two of said electrodes, or which may be proportional to the relative phase and magnitude of the various applied signal potentials.

A further understanding of the invention may be had by reference to the following description of certain illustrative embodiments thereof when considered in connection with the accompanying drawing, in which:

Figure 1 is a schematic circuit diagram illustrating one embodiment of the invention wherein a gaseous electron tube is utilized to control a motor circuit;

Figure 2 is a view in cross section of a gaseous electron tube as utilized in control circuits embodying the invention;

Figure 3 is a schematic circuit diagram illustrating a further embodiment of the invention, wherein a gaseous electron tube is utilized to control the phase and magnitude of a generated alternating-current voltage in accordance with certain characteristics of control potentials or signals from a plurality of control sources;

Figure 4 is a schematic circuit diagram illustrating a still further embodiment of the invention, wherein two elements of a gaseous electron tube are utilized to control an anode output or work circuit;

Figure 5 is a schematic circuit diagram illustrating another embodiment of the invention, wherein a gaseous electron tube is utilized as a cathode-coupled device to directly drive the voice coil of a transducer element;

Figure 6 is a schematic circuit diagram illustrating still another embodiment of the invention, wherein a gaseous grid-controlled electron tube is utilized as a current regulator and wherein negative feedback is applied from an anode circuit to a grid circuit to establish more uniform control; and

Figure 7 is a graph showing curves illustrating the relationship between the current and the voltage of the load circuit of an electron tube adapted for use in a circuit embodying the invention, with different applied control-grid potentials.

Referring to the drawing in which the reference characters designate like parts and circuit elements throughout the various figures, and referring now particularly to Figure 1, there is illustrated a gaseous electron tube 10 having an anode 12, a main cathode 14, an auxiliary cathode 16 and a shield 18 for the auxiliary cathode. The anode 12 and the main cathode 14 provide a diode section through which load currents can be passed in the manner of a conventional gas diode. The auxiliary cathode 16 is an additional electron emitting electrode which cooperates with the anode 12 and main cathode 14 to provide a separate circuit within the tube envelope for ionization of the tube gas. In order to provide operating potentials for the tube 10 a source of direct-current potential or battery 20 is connected across a voltage divider resistor 22. An intermediate tap 24 on the resistor 22 is connected to the main cathode 14 and the negative potential end of the resistor 22 is connected through a cathode resistor 26 and the space path of an electron tube 28, to the auxiliary cathode 16, thereby providing between the main cathode 14 and the auxiliary cathode 16 a sufficiently high potential to cause ionization of the tube gas. A pair of bypass capacitors 30 and 32 are connected across the respective sections of the voltage divider resistor to prevent signal currents from affecting the level of the potential available.

The electron tube 28 is utilized as a signal input device to effectively modulate the ionization current which will be drawn between the auxiliary cathode 16 and the main cathode 14 of the gaseous electron tube 10. It is, of course, believed to be obvious that the modulation control established by the electron tube 28 can also be provided by other coupling means such as a transformer or a fixed or variable resistor, and that an electron tube is shown merely for illustrative purposes as a presently preferred means. In the embodiment shown, an input signal is applied between the control grid 34 and the cathode 36 of the electron tube 28 to vary the impedance of the space path, thus producing between the auxiliary cathode 16 and the main cathode 14 voltage variations which are reflected by corresponding changes in the ionization current of the tube 10.

The load circuit is completed, as shown in Figure 1, by connecting the field winding 38 and armature 39 of a shunt-connected direct-current motor 40 between the anode 12 of tube 10 and the battery 20, being connected in the present example to the high potential or positive terminal of the voltage divider resistor 22. It should be noted that the potential available in the load circuit, that is, the potential available between the high potential end of the resistor 22 and the intermediate tap 24 is less than that required to cause ionization of the gas in the gas tube 10.

When a gaseous electron tube, as shown, described and claimed in the above-identified copending application by E. O. Johnson, and which the tube 10 represents, is connected in this man-

ner, ionization or breakdown of the gas occurs between the auxiliary cathode 16 and the main cathode 14 of tube 10. There is thus provided within the tube envelope, a plasma which acts as an excellent conductor to provide, in effect, a low resistance connection between the main cathode 14 and the anode 12 of the tube 10. Since, as is well known in the art, the density of the plasma generated in the tube will be controlled, at least in part, by the amount of current flowing through the ionization circuit, the effective resistance between the main cathode 14 and the anode 12 of the tube 10 can be effectively controlled by externally controlling the current flow in the ionization circuit. In the embodiment shown in Figure 1 this ionization current control is provided by signal or control potentials applied by means of the electron tube 28.

In a gaseous electron tube of the type utilized, the conductivity between the main cathode 14 and the anode 12 of the tube 10 is a function of the density of the plasma existing within the tube envelope. Accordingly, it is seen that since the ionization current flowing between the auxiliary cathode 16 and the main cathode 14 is effective to control the plasma density any change in ionization current causes a change in the conductivity between the anode 12 and the main cathode 14 of the tube 10. A change in the conductivity thus produced is effective to cause a resulting change in the current flowing in the load circuit which, as shown in Figure 1, is connected between the anode 12 and the main cathode 14 of the tube 10.

The characteristics of the type of gaseous electron tube utilized are such that a relatively small change in the ionization current is effective to produce in the load circuit a relatively large current charge. There has, therefore, been provided a circuit wherein load currents of large proportions which may be dangerous to operating personnel, can successfully and continuously be controlled to any degree through the use of low potential and current.

Referring now to Figure 2 of the drawing, a view in cross section of one form of the gaseous electron tube 10 of Figure 1, that may be utilized in the circuits of the present invention, is shown by way of example. Within the tube envelope, a U-shaped anode 12 of sheet metal is disposed external to and in juxtaposition with a control grid 42 of relatively coarse spacing. The main cathode 14 is mounted within and is partially surrounded by the control grid 42 and the anode 12. The auxiliary cathode 16 is mounted coaxially with respect to a slotted cylindrical shield 18. Thus the tube 10 may be provided with a control grid 42 interposed between the main anode 12 and the main cathode 14.

As shown in Figure 2, the elongated narrow slot in the shield 18 is positioned with its center extending along a plane passing through the axes of the auxiliary and main cathodes 14 and 16. It has been found that the desired degree of ionization may thus be attained with a considerable reduction in the power required to sustain ionization.

The schematic circuit diagram illustrated in Figure 3 of the drawing, to which attention is now directed, shows an embodiment of the invention wherein the load circuit is controllable by a plurality of control potentials or signals in connection with the tube of Figure 2. A first control signal is coupled to tube 10 by means of a conventional vacuum tube 44 having an anode 46 connected to the control grid 42 of tube 10 and a cathode 48 connected to the auxiliary cathode 16 of tube 10. Control signals or potentials may be applied between the control grid 50 and the cathode 48 of the control tube 44 from any suitable source (not shown). A grid resistor 52 and a bias battery 54 connected in series arrangement between the control grid 50 of the control tube 44 and a point of fixed reference potential or ground provide the necessary grid bias for the control tube 44. Signal currents are prevented from affecting the bias battery 54 by a by-pass capacitor 56 which is connected in shunt with the bias battery 54. Energizing potential is applied to the anode 46 of the control tube 44 through an anode resistor from B+ which represents the positive terminal of a source of energizing potential (not shown).

When signal voltages are impressed between the control grid 50 and the cathode 48 of the control tube 44, an amplified signal voltage appears between the control grid 42 and the auxiliary cathode 16 of tube 10. As will be more fully discussed subsequently this signal voltage is effective to produce a change in the conductivity between the cathode 14 and the anode 12 of the tube 10.

The load circuit of the tube 10 comprises a direct-current motor 60 and the secondary winding 62 of an alternating current power transformer 64 which are connected in series between the anode 12 and the main cathode 14 of the tube 10.

The direct-current motor 60 in the load circuit of the tube 10 is mechanically coupled with an alternating-current generator 72 having an output current and voltage which is controllable by controlling the motor 60. In order to provide a control signal which will be in accordance with the output of the alternating-current generator 72, the output circuit of the generator 72 is coupled to the primary winding 74 of a coupling transformer 76. The secondary winding 78 of the coupling transformer 76 is connected between the auxiliary cathode 16 and the shield 18 of the tube 10. There is thereby impressed between the auxiliary cathode 16 and the shield 18 of the tube 10 a signal voltage which is representative in phase and magnitude of the output voltage and current of the alternating-current generator 72.

Three distinct control signals are, therefore, coupled to the various circuits of the gas tube 10 illustrated in Figure 3 of the drawing; the signal coupled between the control grid 42 and the auxiliary cathode 16 by means of the control tube 44, the signal coupled to the load circuit by means of the power transformer 64 and the signal coupled between the shield 18 and the auxiliary cathode by means of the coupling transformer 76. The characteristics of the tube 10 are such that once breakdown or ionization has been caused by the application of potential between the main cathode 14 and the auxiliary cathode 16 the current flowing between the main cathode 14 and anode 12 will be directly proportional to the relative phase and magnitude of the potentials applied between any two of the tube electrodes. Accordingly, it is seen that the load current in the schematic circuit diagram shown in Figure 3 of the drawing will be proportional to the relative phase and magnitude of the source of alternating current, the alternating-current output of the generator 72 and the separate signal supplied through the control tube 44.

There has thus been provided a simple circuit in which the output current and voltage of a

generator 72 is automatically controlled in accordance with the source of power driving the generator and the output current and voltage of the generator itself. Additionally, a distinct and separate control facility is provided to allow an operator to make any adjustments or changes that might be necessary without having to come in contact with the high power load circuit, through control of the potentials or signals applied through the coupling tube 44.

In the schematic circuit diagram of Figure 4, illustrating a further embodiment of the invention, a resistor 80 representing any suitable coupling impedance means, which is common to both the load circuit and the ionization circuit, such as a coupling transformer or an electron tube, is utilized as the input impedance to control the current through the load circuit of the tube 10. The tube 10 may, as indicated, be identical with that illustrated in Figures 2 and 3 of the drawing. The load circuit in this instance is an impedance indicated by the rectangle 82 which is connected in series with a first source of direct-current potential or battery 84 and the input resistor 80, to the main cathode 14, thereby completing the circuit between the anode 12 and the main cathode 14. A signal bypass capacitor 86 is connected in shunt with the battery 84 in order to insure that the level of potential is unaffected by variations in the signal level.

In order to complete the ionizing circuit for the gaseous electron tube 10, a second source of direct-current potential or battery 88 is connected between the common terminal of the first battery 84 and the input resistor 80 and the auxiliary cathode 16 of the tube 10. As in the first instance, this second potential source 88 also is shunted by a signal current bypass capacitor 90. As the control grid 42 is not utilized for control purposes in this arrangement, it is shown as connected directly to the main cathode 14, although alternatively it may be connected to other suitable points in the circuit such as directly to the anode 12, to serve the same purpose.

As above discussed, the second potential source 88 provides sufficient potential to cause ionization of the gas in the tube 10. It is further noted that under normal operating conditions the first potential source 84 would normally provide a potential which is less than that required to cause ionization. However, it is within the purview of the present invention that the first source 84 may under certain conditions, provide a potential exceeding that which is required to cause ionization of the gas. Under these circumstances, that is, with the first source 84 providing sufficient potential to cause ionization, breakdown could occur between the main cathode 14 and the anode 12 of the tube 10. It is to be noted that immediately upon this occurrence the ionization circuit comprising the main cathode 14 and the auxiliary cathode 16 would assume the function of providing plasma within the tube envelope and the potential drop existing between the main cathode 14 and the anode 12 of the tube 10 would immediately fall to a potential in the order of $\frac{1}{10}$ of a volt which, of course, is insufficient to maintain ionization between these two electrodes.

There is thus provided an arrangement wherein the input signal voltage is effectively coupled in the main cathode circuit of the tube 10. This type of coupling is generally referred to as cathode coupling. However, it is to be noted that since the resistor 80 is a part of the ionization circuit connected between the main cathode 14 and the auxiliary cathode 16, signal voltages applied to the resistor 80 will produce a corresponding change in the ionizing current, which as above discussed in connection with Figure 1 will be effective to control the current flowing in the load circuit.

The schematic circuit diagram shown in Figure 5 is illustrative of a further embodiment of the invention wherein a gaseous electron tube 10, identical with the tube 10 of Figures 2, 3 and 4, is utilized to directly drive the voice coil 92 of a transducer device 94 such as a loudspeaker. The load circuit of the tube 10 comprises a first battery or operating potential source 84 which is connected between the anode 12, tube 10 and one side of the voice coil 92. The load circuit is completed by directly connecting the other side of the voice coil 92 to the cathode 14 of the tube 10. As above discussed in connection with Figure 4, the control grid 42, which is not utilized for control purposes in this circuit, is directly connected to the anode 12 of tube 10. There is provided as discussed in connection with Figure 4, a signal bypass capacitor 86 which is connected in shunt with the first battery 84. It is seen, therefore, that the work circuit actually consists of an output circuit commonly referred to as being cathode coupled. In other words, the output impedance, which consists of the voice coil 92 is connected between the cathode and the negative side of the source 84.

The ionization circuit for the tube 10 comprises a second or potential souce 88, having a shunt-connected bypass capacitor 90, connected in series with a cathode resistor 96 and the space path of an electron coupling tube 98 between the common terminal of the voice coil 92 and the auxiliary cathode 16 of the tube 10. Input signals are applied to this circuit by coupling the output of an amplifier, phonograph, or other source 99 of signal, between the control grid 100 and the cathode 102 of the electron coupling tube 98. Input signals thus applied produce potential variations in the ionizing circuit which, as above discussed in connection with Figure 1, are effective to modulate the current flowing in the load circuit of the tube 10. It has been observed that the relationship between input signal voltages and output signal voltages obtainable from a circuit as shown in Figure 5 arranged in this manner is substantially linear throughout the entire working range.

The low impedance obtainable in the type of gaseous electron tube as utilized by the present invention provides excellent coupling to such low impedance load devices as loudspeakers. It has long been a problem in the audio frequency field to provide an output circuit for an amplifier capable of low impedance and low distortion. Output transformers which are generally required as coupling devices between the high impedance anode circuit of an electron tube and the low impedance voice coil of a loudspeaker frequently limit the quality obtainable in an audio frequency circuit. The circuit shown in Figure 5 obviates these problems by providing a low impedance, substantially linear coupling circuit without the use of coupling transformer.

In view of the high current capabilities and the particular characteristics of the triode section of the gaseous electron tubes utilized by the present invention, these tubes provide excellent control for current regulator systems. Such a

system is illustrated in Figure 6 of the drawing. In a regulator of this type, the general problem to be overcome is the variation in the current available at a load under different load conditions. In the embodiment illustrated in Figure 6, the source of current to be regulated is shown as a battery 84 which is connected in series with a load impedance, indicated by the rectangle 104, and the primary winding 106 of a feedback transformer 108 between the anode 12 and the main cathode 14 of a tube 10. The ionizing circuit for the tube 10 comprises a potentiometer 110 which is connected in series arrangement with a second battery or potential source 88 between the main cathode 14 and the auxiliary cathode 16 of the tube 10. A bypass capacitor 90 is connected in shunt with the second battery 88 to prevent signal variations from affecting the source of potential. Control potentials for the control grid 42 of the tube 10 are provided by connecting the control grid 42 of the tube 10 through the secondary winding 112 of the feedback transformer 108 to a variable tap 114 on the potentiometer 110.

An examination of the curves shown on the graph illustrated in Figure 7 of the drawing may now be referred to for a further understanding of the operation of the present embodiment of the invention as illustrated in Figure 6 of the drawing. The magnitude of the voltage source is represented by the ordinate of the graph and the currant to be regulated is illustrated as the abscissa. Three distinct curves A, B and C are illustrated which represent respectively different grid bias potentials, curve A representing the least potential and curve C representing the greatest potential of the applied control grid bias potentials. It is noted that in each instance the curve rises with a substantially constant slope to a knee which is determined by the magnitude of the grid bias potential. After passing the knee, each of the curves A, B and C represents a substantially constant current. However, without the feedback transformer 108 the slope of portion of the curve above the knee may vary by as much as 5 per cent. It, therefore, appears to be obvious that if the circuit is operated beyond the knee of the curve any variations in load will not be reflected by variations in the current flowing in the circuit.

This result is obtained due to the fact that the current flowing in the work circuit is controlled by two separate factors. One of these factors being the plasma density existing in the tube and the other being the control grid bias potential existing between the control grid 42 and the main cathode 14 of the tube 10. If a greater current starts to flow in the load circuit, a representative voltage will be transferred to the grid circuit by means of the feedback transformer 108 which will cause an increase in the negative grid bias potential, thereby tending to reduce the amount of current flowing in the load circuit.

There will also be a tendency to increase the current in the ionization circuit which will also produce a greater negative grid bias potential which will be applied to the control grid 140 and act to reduce the current flow in the load circuit. It, therefore, appears to be obvious that the combined action of inverse voltage feedback and the increase in applied grid control potential through the increase in plasma density will provide adequate control to establish constant current in the load circuit.

The operation of the above discussed embodiments of the invention are based upon the utilization of a gaseous electron tube 10 in which the functions of providing ionization needed for space change neutralization and providing the field needed for drawing the required work current have been separated. In a gaseous electron tube of this type it has been found as illustrated in Figure 3 of the drawing, that voltage variations or input signals when applied between any two of the electrodes in the gaseous electron tube will produce in the load or output circuit a current and/or voltage variation representative of the applied signal variations. It has been found that a current of a few milliamperes flowing in the ionization circuit can be made to modulate and control a current of relatively heavy amperage in a work circuit.

In the embodiment of the invention illustrated in Figure 1 this control facility has been utilized to control the current through the shunt field 38 of the direct-current motor 40. Generally, control of this type requires the handling of excessively large currents. However, the combination provided by the present invention permits a conventional electron tube 28 having a grid control circuit which may be varied by small voltages to be utilized to control the very large currents circulating through the load circuit.

In the embodiment illustrated in Figure 3 of the drawing a gaseous electron tube 10 capable of continuous grid control action is utilized to provide control of a work circuit from a plurality of control sources. A first control signal is applied between the control grid 42 and the shield 18, a second control signal is applied between the shield 18 and the auxiliary cathode 16 and a third control signal is applied between the anode 12 and the main cathode 14 of the gaseous electron tube 10. Thus the single load circuit of such a tube may be controlled in accordance with two or more applied signal voltages by applying them between any two of the tube electrodes.

Cathode coupling as an input circuit as shown in Figure 4 and as an output circuit as shown in Figure 5 of the drawing, provides further flexibility for the utilization of the gaseous electron tube 10. The substantially linear control provided by the ionization circuit provides an excellent circuit to control and drive a loudspeaker 94 when it is coupled to the cathode 14 of the triode section of the gaseous electron tube 10. It has been found that the characteristic of this type of gaseous electron tube are sufficiently linear to provide substantially distortionless output when utilized in any of the illustrated embodiments.

There has further been illustrated, as in Figure 6 of the drawing, that the large current capabilities of such a gaseous electron tube and the combined factor of continuous grid control of the load circuit can be utilized to provide an excellent current regulating device. It is, of course, obvious that such a gaseous electron tube could also be utilized in a voltage regulator system wherein a shunt current regulator is connected to establish substantially constant current through resistor to provide a constant voltage at a load under varying load conditions.

Accordingly, there has been shown that the aforesaid type of gaseous electron tube can be utilized efficiently and effectively under various circuit conditions where grid control action is desirable to control high current circuits by

means of low current or low potential control signals. Further, it has been shown that such a device may be utilized as a form of mixing circuit wherein the application of two or more control signals may be utilized to provide in a load circuit a voltage or current which is representative of the relative magnitude or phase of the applied control signal.

What is claimed is:

1. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode and an auxiliary cathode for passing ionizing current through the space path of the tube, and a shield electrode in proximity with said auxiliary cathode, in combination, an output circuit including a first source of energizing potential connected between said anode and another one of said electrodes, an input circuit coupled between said main cathode and one of said other electrodes, and a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas, said last named source being connected between said main cathode and said auxiliary cathode.

2. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, a control grid between said anode and main cathode, an auxiliary cathode for passing ionizing current through the tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, an output circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas and connected between said anode and another one of said electrodes, and a control circuit connected between said main cathode and said auxiliary cathode and including a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of the tube gas.

3. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, a control grid disposed between said anode and main cathode, an auxiliary cathode for passing ionizing current through the tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, an output circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas connected between said anode and another of said electrodes, an input grid control circuit connected between said control grid and said auxiliary cathode, and a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas and being connected between said main cathode and said auxiliary cathode.

4. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a control grid, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, an output circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas connected between said anode and another of said electrodes, input impedance means connected between said shield electrode and said auxiliary cathode, and a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas and being connected between said main cathode and said auxiliary cathode.

5. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a control grid, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, an output circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas connected between said anode and another of said electrodes, input impedance means connected between said shield electrode and said auxiliary cathode, means for applying a control current through said input impedance means, and a load impedance in said output circuit for deriving a current therefrom.

6. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, an output circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas and connected between said anode and another of said electrodes, an input circuit coupled between said main cathode and another of said electrodes, an impedance connected in common with said main cathode and each of said anode and said auxiliary cathode, and a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas and being connected between said main cathode and said auxiliary cathode.

7. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, an output circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas and connected between said anode and another of said electrodes, said output circuit further including a load impedance, an input circuit connected between two of said electrodes, impedance means connected in common with said main cathode and each of said anode and said auxiliary cathode, a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas and being connected between said main cathode and said auxiliary cathode, and signal input means for applying through said impedance means a control signal to said tube to control the current flow in said load impedance.

8. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, a control grid between said main cathode and anode an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, a work circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas connected and between said anode

and another of said electrodes and for supplying work current through the space path of the tube, said work circuit further including a load impedance, an input circuit comprising a variable impedance device connected between said control grid and said auxiliary cathode to control the current flow in said work circuit, and a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas and being connected between said main cathode and said auxiliary cathode.

9. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, a control grid between said main cathode and anode an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas and connected between said anode and another of said electrodes, an input circuit coupled between said main cathode and one of said other electrodes, impedance means connected in common with said main cathode and each of said anode and said auxiliary cathode, and a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas and being connected between said main cathode and said auxiliary cathode.

10. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, a control grid between said main cathode and anode an auxiliary cathode for passing ionizing current through the tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, a work circuit including a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas and connected between said anode and another of said electrodes said work circuit further including a load impedance of high current passing capability, a control circuit connected between said main cathode and said auxiliary cathode and including a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas, and an input grid control circuit including an impedance means connected between said control grid and said auxiliary cathode.

11. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a control grid, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, a work circuit and a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gasfi said work circuit being connected between said anode and another of said electrodes, a control circuit connected between said main cathode and said auxiliary cathode and including a second source of energizing potential capable of delivering a potential greater than that required to cause ionization o fsaid tube gas, and an input impedance connected between said shield electrode and said auxiliary cathode.

12. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a control grid, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, a work circuit connected between said anode and said main cathode and including a first source of energizing potential, said work circuit further including an output impedance of high current carrying capabilities, impedance means connected in common with said main cathode and each of said anode and said auxiliary cathode to control the work circuit current, and a control circuit connected between said main cathode and said auxiliary cathode and including a second source of energizing potential capable of providing a potential greater than that required to cause ionization of said tube gas.

13. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiilary cathode, in combination, a work circuit and a first source of energizing potential capable of providing a potential less than that required to ionize the tube gas, said work circuit being connected between said anode and another of said main cathode, a control circuit connected between said main cathode and said auxiliary cathode, said control circuit including a variable impedance for controlling the work circuit current and further including a second source of energizing potential capable of providing a potential greater than that required to cause ionization of said tube gas, whereby current in the order of milliamperes in the control circuit is effective to control a relatively greater current in flowing in the work circuit.

14. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a control grid, a main cathode, an auxiliary cathode for passing ionizing current through said tube gas and a shield electrode in proximity with said auxiliary cathode, in combination, a loudspeaker voice coil and a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas, said voice coil and said first source of potential being connected between said anode and said main cathode, a control circuit connected between said main cathode and said auxiliary cathode, said control circuit including a variable impedance means and a second source of energizing potential capable of delivering a potential greater than that required to cause ionization of said tube gas, whereby current through said voice coil is controlled in accordance with variations of said variable impedance.

15. In a system for operating a gas filled electron tube of the type having a plurality of electrodes including an anode, a control grid, a main cathode, an auxiliary cathode for passing ionizing current through the tube gas and a shield electrode in proximity with said auxiliary cathode in combination, a work circuit including an electric motor and a first source of energizing potential capable of delivering a potential less than that required to ionize the tube gas, said work circuit being connected between said anode and another of said electrodes, a control circuit connected between said main cathode and said auxiliary cathode, said control circuit including a first variable impedance means and further including a second source of energizing potential capable of delivering a potential greater than that required

to cause ionization of the tube gas, an input grid control circuit comprising an electron tube connected between said control grid and said auxiliary cathode, an input transformer connected between said shield electrode and said auxiliary cathode, and a second variable impedance connected in common with said main cathode and each of said anode and said auxiliary cathode, whereby current flowing in the work circuit is proportional to the relative adjustments of the control circuits.

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