Nov. 25, 1952 L. MALTER 2,619,593

PULSE ENERGIZED GAS TUBE CIRCUITS

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Fig. 1.

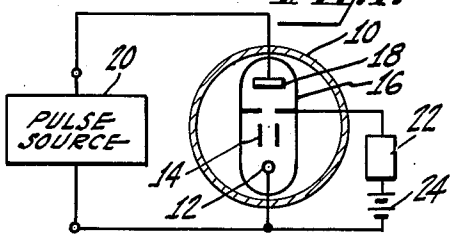


Fig. 1a.

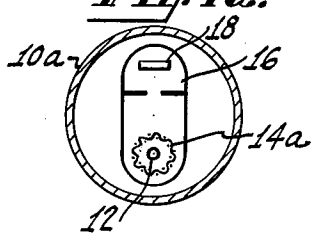


Fig. 2.

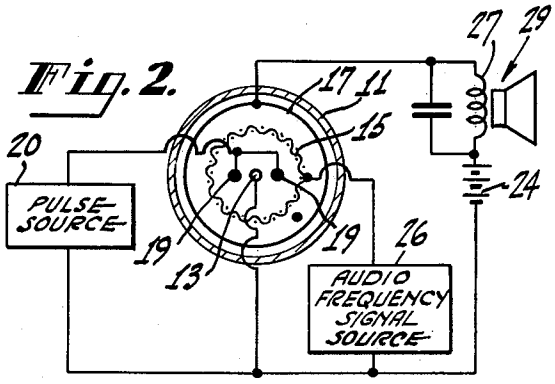


Fig. 3.

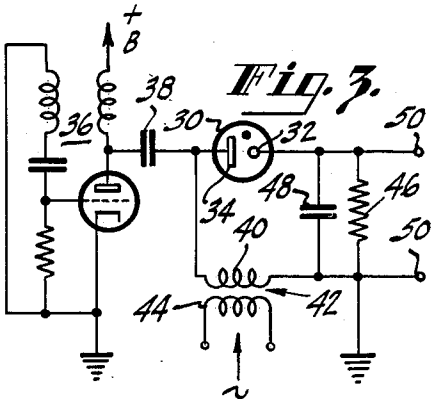
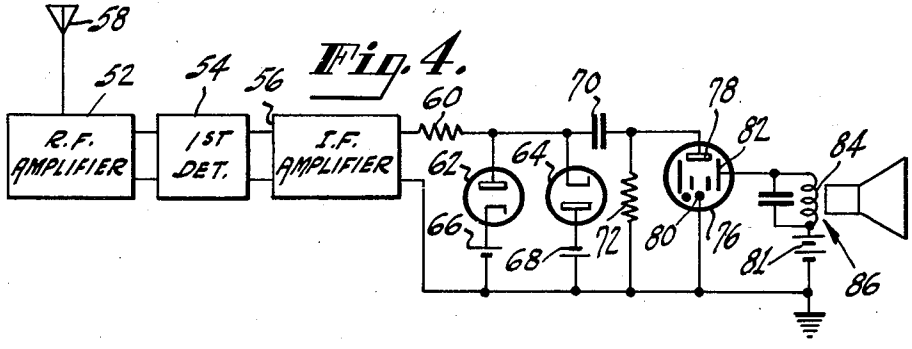


Fig. 4.



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PULSE ENERGIZED GAS TUBE CIRCUITS

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Application January 2, 1951, Serial No. 203,923

14 Claims. (Cl. 250—27)

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This invention relates to improvements in gaseous electron tube systems, and particularly to an improved method of and apparatus for operating gaseous electron tubes.

It is well known in the electron tube art that the limiting effect of space charge on the current that will flow in an evacuated tube can be overcome by adding a small quantity of gas to the tube, and ionizing the gas. If a sufficiently high voltage is applied between the emitting and collecting electrodes in the tube, the gas will be ionized by electron bombardment of the gas molecules, thereby developing positive ions which will neutralize the negative space charge of the electrons. The combined cloud or "plasma" of ions and electrons will act as an excellent conductor, allowing the tube current to rise very rapidly until the full electron emitting capacity of the emitter is being utilized.

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

For one thing, a certain minimum voltage is required to ionize the gas in the tube. That is, in general, a certain amount of energy must be given to an atom or molecule in order to remove an electron therefrom. In the case of a gas tube, this means that the ionizing (bombarding) electrons must be given a certain minimum velocity to sustain ionization. To give the ionizing 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 wasted in any case where a principal objective is to transfer voltage from a source to a load with the least possible voltage loss in the transfer circuit.

Another difficulty is the problem of controlling gas tube current efficiently. In a conventional vacuum tube, a control electrode placed between the emitting and collecting electrodes provides a very efficient means of controlling the tube current. A very small change in the control electrode voltage will have a relatively large effect on tube current, it being possible to vary the tube current smoothly and continuously within relatively wide limits simply by varying the control electrode voltage.

In the case of the conventional gas tube, however, a somewhat different situation exists. It is found that a control electrode in a conventionally operated gas tube has only a "trigger" type control action. The proper amount of negative voltage on such control electrode will prevent tube current from flowing, and tube current flow can be started by a suitable decrease in the negative control electrode voltage. However, once the conventionally operated gas tube begins to conduct current, the control electrode loses practically all control, and the tube current becomes substantially independent of the control electrode voltage.

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In a copending application of E. O. Johnson, Serial No. 185,745, filed September 20, 1950, assigned to the assignee of the present invention, there is described a gaseous electron tube system in which a space charge neutralizing plasma is generated by an auxiliary ionizing discharge of electrons. In said copending Johnson application, a system is described wherein an auxiliary emitter electrode provides the ionizing current. With this arrangement, two very important advantages are attained.

First, it is found that very high current can be passed between the main emitter and collector electrodes at potentials far below those required to ionize the gas. Second, it is found that the current flow between main emitter and collector can be controlled in various ways, one of which is by means of a control electrode similar to that used in the conventional vacuum tube.

While gas tube systems of the type just described have many useful and important applications, it has been found that random oscillatory voltages originate in the plasma when the latter is maintained by a continuous auxiliary discharge. In some instances, the effect of these oscillatory voltages on the main tube current is objectionable, particularly in the case where the gas tube used has only one emitter electrode.

It is a general object of the present invention to provide an improved method of and apparatus for operating gaseous electron tubes.

A more specific object of the invention is the provision of a method of and apparatus for operating a gaseous electron tube under conditions such that relatively high current can be passed through the tube at a voltage lower than the arc drop required to sustain ionization of the gas in the tube.

A further object of the invention is the provision of a method of and apparatus for operating a gaseous electron tube in such a way that the principal tube current can be controlled in a simple and efficient manner.

Another object of the invention is the provision of an improved method of and apparatus for separating the functions of gas ionization and high current discharge in a gaseous electron tube

system in a manner such that a substantially "noiseless" current can be drawn through the gas tube.

In accordance with the invention, the foregoing and other related objects and advantages are attained in a method and system wherein space charge neutralizing ions are generated in a single emitter gas tube in spaced "bursts" by applying suitable voltage pulses between the emitter and another tube electrode. The plasma so created will conduct very high, substantially noiseless currents at voltages considerably below the gas ionizing potential. Furthermore, this current can be substantially continuously controlled in a number of different ways as, for example, by means of a control electrode.

A more complete understanding of the invention can be had by reference to the following description of illustrative embodiments thereof, when considered in connection with the accompanying drawing, wherein:

Fig. 1 is a schematic diagram of a gaseous electron tube circuit illustrating the general principles of the invention,

Fig. 1*a* is a sectional view of a modified form of gas tube,

Fig. 2 is a schematic diagram of a grid-controlled gas tube system arranged in accordance with the invention,

Fig. 3 is a schematic diagram of a gas tube rectifier system arranged in accordance with the invention, and

Fig. 4 is a schematic diagram illustrating application of the principles of the invention to a frequency modulated wave detection system.

As was previously stated, an ordinary gas tube operated in the conventional manner does not have as much utility as might be expected. Consider, for example, the gas tetrode tube **10** shown in Fig. 1. This tube, which may be a commercial type 2050 tube for example, has an electron emitter or cathode **12**, usually heated by a filament (not shown), a control electrode **14**, a shield electrode **16**, and a collector electrode or anode **18**.

In the usual case, the anode **18** would be connected to the cathode **12** through a work circuit including a load device and a source of voltage at least equal to and usually greater than the arc drop required to sustain ionization of the tube gas. The shield electrode **16** usually would be operated at the same voltage as the cathode **12**. The control electrode **14** normally would be at a potential sufficiently negative to keep the tube cut off, and the tube would be "fired" by decreasing the control electrode voltage.

Once the tube had been fired, the electrode **14** would lose control of the tube current. This loss of control is believed to come about from the fact that positive ions collect and form a "sheath" around the control electrode. This sheath builds up to a thickness such that, at the outer boundary of the sheath, the negative control electrode voltage is balanced by the positive field from the sheath. The main part of the discharge is thereby shielded from and unaffected by the control electrode. If the control potential is increased in an effort to restrict the main discharge area by increasing the sheath thickness, the result is a temporary increase in potential drop through the restricted area. This causes an increase in electron velocity and an increase in ionization, with the result that the sheath density increases without appreciable change in the sheath thickness.

In the conventional arrangement just described, the work circuit voltage must initially be high enough to cause ionization. Even after ionization occurs, the arc drop between the work circuit electrodes must be kept high enough to sustain ionization. The voltage required to sustain ionization in the tube is, of course, wasted as far as the load is concerned. Frequently it would be very advantageous if the high currents characteristic of a gas tube could be obtained with a voltage loss of, say, one volt or less in the tube. Furthermore, if the work circuit voltage could be reduced, then the electron velocity changes which interfere with the control electrode influence on the tube current might be eliminated.

In Fig. 1 of the drawing, there is shown a circuit with which certain of the basic principles of the invention have been tested and established.

In the circuit of Fig. 1, a pulse generator **20** is connected to apply voltage pulses between the anode **18** and the cathode **12** of the tube **10**. The shield electrode **16** is connected in a work circuit which includes a load device **22** (e. g. an ordinary resistor), a voltage source shown as a battery **24**, and the cathode **12**. The control electrode **14** is allowed to "float" in this circuit.

Specific example of suitable pulse sources are given hereinafter. For the moment, it will suffice to state that the pulse source **20** should be adapted to provide pulses of amplitude at least sufficient to ionize the gas in the tube **10**.

In the circuit of Fig. 1, the pulses applied between the anode **18** and the cathode **12** will ionize the gas in the tube **10**. It has been found that the conductive plasma generated by such pulses will permit a work circuit current of the order of 150 milliamperes to flow from the cathode **12** to the shield electrode **16**, it being noted that the latter is serving as an electron collector electrode in the circuit of Fig. 1. Currents of this order of magnitude have been obtained with a voltage drop between the shield **16** and the cathode **12** of less than 0.1 volt.

In the circuit of Fig. 1, it is not feasible to control the work circuit current flowing to the shield electrode **16** by means of the control electrode **14** since the control electrode **14** does not have the proper configuration. If, however, as shown in Fig. 1*a*, a tube **10***a* is provided with a mesh-type grid electrode **14***a* between the cathode **12** and the shield or collector **16**, the current to the collector readily can be controlled by a voltage applied to the grid **14***a*.

It might seem that pulsed ionization of the tube gas would provide a pulsating work circuit current of comparatively limited utility. However, due to the behavior of the ion-electron plasma, it is found that a substantially continuous work circuit current can be drawn through a pulse generated plasma under suitable conditions. This is possible for two reasons.

First, when ionizing current flow through a gaseous electron tube is cut off, a finite time is required for the plasma to "decay" (i. e. removal of ions and electrons by diffusion, etc.). This decay time is primarily a function of the type of gas involved and the gas pressure.

Therefore, it can be seen that it should be possible to pass current through a decaying plasma even though the ionizing current has been interrupted. Even so, one might assume that the amplitude of the current drawn through a decaying plasma would decrease in accordance with the plasma decay curve.

It has been found, however, that the work

circuit current is not a continuous function of plasma density. That is, for a given voltage between the work circuit electrodes 12, 16 in Fig. 1, the current that will flow in the work circuit will be proportional to plasma density only up to a certain point. For greater plasma densities, the work circuit current will not increase, but will have a substantially constant value independent of plasma density. Therefore, if the ionizing pulses are large enough and are repeated at a high enough rate, the work circuit current can be a continuous current substantially unaffected by the ionizing pulses. Also, the shorter the duration of ionizing pulses, the less chance there will be of generating "plasma noise" that might interfere with the work circuit current.

While the "plasma noise" phenomenon just referred to is not entirely understood, it is known that as long as ionizing current is flowing, the voltage drop across the plasma (between the electrodes carrying the ionizing current) rises and falls rapidly and in a more or less random fashion. This is thought to be due, in part, to the fact that as soon as plasma is created the ionizing current is able to flow at a lower voltage, similar to the work circuit current flow. The plasma then may begin to decay, causing the voltage between the ionizing electrodes to go up, and repeating the ionizing process. In any event, it is known that random fluctuations can be detected in many instances in the current drawn through a continuously generated plasma, whereas they are not found in the current drawn through a decaying plasma. Therefore, if ionizing current is passed through the gas in very short, sharp bursts, followed by a relatively long decay time, plasma noise can be kept at a very low level.

As was stated, the plasma decay time is a function of the type of gas in the tube and the gas pressure. Therefore, it is not possible to state absolute values for the pulse repetition rate and pulse amplitude required for continuous work circuit current in all cases. However, a pulse amplitude, say, 100 percent greater than the arc drop required to sustain ionization, coupled with a pulse rate such that the interval between pulses is, say, 60 percent less than the time required for complete plasma decay, ordinarily will suffice. It will, of course, be understood that these percentages are intended to be illustrative and are not to be taken as absolute limits.

Although the voltage between the work circuit electrodes will be much less than the arc drop required to sustain ionization, it is not essential that the work circuit voltage source itself be so limited. Assume, for example, in the circuit of Fig. 1 that the ionizing arc drop required for the gas in the tube 10 is 25 volts, and that the voltage of the source 24 is 100 volts. Assume also that the pulse generator 20 is disabled. Under these circumstances, it has been found that the tube 10 will operate in rather conventional manner, with a voltage drop of about 25 volts, between the emitter 10 and the collector 16, and with the remainder of the source voltage appearing across the load 22. Now if pulses of amplitude greater than 25 volts and of repetition rate properly correlated with the plasma decay rate are applied between the anode 18 and the emitter 12, it will be found that the voltage between the collector 16 and the emitter 12 will drop to a very low value, say of the order of 0.1 volt, as previously described, with practically all of the source voltage appearing across the load 22.

In Fig. 2 there is shown a system wherein the work circuit current through a pulse ionized gas tube is controlled in a manner analogous to vacuum tube grid control.

In the system of Fig. 2, a gas tube 11 is provided with a thermionic emitter or cathode electrode 13 surrounded by a mesh-type control electrode or grid 15 and, outside the control electrode 15, by a collector electrode 17. An additional cold electrode 19 is provided adjacent to the emitter 13 to receive ionizing current from the emitter 13. This electrode 19 may comprise two rods disposed on opposite sides of and parallel with the emitter 13. While the tube shown in Fig. 1*a* also would be suitable for use in a system of the type presently being described, the arrangement of electrodes in the tube 11 is somewhat better from the standpoint of efficient ionization and allows for a greater range of grid control. That is, the tube shown in Fig. 1*a* has the disadvantage that the grid 14*a* may interfere to some extent with the ionizing current.

An ionizing pulse source 20 is connected between the cathode 13 and the electrodes 19, while a work circuit connecting the cathode 13 to the collector 17 includes a voltage source, shown as battery 24, and a load, shown as the voice coil 27 of a loudspeaker 29.

An audio frequency signal source 26 is connected between the control grid 15 and the cathode 13. The signal source 26 may comprise a conventional radio receiver, a phonograph pickup system, or the like.

When pulses of suitable amplitude and repetition rate are applied to the electrodes 19 from the source 20, current pulses will flow from the cathode 13 to the electrodes 19 and the gas in the tube 11 will be ionized as already explained in connection with the system of Fig. 1. The plasma so generated will allow current to flow from the cathode 13 to the collector 17 and through the voice coil 27. Due to the low voltage drop between the cathode 13 and the collector 17, this current can be modulated in accordance with the voltage applied to the control grid 15. Moreover, the pulse-generated plasma will not contribute noise voltages to the work circuit curent flowing through the voice coil as would be the case if a steady plasma-generating current were to flow from the cathode 13 to the electrode 19.

An important application of the principles of the invention is the use of a simple two-electrode gas tube, pulse-ionized to obtain high currents with low voltage losses. A circuit exemplifying such an embodiment of the invention is shown in Fig. 3.

The circuit of Fig. 3 comprises a rectifier system for converting alternating voltage to unidirectional voltage. In this case, a gas filled diode 30 is provided, having an electron emitter or cathode 32 and an electron colector or anode 34. The cathode 32 and the anode 34 are connected in a pulse ionizing circuit which includes a pulse generator 36 connected to the anode 34 through a coupling capacitor 38.

The anode 34 and the cathode 32 also are connected in a work circuit which includes the secondary winding 40 of a transformer 42. The transformer primary winding 44 is adapted to be connected to a suitable alternating voltage source (not shown). The work circuit is completed by a capacitor 48, in shunt with which may be con-

nected a load, shown as a resistor 46. A pair of terminals 50 are shown at opposite ends of the capacitor 48 to designate points between which unidirectional output voltage can be obtained.

The pulse generator 36 is a so-called blocking oscillator of conventional design, energized with unidirectional voltage from any suitable source (not shown). A statement of the operation of such an oscillator will be found in Terman's Radio Engineers' Handbook, first edition, page 514. The generator 38 should provide output pulses of amplitude sufficient to ionize the gas in the tube 30 and of repetition rate selected in accordance with the previously mentioned factors of gas type, gas pressure etc.

The voltage applied to the transformer primary winding 44 may be the conventional sixty cycle commercial supply voltage. The peak voltage across the secondary winding 40 usually will be slightly less than the pulse amplitude, although this is not essential since there will be a voltage drop across the load.

The pulses supplied to the tube 30 from the source 36 will provide the necessary plasma to allow the tube 30 to conduct curent during every other half cycle of the transformer secondary voltage. The resultant rectified voltage will appear at the terminals 50 across the capacitor 48 and load 46, and with a voltage loss across the tube 30 of as little as 0.1 volt.

In Fig. 4 there is shown a system embodying a further application of the principles of the invention, wherein a pulse-operated gas tube is used as an element in a frequency modulation detection system.

The system of Fig. 4 includes three elements commonly found in radio receivers adapted for frequency modulated signal reception. In block diagram form, these elements are shown as a radio frequency amplifier 52, a first detector 54, and an intermediate frequency amplifier 56. Frequency modulated signals received at an antenna 58 will be amplified in the R. F. amplifier 52 and converted to a lower (intermediate) frequency in the detector 54. The intermediate frequency signals from the detector 54 will be amplified in the I. F. amplifier 56, and the amplified intermediate frequency signal will be applied to a shaping circuit. This shaping circuit comprises a resistor 60, and two rectifiers 62, 64 and bias cells 66, 68 connected in parallel in opposite polarity. The rectifiers 62, 64 will convert the intermediate frequency signal to a square wave of the same varying frequency, and of peak-to-peak amplitude determined by the resistance of the resistor 60, the conductive impedances of the rectifiers 62, 64, and the voltages of the bias cells 66, 68.

This square wave then will be applied to a differentiator circuit comprising a capacitor 70 and a resistor 72. By differentiation, the square wave will be converted to one positive and one negative pulse for each cycle of the I. F. signal. These pulses will be applied to one of the cold electrodes of a gas tube 76.

The tube 76 may comprise a type 2050 tube, for example, with the anode 78 connected to the junction of the capacitor 70 and the resistor 72.

The other cold electrode 82 (in this case, the shield electrode) and the cathode 80 of the tube 76 are connected in a work circuit which includes a voltage source 84 and the voice coil 87 of a loudspeaker 86.

As was previously pointed out, the work circuit current in a pulse-ionized gas tube will be independent of the ionizing pulses, provided the latter are large enough and are repeated often enough. However, if the plasma is allowed to decay completely between pulses, then the work circuit current will drop to zero between pulses. Under these conditions, if the ionizing pulses are all of equal amplitude, then the average value of the work circuit current will be a function of the pulse repetition rate.

In the system of Fig. 4, the intermediate frequency and the differentiator output pulse amplitude are adjusted so that the "pulsed plasma" can decay sufficiently after each pulse to affect the work circuit current amplitude. Thus, the average value of the work circuit current becomes a function of the modulating frequency, and the latter will be reproduced as loudspeaker output.

It can be seen that the present invention provides a unique method of and apparatus for operating a gaseous electron tube in a manner that efficient control of work circuit current can be readily attained and with unusually low work circuit voltage loss at the gas tube.

What is claimed is:

1. In a method of operating a gas filled electron tube of the type having a plurality of electrodes including a single electron emitting electrode, two of said electrodes including said emitter electrode being connected in a work circuit which includes a voltage source and a load device, the step of generating conductive plasma in said tube by applying between said emitter electrode and another of said electrodes voltage pulses of amplitude sufficient to ionize the gas in said tube.

2. Method of operating a gas filled electron tube of the type having a plurality of electrodes including a single electron emitter electrode, said method comprising the steps of generating voltage pulses of sufficient amplitude to ionize the gas in said tube, applying said voltage pulses between two of said electrodes, one of said two electrodes being said emitter electrode, and applying between said emitter electrode and another of said electrodes a voltage of amplitude less than that required to sustain ionization.

3. Method of operating a gas filled electron tube of the type having a plurality of electrodes including a single electron emitter electrode, said method comprising the steps of generating voltage pulses of sufficient amplitude to ionize the gas in said tube, applying said voltage pulses between two of said electrodes, one of said two electrodes being said emitter electrode, and applying a separate voltage between said emitter electrode and another of said electrodes.

4. Method of operating a gas filled electron tube of the type having a plurality of electrodes including a single electron emitter electrode, said method comprising the steps of generating voltage pulses of amplitude substantially greater than that required to ionize the tube gas, applying said voltage pulses between said emitter electrode and another of said electrodes, and applying a separate voltage between said emitter electrode and another of said electrodes.

5. The method of controlling a flow of electrons from an electron emitter to an electron collector in a gas filled electron tube, said method comprising the steps of impressing voltage pulses of amplitude sufficient to ionize the tube gas between said electron emitter and another electrode in said tube, impressing a separate potential between said emitter and said collector electrodes, and impressing a variable control potential be-

tween said electron emitter and an electrode adjacent to said emitter.

6. A gas tube system comprising a gas filled electron tube having a plurality of electrodes including a single electron emitter electrode, a source of voltage pulses of amplitude greater than that required to ionize the gas in said tube, a circuit connecting said pulse source between said emitter electrode and another of said electrodes to generate a conductive ion-electron plasma in said tube, a voltage source, and a work circuit including said last named voltage source connecting two of said electrodes including said emitter electrode to pass current between said two electrodes through said plasma.

7. A gas tube system comprising a gas filled electron tube having an anode and a cathode, a source of voltage pulses of amplitude sufficient to ionize the gas in said tube, a circuit connecting said voltage pulse source between said anode and said cathode to ionize the gas in said tube in periodic bursts, a load device, and a circuit separate from said first named circuit connecting said anode to said cathode through said load device.

8. A system for operating a gas filled tube of the type having a plurality of electrodes including a single electron emitter electrode, said system comprising a source of voltage of amplitude less than that required to ionize the gas in said tube, a load device, a work circuit connecting two of said electrodes and including said voltage source and said load device, a source of voltage pulses of amplitude greater than that required to ionize said tube gas, and a circuit connecting said voltage pulse source between said electron emitter electrode and another of said electrodes.

9. In a system for passing space charge neutralized current between an electron emitter electrode and an electron collector electrode in a multi-electrode gas filled electron tube under conditions such that the potential between said emitter and collector electrodes is less than that required to sustain ionization of said gas, the combination with said tube of a source of voltage pulses of amplitude greater than that required to ionize said gas and of repetition rate such that the interval between said pulses is substantially less than the time required for complete elimination of ions and electrons from said gas after ionization thereof, a circuit connecting said pulse source between said emitter electrode and another of said tube electrodes, and a work circuit connecting said emitter electrode to said collector electrode.

10. In a system for passing space charge neutralized current between an electronic emitter electrode and an electron collector electrode in a multi-electrode gas filled electron tube under conditions such that the potential between said emitter and collector electrodes is less than that required to sustain ionization of said gas, means connected to said emitter electrode and to another of said electrodes to periodically ionize said gas at intervals substantially shorter than the time required for complete elimination of ions and electrons from said gas after ionization thereof, and a work circuit including said emitter electrode.

11. An electrical system comprising a gas filled electron tube having a plurality of electrodes including an electron emitter, a voltage pulse generator adapted to generate voltage pulses of amplitude at least sufficient to ionize the gas in said tube, said generator being connected to apply said voltage pulses between said emitter electrode and another of said electrodes, and a work circuit connecting said emitter electrode and a third one of said electrodes.

12. A gas tube system comprising a gas-filled electron tube having electrodes including a cathode and a control electrode surrounding said cathode, means connecting said cathode and another of said electrodes for periodically ionizing the gas in said tube, means to control the voltage between said control electrode and said cathode, and a work circuit connecting said cathode and another of said electrodes.

13. A gas tube system comprising a gas-filled electron tube having an anode, a control grid, a cathode and an auxiliary electrode, a source of voltage pulses of amplitude greater than that required to ionize the gas in said tube, said pulse source being connected between said cathode and said anode, a voltage source, a work circuit connecting said auxiliary electrode to said cathode through said last named voltage source, and means to control the voltage on said control electrode.

14. A gas tube system comprising a gas filled electron tube having a plurality of electrodes including a single electron emitter electrode, a voltage pulse source, circuit means connecting said emitter electrode and another of said electrodes to cause pulsating ionizing current to flow between said emitter electrode and said another electrode, said circuit means including said voltage pulse source, and a work circuit, separate from said circuit means connecting said emitter electrode and another of said electrodes, to draw current between said last named electrodes at a voltage between said last named electrodes less than that required to ionize the gas in said tube.

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