

June 30, 1942.

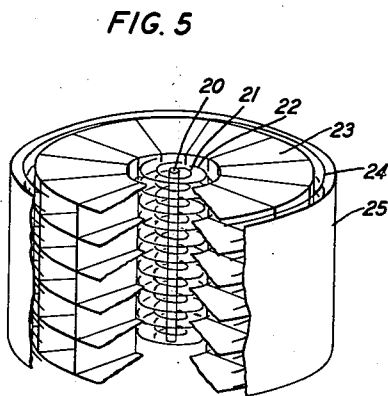
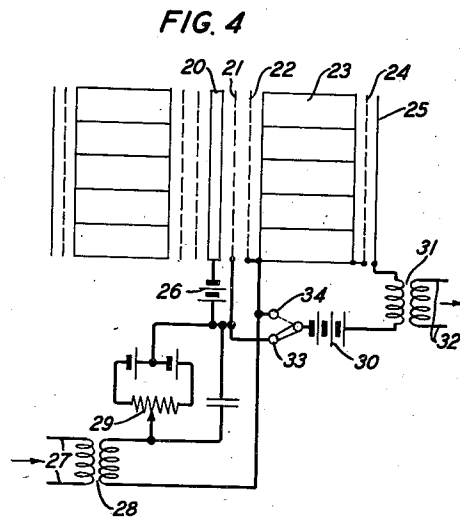
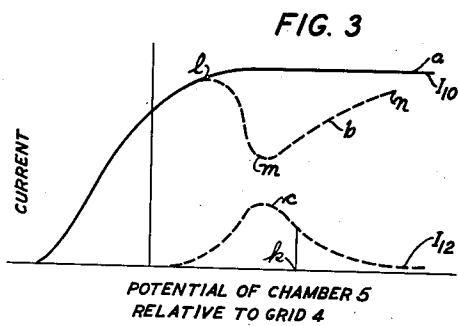
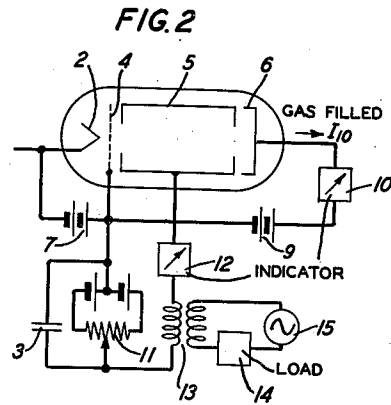
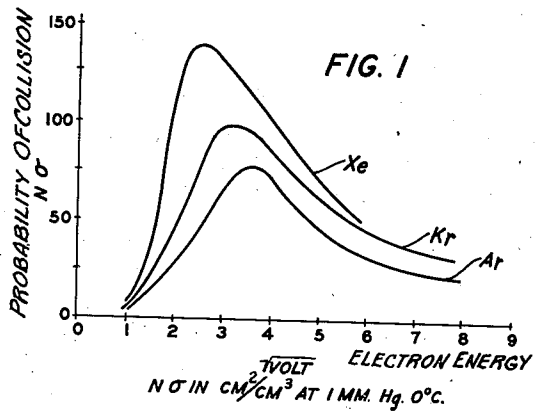
W. G. SHEPHERD

2,288,256

TRANSMISSION THROUGH SPACE DISCHARGE DEVICE

Filed May 17, 1940

2 Sheets-Sheet 1



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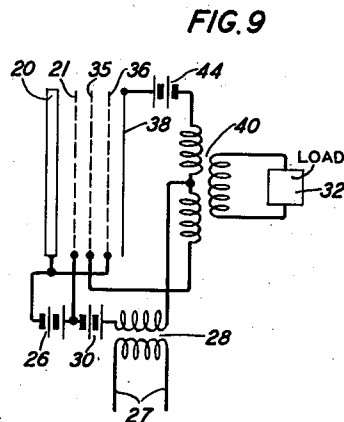
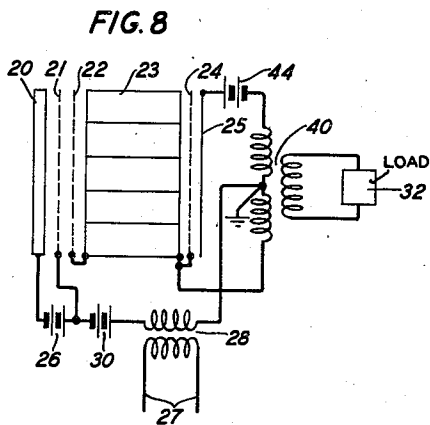
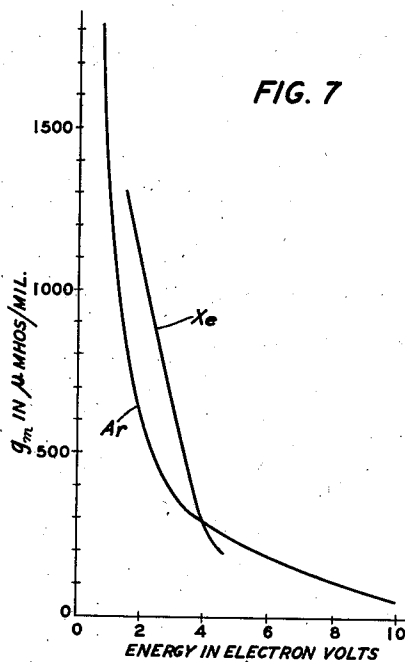
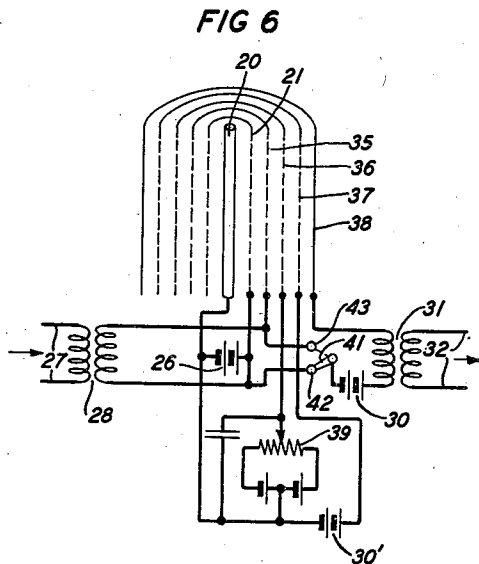
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TRANSMISSION THROUGH SPACE DISCHARGE DEVICE

Filed May 17, 1940

2 Sheets-Sheet 2



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2,288,256

TRANSMISSION THROUGH SPACE
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Application May 17, 1940, Serial No. 335,647

20 Claims. (Cl. 250-27)

The present invention relates to space discharge apparatus and circuits therefor. More specifically, the invention relates to apparatus utilizing electron discharge through gas, in which certain effects of electron scattering or effects of collisions of electrons with gas particles are made use of for such purposes as securing amplification of input waves, producing a negative resistance, or controlling the current in an external circuit for any purpose.

When a stream of electrons traverses a gas-filled region some of the electrons will undergo collisions which will, in general, change both the magnitude and direction of their velocities.

By separating the electrons which have undergone collisions from those which have not, it is possible to derive an output current whose magnitude depends upon the rate of collisions. By controlling some quantity which determines the rate at which collisions occur, it is then possible to vary the output current.

The invention provides method and means for accomplishing these results. Electrons are projected into a region containing gas under conditions producing collisions. Control of the rate of collisions is obtained by controlling the velocity at which electrons are projected into this region; and the electrons which have not undergone collision are collected as output current, while the electrons that have experienced collisions are diverted from the collector in a manner to be described.

As stated, the velocity of the electrons that undergo collision is changed. The electron may be deflected to one side or it may be slowed up with little or no change of direction. Separation of electrons that have not collided from electrons that have collided can be made on the basis of their velocity differences. Two general ways will be disclosed herein, one depending on angle of deflection and the other depending on loss of velocity in the forward direction.

The nature of the invention and its objects will be more fully set forth in the following detailed description in which will be given the general theory together with certain preferred ways of carrying out the invention in practice. These illustrative embodiments are shown in the accompanying drawings, in which:

Fig. 1 shows curves to be referred to in the description of the theory and operation;

Fig. 2 is a diagrammatic representation of one type of tube which may be used in accordance with the invention to secure novel results;

Fig. 3 shows curves illustrating the operation of the tube of Fig. 2;

Fig. 4 shows a sectional view in elevation, and circuit diagram, of one type of tube according to the invention;

Fig. 5 shows a perspective view, partly broken away, of the tube of Fig. 4;

Fig. 6 is a schematic representation of an alternative type of tube and circuit according to the invention;

Fig. 7 shows transconductance curves such as are obtainable in accordance with the invention; and

Figs. 8 and 9 show tubes and circuits similar to Figs. 4 and 6 but with push-pull outputs.

In the following discussion of the theory and operation the general assumption is made that the electron energies are kept below the ionization value. This simplifies the treatment and, moreover, according to applicant's present information, this represents the preferred practice as will be indicated later on. This is not known, however, to constitute a limiting condition for the invention and there is no intent to limit the invention to the region below the ionization level but rather that the invention shall extend to all regions and fields in which it may be applicable in practice.

The probability that an electron in traveling unit distance under standard conditions of temperature and pressure will undergo a collision may be represented by P . The meaning of the probability is that if a stream of electrons of current strength I passes a distance dx through the gas and if the current measuring device at the end of the gas chamber will accept and indicate only those electrons whose velocity does not differ in magnitude or direction from that of the electrons entering the gas chamber by more than some definite increment, then the decrease in the current strength will be

$$-dI = IPpdx \quad (1)$$

The factor p , the pressure, appears since the chance of collision will increase in direct proportion to the number of molecules present.

The final current received at the collector is found by integrating (1) to give

$$I = I_0 e^{-Pxp} \quad (2)$$

which may be written in a slightly different form as

$$I = I_0 e^{\frac{-N_0 p x}{p_0}} \quad (3)$$

where N_0 is the number of molecules of gas per

unit volume at pressure p_0 and σ has the dimensions of an area and is called the cross-section for collision of an electron with the molecule. Further reference to Formula 3 will be made later on.

From (2) it is seen that the output current in the case of a fixed path and gas pressure depends only on the collision probability or rate. Attention will be confined for the moment to elastic collisions and some discussion will be given later of the effect of inelastic collisions. In an elastic collision an electron loses only that amount of energy necessary for the conservation of momentum in the collision. If the elastic collisions between the electrons and gas molecules were exactly similar to those between hard spheres then the probability or rate of elastic collision would be independent of electron energy and therefore independent of the electron velocity. The electron has, however, wave properties and the wave-length associated with the electron depends upon its energy. As is the case with the scattering of light from particles the scattering will then be a function of the wave-length or energy of the electrons. At any rate, whatever may be the correct and complete theory to account for it, the output current can be controlled by varying the velocity with which the electrons are projected into the collision space. The curves given in Fig. 1 are taken from a paper by Ramsauer published in *Physikalische Zeitschrift* 1928, vol. 29, page 823, and show the probability of collision of electrons in argon, krypton and xenon as a function of the square root of their energy in electron volts which is proportional to their velocity. Similar variations for the probability of collision and electron scattering are exhibited by other gases.

R. Kollath and E. Steudel in studying electron scattering used a tube structure of the general type shown in Fig. 2. Their work is published in *Zeitschrift fur Tech. Physik* 1939, Nr. 2, pp. 36-38. In this figure the tube 1 contains a cathode 2, grid electrode 4, scattering chamber 5 and collector 6. Batteries 7 and 9 apply positive potentials to the electrodes 4, 5 and 6. An indicating instrument 10 shows the output current. A source of variable voltage 11 is provided for varying the potential of the chamber 5 and the current in this connection is indicated at 12. The electron stream enters the chamber 5 through the slit opening shown and, depending upon the magnitudes of the voltages applied to electrodes 4 and 5, passes through to the collector 6, which has positive voltage applied to it by 9 sufficient to insure that all the electrons leaving 5 will be collected on 6. A by-pass condenser is shown at 3.

Assuming first that the tube contains no gas, if the current at 10 is observed as the voltage of source 11 is varied starting from negative values greater than cut-off and progressing through zero to positive values, curve *a* of Fig. 3 is obtained. If some suitable gas such as argon is admitted at a suitable pressure related to the length of the scattering chamber, e. g. a pressure of 5×10^{-2} millimeters Hg for a path length of 1 centimeter, and if the current at 10 is again observed as a function of the voltage of source 11, the curve *a* will be retraced in part but will then take the course indicated at *b*. A xenon filling at the same pressure would call for a path length of .50 centimeter. If, as assumed, there is no ionization, no new ions are formed and the total

current will remain the same. The current I_{12} to electrode 5, observed at 12, is therefore given by the difference between curves *a* and *b*, or curve *c* in the figure. This curve *c* on the right-hand side of its maximum point exhibits a decreasing current I_{12} for increasing applied control voltage, or a negative resistance effect in the circuit to the chamber 5.

The current I_{12} is the current that is diverted to the chamber 5 by electron scattering. Electrons suffering more than a certain small angular deflection fail to pass through the output aperture toward collector 6 but are collected on the walls of chamber 5. This device, therefore, makes use of the angle of deflection to separate the current into two components.

In accordance with the invention this negative resistance effect can be utilized, as by biasing the chamber 5 to some suitable point *k* by means of source 11 and applying a variable or input voltage at 13 from a source 15 in any suitable manner to operate the tube about point *k* on the falling portion of curve *c*. The negative resistance effect is produced in the circuit carrying current I_{12} and may be utilized in a suitable load impedance related to this circuit. For example, 12 may in this case be the load or the load may be in a circuit such as 14 coupled to the I_{12} branch, for example, it may be in series with the source of control voltage or input voltage 15.

This circuit may be used for amplification between input variations at 13 and output variations at 10 in similar manner to the tube described below in connection with Figs. 4 and 5.

It is important in the operation of this device that the strength of the electron current entering the scattering chamber shall not change as a function of the voltage variations applied to the chamber but that only the electron velocity shall change. The grid 4 is arranged to draw out the electrons from the cathode and provide a constant supply to the chamber. The potential difference between the cathode and grid 4 is constant. The velocity of the electrons projected into the chamber 5 is kept below the ionization level.

Another form of device depending upon angle of deflection to separate the total current into two components is shown in Figs. 4 and 5. This is a cylindrical type tube with cathode 20, accelerating grid 21, positive grid 22, scattering chamber 23, shield grid 24 and plate 25. Cells 26 bias grid 21. The control potentials or input variations (signal) are applied between chamber 23 and cathode from a suitable signal or other input circuit 27 through transformer 28. Grids 22 and 24 are shown strapped directly to chamber 23 and these three elements are given a bias of suitable type from source 29 of sufficient range of adjustability to permit of a positive or negative bias relative to grid 21. Cells 30 place positive potential on the anode or collector 25 and output transformer 31 leads to outgoing utilization circuit 32.

Collisions occurring in chamber 23 produce electron scattering and those scattered electrons that have a sufficiently large angle of deflection are collected on the walls of the compartments into which the scattering chamber 23 is subdivided as indicated. The electron current entering the chamber 23 is kept constant and of the desired value by the first grid 21 which should be of sufficiently fine mesh to prevent changes in

the fields from the outer electrodes from appreciably affecting the current drawn from the cathode. The electron current is, thus, as a result of the collisions and scattering, resolved into a component passing to the electrode 23 and another component to the anode 25. Grids 22 and 24 serve to keep the chamber 23 as a whole immune from the influence of the relatively variable fields existing on each side of it. These grids, especially grid 22, may not be necessary in actual practice. The positive potential on the plate 25 is of such value as to bring the velocities of the electrons emerging from the chamber 23 up to a useful value. Alternative connections from the negative pole of battery 30 to point 33 or point 34 are indicated, and can be effected by a switch, if desired. Connection to point 33 returns the alternating current from the chamber 23 through the secondary of input transformer 28. This may be avoided and instead the direct current passed through coil 28 by connection at point 34. Since the variations in current to chamber 23 and anode 25 are substantially complementary, the alternating current flows between them by way of the load.

Referring to the curves of Fig. 3, it will be seen that the output current curve labeled I_{10} has a falling portion $l-m$ and a rising portion $m-n$. Operation about a point intermediate l and m results in decreased output for a positive swing of the input or control voltage and increased output for a negative swing of the control voltage. This means that the tube has a negative transconductance from the control voltage to the output current when operated within the $l-m$ part of the characteristic. The $m-n$ region corresponds to positive transconductance since a positive swing in input voltage produces increasing output current and vice versa. These curves apply to the tubes of Figs. 4 and 5 as well as to the tube of Fig. 2.

Referring to Fig. 4, adjustment of the slider on resistor 29 determines the portion of the tube characteristic on which the tube is operated. Movement of the slider to the left in the figure (or similar movement of the slider on resistance 11 of Fig. 2) makes the bias less positive and may be thought of as moving the operating point to the left in Fig. 3, for example, to some point intermediate between l and m . A more positive bias will shift the operating point to the right, for example, to the region $m-n$.

The negative resistance effect described in connection with Fig. 2 can be obtained in similar manner in the case of Fig. 4 using the connection at point 33. The effect appears in series in the lead to the chamber 23.

It was stated above that the preferred voltage operating range is that below the ionization level. In the case of the particular gases indicated in Fig. 1 the most advantageous operating ranges would be either on the left-hand slopes or on the right-hand slopes of the curves since these portions are the steepest. Another reason for keeping below the ionization potential is in order that positive ions may not be produced in large numbers in the body of the gas since they would tend to drift back toward the cathode where they would produce space charge effect and change the supply of electrons entering the chamber. This would give variable or unstable operation.

Fig. 6 shows a tube in which the electrons that have lost velocity due to collisions are stopped by a grid 36, which is preferably at substantially cathode potential but may have its potential

varied from cathode potential in either positive or negative direction by movement of slider 39 as may be desired in any particular case. The similarly numbered parts may be the same as in Fig. 4. The control potentials are applied between the grid 21 and another suitable electrode and are here shown as impressed between the positive grid 21 and a grid 35 located just outside grid 21. The useful collisions occur in the space between grid 21 and stopping grid 36. The electrons that have been slowed down to a velocity below a given value are unable to traverse the retarding field of grid 36 and are attracted toward grid 35 while those electrons with greater velocity than this given value are able to pass through to the accelerating field of the anode 38 or of the accelerating grid 37 if used. Grid 37 is connected to a point of suitable positive potential in battery 30', such as to its positive terminal. By throwing switch 41 to connect to point 42 or 43 either the alternating current from grid 35 or the direct current from battery 30 is returned through the input coil as explained above under Fig. 4.

In the Fig. 6 construction as in the case of Fig. 4, the grid 21 is used to fix the current so that variations in potential of the control grid 35 will not change the value of the injected current. In this type of tube the electrons need not collide with a wall in order to be removed from the current stream, hence the spacing between grids 35 and 36 may be made as small as mechanically possible. This fact has an important bearing on the tube design and performance as may be seen from a comparison with the case depending on angular deflection. In both cases it is essential that the density of the current injected into the scattering space be sufficiently low so that a virtual cathode will not be formed for the lowest velocities reached by the injected electrons, since the action of the virtual cathode is partially to compensate the action of the collisions. The permissible current density depends only upon the path length in the scattering space and the lowest energy of the electrons entering this space.

Since the length of the scattering space can be so much smaller in the stopping grid case, for the reason given above, the density of the injected current can be greater. The permissible injected current density varies inversely as the square of the length of the scattering space, which means that the current density may be increased in the order of twenty-five fold over the optimum angular discrimination case with a corresponding increase in the figure of merit.

It should be noted that the stopping grid method discriminates against all the electrons that have undergone collisions, while in the method depending on angular deflection, only those electrons experiencing more than a given angular deflection are removed from the electron stream. Electrons deflected from their initial direction, even if they should maintain the same numerical value of velocity, lose velocity in the forward direction and are stopped by the stopping grid. Moreover, the stopping grid method is particularly effective in the case of collisions involving excitation since in this case the velocity changes would be large.

Up to this point only the elastic type collisions have been discussed, and the curves in Figs. 1 and 3 are for cases involving only elastic type of collisions. There will be a certain number of inelastic collisions resulting in excitation, and

this number will vary with variations in velocity of the injected current independently of the variation in number of elastic collisions. The total collision rate will be the sum of the individual rates. Collisions resulting in excitation require that a definite quantum of energy be given up by the electron. Hence the probability P_s , meaning that a certain fraction of the electrons in traveling unit distance under given conditions of temperature and pressure will undergo collision producing excitation, will have a definite energy threshold. A control of the electron velocity will, therefore, give a control of P_s and thus a control of the transmitted current. The total probability of electron collision

$$P_c = P_s + P_e$$

(the subscript e referring to the elastic collision case) and the total current I_c due to both types of collisions is given by

$$I_c = I_0 \exp [-(P_s + P_e)px]$$

which is similar to the expression in Equation 2.

In both the types of discrimination depending upon angular deflection and stopping grid action, the transmitted current is given by 3. In this formula the probability of collision

$$P = \frac{N_0 \sigma}{p_0}$$

is a function of the electron energy which will depend upon the potential drop through which the electrons falls prior to the scattering chamber. Since N_0 and p_0 are fixed σ is a function of this potential and hence the transconductance,

$$g_m = \frac{dI}{de_g} = -I_0 \frac{N_0 p x}{p_0} \frac{\partial \sigma}{\partial e_g} \exp \left[-\frac{N_0 \sigma p}{p_0} x \right] \\ = -I \frac{N_0 p x}{p_0} \frac{\partial \sigma}{\partial e_g}$$

Thus, if the operating point is in a region in which the cross-section for collision increases with energy a negative transconductance can be obtained and a positive transconductance where the operating point is in a region where the cross-section decreases with energy.

The transconductance is a function of pressure and an investigation of the optimum pressure condition shows that for a maximum

$$\frac{N_0 p \sigma x}{p_0} = 1$$

which may be interpreted as a condition on px . The transmitted current under these conditions is $I = I_0 e^{-1}$ and

$$\frac{(g_m)_{\max}}{I} = -\frac{1}{\sigma} \frac{\partial \sigma}{\partial e_g} \times 10^{+3} \text{ } \mu\text{mhos/milliamper}$$

Thus for a maximum transconductance

$$\frac{1}{\sigma} \frac{\partial \sigma}{\partial e_g}$$

should be maximum. Using the experimental values of σ versus electron energy given in Fig. 1 data for g_m versus energy are shown for argon and xenon in Fig. 7. Here it will be observed that the transconductance per milliamper is comparable with that produced in more conventional vacuum tubes. These calculations are only for the negative transconductances and corresponding values may be computed for positive transconductances. These values are not necessarily the best available since other gases may yield higher values.

In Fig. 8 a tube of the same type as that of

Fig. 4 is shown but in this case the output circuit is connected in push-pull relation to the anode 25 and scattering chamber 23, thus utilizing both of these elements as output electrodes. Balanced transformer 40 couples these electrodes to load circuit 32 in push-pull. Battery 44 makes the anode more positive than the other tube elements. Since the electron current entering the chamber is substantially constant in density and is divided into two components in complementary manner, substantially equal and opposite variations occur in the current to the chamber 23 and the anode 25. With no signal impressed at 27, 28 the entering electron current into the chamber divides in some proportion, depending on the bias potential, into a steady component to the anode 25 and another steady component to the chamber 23. An input signal variation which is in a direction to increase the probability of scattering decreases the current to the anode and increases the current to the chamber, and vice versa. Transformer 40 is so wound as to make these current changes cumulative in their effect on the output 32.

Fig. 9 shows how a push-pull output may be applied to a tube using the stopping grid method. The divided primary of transformer 40 has its outside terminals connected across the anode 33 and control grid 35. In this case, in the absence of any signal input, the electron current projected into the space between grids 35 and 36, assuming a bias near the middle of some operating range, passes in part to the anode and is in part stopped at 36, the portion stopped consisting of slowed electrons that are unable to pass through the retarding field of grid 36. These electrons drift back to the positive grid 35 and are returned to the cathode through the lower primary winding of the transformer 40. When signal variations are present in 27 the portions of the total current passing to the anode and to the positive grid 35 vary oppositely and substantially equally and the variations to each electrode act cumulatively in the output circuit 32.

In both Figs. 8 and 9 feedback occurs from the output to the input. Assuming a positive transconductance, an increase in voltage of 23 or 35 in the positive direction increases the current to the anode and decreases the current flowing in the circuit of 23 or 35. This results in decreased drop of potential across the lower half of winding 40 which is in a direction to augment the assumed initial effect. Hence this feedback is positive. With negative transconductance negative feedback is obtained.

The push-pull connection reduces even order distortion. Positive feedback increases the gain. Negative feedback reduces distortion, improves the gain stability and is accompanied by the usual advantages secured by negative feedback in amplifiers generally.

The invention is not to be construed as limited to the particular constructions of tube or circuit that have been disclosed since these are to be considered as illustrating the principle and manner of operation of the invention, the scope of which is defined in the following claims.

What is claimed is:

1. The method comprising controlling the current between a first and a second electrode in a tube containing gas by establishing current flow between said electrodes and diverting current away from said second electrode by pro-

duction of electron scattering in a region between said electrodes by collision between electrons and gas molecules, variably controlling the strength of the current diverted by such scattering, and utilizing the current so diverted.

2. The method according to claim 1 in which the component of the electron velocity in the direction toward said second electrode is dependent upon the scattering, including the step of intercepting electrons having less than a predetermined magnitude of velocity component in said direction.

3. The method of controlling transmission through a discharge device containing gas comprising producing electron scattering therein by collision between electrons and gas molecules, stopping transmission to the output of the device of electrons that have lost velocity because of such scattering and producing flow of current in said output from the remaining, fast-moving electrons.

4. The method of producing output current under control of input voltage variations comprising producing electron discharge between electrodes in a gas, producing electron scattering by collision between electrons and gas molecules, variably controlling by the input voltage variations the electron velocity, such variations being confined to a region within which the collision probability varies markedly and in the same sense with variations in electron velocity, separating the scattered electrons as one group from the electrons that have not experienced scattering as another group and producing output current flow from the electrons of one of said groups.

5. The method of producing output current under control of input voltage variations comprising producing electron discharge between electrodes in a gas, producing electron scattering by collision between electrons and gas molecules, the scattering electrons experiencing reduced velocity in the forward direction, variably controlling by the input voltage the electron velocity between limits within a region in which the collision probability varies markedly with variations in electron velocity, stopping the electrons with reduced velocity in the forward direction resulting from the scattering while allowing the fast-moving electrons to proceed thereby separating the reduced velocity electrons and the fast-moving electrons into groups and producing output current flow from the electrons of one of said groups.

6. The method according to claim 4 in which the scattered electrons experience angular deflection with respect to their original direction and in which said separating comprises intercepting electrons having greater than a predetermined angle of deflection with respect to their original direction of travel as a result of such scattering while allowing electrons of a lesser angle of deflection to proceed.

7. The method of producing output current variations under control of input voltage variations comprising producing electron discharge between electrodes in a gas, varying the probability of collision between electrons and gas molecules by varying as a function of the input voltage variations the electron velocity between limits within a region in which the collision probability varies markedly with variations in electron velocity and producing output current variations of a magnitude dependent upon such variations in probability of collision.

8. The method of according to claim 7 in which the variation of probability of collision when plotted with respect to electron velocity follows a characteristic curve of varying slope, the method including causing such variations in input voltage to take place about an operating point near the middle of a steep portion of the characteristic curve between electron velocity and probability of collisions.

9. A space discharge device having a centrally positioned cathode and concentrically arranged electrodes surrounding said cathode in an envelope containing gas, means producing discharge between said electrodes, means producing scattering of electrons within said envelope by collisions between electrons and gas molecules, means for variably controlling the amount of electron scattering comprising means responding to an input voltage for varying the electron velocity, and means deriving an output current from said device of a magnitude depending upon the amount of such scattering.

10. A space discharge device comprising a cylindrical envelope containing gas, a centrally located source of electrons therein, means cooperating with said electron source for producing a stream of electrons in said gas of substantially constant current strength, a source of input voltage variations, an output electrode concentric with respect to said source and means controlled by said voltage variations for varying the velocity of said electrons, thereby to vary the rate of collision between said electrons and gas molecules, said means for varying the velocity of said electrons comprising means for diverting electrons from said stream at a point between said electron source and said output electrode, at a rate dependent upon said rate of collision.

11. A device according to claim 10 in which the diverted electrons are angularly deflected by different amounts as a result of variations of electron velocity and in which said means for diverting electrons comprises an annular scattering chamber having a plurality of orifices of restricted dimensions on the side toward said output electrode and walls for intercepting electrons having too great an angle of deflection to pass through said orifice.

12. A device according to claim 10 in which said means for diverting electrons comprises a stopping grid interposed ahead of said output electrode and means maintaining said grid at low potential relative to said output electrode.

13. In combination, a space discharge device comprising an envelope containing gas, cathode and anode electrodes therefor, means producing electron discharge between said electrodes, means producing scattering of electrons within said envelope by collisions between electrons and gas molecules, a control electrode located between said anode and cathode, a source of voltage variations connected between said cathode and said control electrode for varying the velocity of electrons thereby to control the amount of scattering, means to bias said control electrode to produce a negative resistance effect in the circuit between said cathode and control electrode, and means to utilize said negative resistance effect.

14. In combination, a space discharge device comprising cathode and anode electrodes in an envelope containing gas, means producing electron discharge between said electrodes, means producing scattering of electrons within said envelope by collisions between electrons and gas molecules, a control electrode located between

said cathode and anode, a source of variable voltage connected to said control electrode for varying the electron velocity and, as a function thereof, the amount of such scattering, said control electrode constituting a collector of scattered electrons, and means in circuit with said cathode and control electrode for utilizing the current resulting from electrons collected by said control electrode.

15. In a space discharge device, an envelope containing gas, a cathode and, in the order named, a first grid, a second grid, a third grid and an output electrode, means to apply positive potential to the first and second grids, a low potential including zero value to the third grid and positive potential to the output electrode, means including said electrodes and potentials for producing electron discharge in said device and scattering of electrons by collision between electrons and gas molecules, means including a source of variable potential applied to said second grid for varying the amount of such scattering, thereby variably diverting electrons away from said output electrode, and means connected to said output electrode for utilizing the current variations resulting from such variable diverting of electrons therefrom.

16. The combination according to claim 15 including a push-pull output connection between said second grid and said output electrode with its mid-point connected to said cathode.

17. In combination, a space discharge device containing gas, a source of supply of electrons therein of substantially constant density for producing electron scattering by collision between electrons and molecules of said gas, a control grid, a stopping grid and an output electrode in the order named, means to apply varying potential to said control grid to vary the velocity of electrons in the direction toward the output electrode, means comprising the amount of gas pressure used and the velocity imparted to the electrons for operating said tube on a steep portion of the characteristic curve between the rate of electron scattering and the velocity of electrons whereby the variation in scattering is

controlled by variations in said potential applied to the control grid and the current to said output electrode is varied in accordance with the variation in electron scattering, and a circuit connected to said output electrode for utilizing the resulting varying output current.

18. In combination, a space discharge device containing gas, a cathode therein, an accelerating grid adjacent the cathode and means for applying a steady positive potential thereto, a control grid beyond the accelerating grid, means to apply a variable signal voltage thereto, a stopping grid beyond the control grid and means to maintain its potential at substantially cathode potential, an output electrode beyond said stopping grid and means to apply positive potential thereto, means comprising the pressure of the gas and the velocity with which the electrons are injected by said accelerating and control grids into the space between said control grid and stopping grid for producing effective electron scattering as a function of said signal voltage, whereby the current to said output electrode is varied in accordance with variations in electron scattering, and signal responding means connected to said output electrode.

19. A space discharge device comprising an envelope containing gas, a source of electrons therein, means cooperating with said electron source for producing a stream of electrons in said gas of substantially constant current strength, a source of input voltage variations, means controlled by said voltage variations for varying the velocity of said electrons, thereby to vary the rate of collision between said electrons and gas molecules, an output electrode and output circuit, and means comprising a stopping grid interposed ahead of said output electrode for diverting electrons from said stream at a rate dependent upon said rate of collision.

20. A combination according to claim 19 including feedback means for varying the velocity of said electrons under control of current variations in said output circuit.

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