July 23, 1957 L. M. FIELD ET AL 2,800,602

LOW NOISE ELECTRON DISCHARGE TUBES

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Fig. 1.

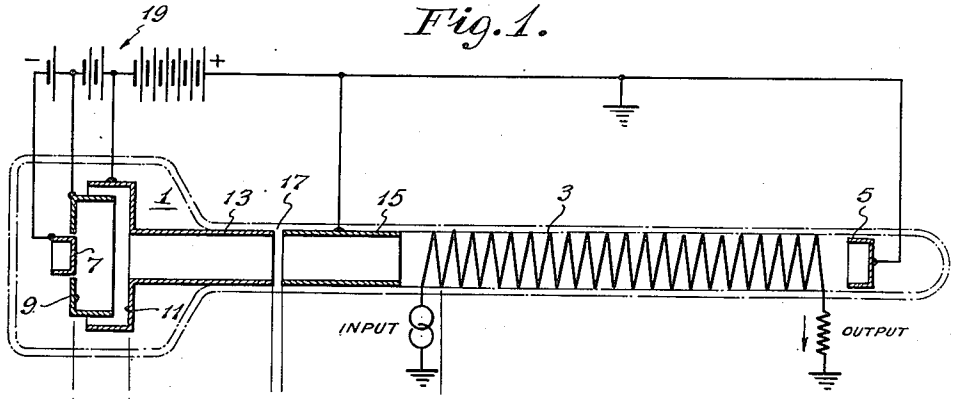


Fig. 2.

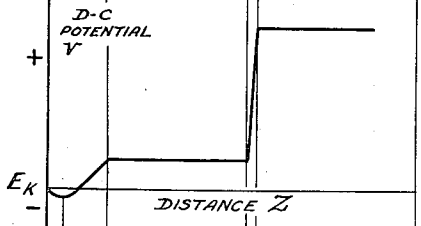


Fig. 3.

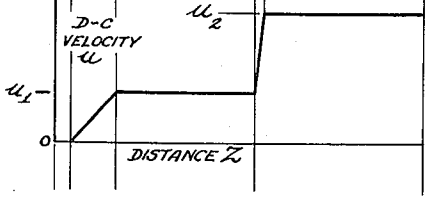


Fig. 4.

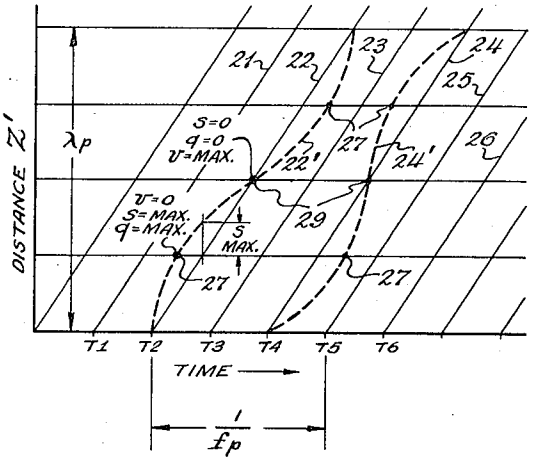
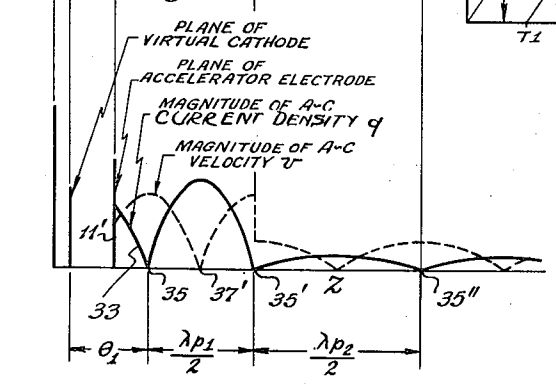


Fig. 5.



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Fig. 6.

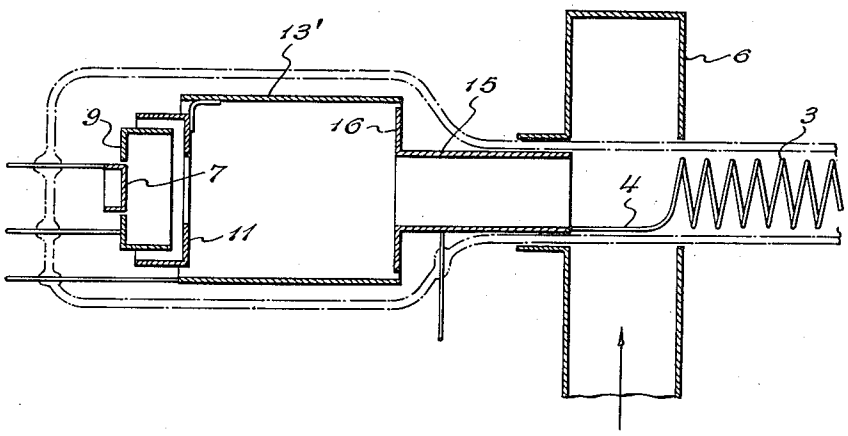
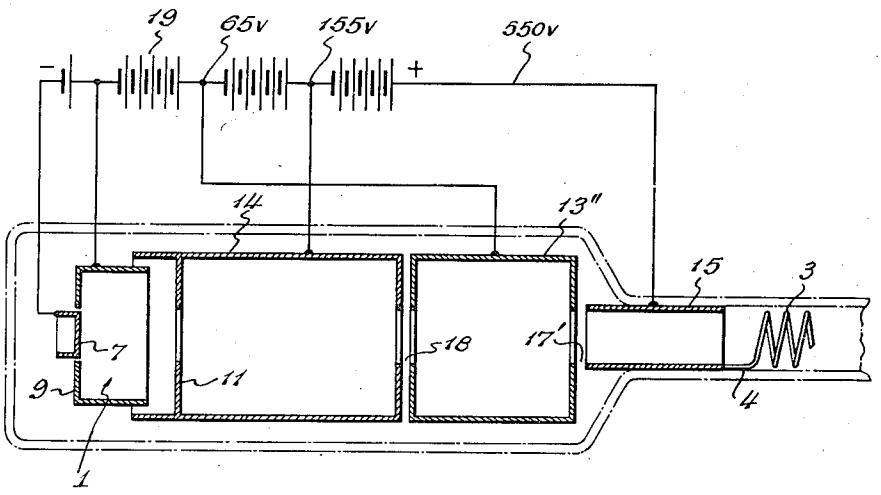


Fig. 7.



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LOW NOISE ELECTRON DISCHARGE TUBES

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Application June 5, 1951, Serial No. 229,902

27 Claims. (Cl. 315—3.5)

This invention relates to improvements in high frequency electron discharge apparatus, and particularly to low-noise amplifiers, for example of the travelling wave or klystron type. Noise is undesired signal present in the output of an amplifier. It is usually of random nature, and has two principal components, one caused by thermal agitation in the input circuit and the other caused by irregularities in the emission of electrons from the cathode. The latter effect is called "shot" noise. An amplifier with its input circuit operating at a given ambient temperature will exhibit a certain amount of thermal noise which depends upon the temperature, and is independent of the presence or absence of signal or other noise. The thermal agitation is regarded as the irreducible minimum noise level. Noise figure is the ratio, usually expressed in decibels (db), of the total noise output power to the noise output power attributable to thermal noise at the input.

One of the principal objects of the present invention is to provide a method of reducing the noise figure of amplifiers which utilize electron beams, such as travelling wave tubes and klystrons.

Specifically, it is an object of this invention to provide improved means for increasing the uniformity of an electron beam by reducing the magnitude of the noise produced variations of velocity and density of the electrons in it.

Another and related object is to provide electron discharge tube devices embodying improved means for minimizing noise carried by the electron stream.

The invention will be described with reference to the accompanying drawings, wherein:

Fig. 1 is a schematic diagram of a travelling wave tube embodying the invention,

Fig. 2 is a graph of the D.-C. potential along a portion of the tube of Fig. 1,

Fig. 3 is a graph of the D.-C. or average beam velocity corresponding to the potential distribution shown in Fig. 2,

Fig. 4 is a graph illustrating the longitudinal motions of electrons in a portion of an electron beam, and the nature of space charge waves therein,

Fig. 5 is a graph showing the variations in magnitude of space charge waves of A.-C. current density and A.-C. velocity along the electron beam in the tube of Fig. 1,

Fig. 6 is a longitudinal section of a portion of a tube constructed in accordance with the invention, and

Fig. 7 is a schematic diagram of a modification of Fig. 6.

Referring to Fig. 1, the travelling wave tube as shown includes an electron gun generally designated by the reference numeral 1, a conductive helix 3, and a collector electrode 5. These elements are all enclosed in a vacuum envelope, as shown. The gun 1 directs a stream of electrons through the helix 3 to the collector 5. High frequency energy to be amplified is applied to the helix at its end nearer the gun 1, and is amplified in a known manner by interaction of the resulting field, travelling on the helix, with the moving stream of electrons. The amplified energy is taken off the helix at the end nearer the collector 5.

The electron gun includes a cathode 7, focussing electrode 9, and an accelerator electrode or anode 11. The electrode 11 has a tubular extension 13 surrounding the path of the electron stream for a certain distance to provide a drift space substantially free of D.-C. fields. An additional electrode, shown in Fig. 1 as a tubular member 15 like the part 13, is disposed adjacent the end of the member 13 to define a relatively short gap 17. The optimum lengths of the drift spaces provided by the tubular members 13 and 15, for low-noise operation of the device, depend upon the geometry of the particular cathode used, and upon the voltages at which the various electrodes are operated, as will be explained.

A D.-C. source such as a battery 19 is connected as shown to maintain the various electrodes at suitable potentials with respect to each other. By way of example, the voltages, referred to the cathode as zero, may be:

	Volts
Focussing electrode 9	1
Anode 11	32
Tubular element 15, helix 3, and collector 5	2600

All of the above potentials are positive with respect to the cathode. The positive terminal may be grounded as shown in order to place the input and output terminals of the helix 3 at ground potential. The input and output connections may be conductive as shown schematically in Fig. 1, or may be made in other conventional manner as by probes or antennas.

Fig. 2 indicates the D.-C. potential V in the tube as a function of the distance Z along the axis. Starting at the cathode and going toward the higher voltage elements, the potential first becomes slightly negative with respect to the cathode, then increases up to the voltage at the anode 11. The potential remains at this value along the drift tube 13, and increases abruptly across the short gap or region 17 to the voltage on the member 15, maintaining the latter value throughout the remainder of the distance to the collector 5.

The potential minimum near the cathode is actually very much closer to the cathode than is indicated in Fig. 2, where the scale has been enlarged for the purpose of clarity. It is caused by the space charge of a cloud of electrons which is formed in the vicinity of the cathode in normal operation. Individual electrons are emitted from the cathode at random velocities and at random times. The mean velocity depends upon the cathode temperature. Slow-moving electrons are repelled back toward the cathode by earlier-emitted slow electrons, and fast-moving electrons have enough momentum to overcome the repulsion and pass the slower, earlier electrons. Thus a more or less stationary cloud is formed, with electrons entering it from the cathode, some returning to the cathode and some going on toward the anode. The center of the cloud, at the potential minimum, is called the virtual cathode, since the electrons which get through it behave as if they emanated from that point.

Beam current, also called convection current or conduction current, is proportional to the total number of electrons per second passing through a plane normal to the beam. The current density is proportional to the number of electrons per second passing through a unit area. Charge density is the number of unit charges or electrons in a unit volume. Thus the current density is the product of the charge density and the beam velocity.

All of these quantities are variable, and each may be regarded as having an average or constant component with a superimposed varying component, like the D.-C. and A.-C. components which may exist in an electric voltage or current wave. In fact the terms "A.-C." and "D.-C." are used to distinguish such components even in the case of quantities which do not involve current; for

example "A.-C. velocity" means the varying component of a velocity.

The symbols which will be used are:

	A.-C.	D.-C.
velocity	v	u
current density	q	q_0
charge density	ρ	ρ_0

Inside an electron beam where lateral motion is substantially prevented, as by a strong longitudinal magnetic field, there is a longitudinal equilibrium position for each electron, where the repulsion forces of all the other electrons on it are exactly balanced and the total repulsion force tending to displace the electron longitudinally from that position is zero. This equilibrium position moves with the beam at the D.-C. velocity. When the beam is current or velocity modulated in any manner, some of the electrons are displaced from their equilibrium positions either initially or after an interval during which velocity modulation produces the displacement. Density modulation is variation in current density of the beam as it passes through a given transverse plane; i. e., the current density in that plane, varies with time. Velocity modulation is variation in electron velocity as the beam passes through a given plane.

When the amount of the modulation, either velocity or density, is small, as it is in the usual operation of many types of electron discharge tubes, each electron displaced from its equilibrium position tends to return to that position. It is possible for the modulation to be so great that displaced electrons lose their original equilibrium positions completely, and tend to go to positions formerly occupied by other electrons. Only the former case, so called "small signal operation" is considered herein.

The restoring force on a displaced electron, when the displacement is small, is directly proportional to the displacement, and also to the charge density in the surrounding space. Since the electron has mass and therefore inertia, it will not simply return to its equilibrium position and stop there, but will be carried by its momentum to a point on the other side of equilibrium, where the momentum is overcome by the opposing restoring forces. Thus the electron once displaced from its equilibrium position will oscillate about that position like a weight supported between two opposed compression springs. This is called plasma oscillation.

Refer to Fig. 4, which represents the motions of electrons in a stream. The solid lines **21**, **22**, **23**, **24**, **25** and **26** represent the motions of the equilibrium positions of electrons which pass the point $Z'=0$ at times **T1**, **T2**, etc. respectively. The slope of lines **21—26** is the D.-C. velocity u. Suppose the electron starting at **T2** has a higher velocity than the average velocity u. It will oscillate about its equilibrium position as shown by the dash line **22'**, alternately approaching the previous electron starting at **T1**, and the subsequent electron starting at **T3**. Similarly, the electron starting at **T4**, with less than average velocity, will first approach the subsequent electron starting at **T5** and then the preceding electron which started at **T3**.

In the weight and spring analogy, the frequency of oscillation is determined by the mass of the weight and the stiffness of the spring. In the plasma oscillation, the mass is that of the electron, and the stiffness is the product of the charge of the electron and the charge density in the surrounding space. Since the charge to mass ratio

$$\frac{e}{m}$$

is the same for all electrons, the plasma frequency depends on the charge density, ρ_0. The plasma frequency in an actual beam of finite cross section may differ somewhat from the theoretical value of an unbounded beam, but

nevertheless it is determined principally by the charge density ρ_0.

When the instantaneous displacement of an electron from its equilibrium position is at a maximum, the A.-C. velocity v is zero because the electron is reversing its direction of motion with respect to the equilibrium point. This is shown at the points **27** in Fig. 4. When the displacement is zero, the velocity is at its maximum value, as at points **29** in Fig. 4. Still considering temporarily a thin filamentary element of the stream, it will be seen that the A.-C. current density q is maximum where the displacement is maximum, and q is zero where the displacement is zero, i. e. where the electrons are equally spaced. The same thing is true of each other filamentary element, and of the beam as a whole.

Thus, under small signal conditions, a velocity modulation imposed on a beam at one point will change, as the electrons travel and oscillate about their mean positions, to density modulation at another point, then back to velocity modulation at a subsequent point, and so on. Similarly, if density modulation is imposed on the beam at a first point, it will become velocity modulation at a later point, changing from one to the other along the path of the beam. The distance along the beam an electron would travel at the D.-C. velocity u during one cycle of electron oscillation is called the space charge wavelength or plasma wavelength λp.

Any single modulation or disturbance, in velocity or in density, or in both, produces a space charge wave having a plasma wavelength λp. A space charge wave is composed of correlated stationary waves of alternating velocity and alternating current density whose magnitudes are a function of distance along the electron stream as is illustrated in Fig. 5. Minima of magnitude variations in alternating velocity occur at points spaced apart by

$$\frac{\lambda p}{2}$$

with maxima of magnitude variations in alternating current density occurring at the same points. The maxima of magnitude variations in alternating velocity and minima of magnitude variations in alternating current density occur midway between the aforementioned points as is clearly illustrated in Fig. 5. Thus, the magnitude variations of the space charge waves of alternating velocity and alternating current density are in space quadrature like the magnitude variations of alternating voltage and alternating current in a standing electromagnetic wave.

In an ideally uniform beam (of unlimited transverse cross section, so that boundary effects do not enter into consideration), each electron would be equally spaced from its neighbors, and all would be moving at the same velocity. Such beams do not exist, because the exact instant at which an electron will be emitted, from a certain point on a surface such as a hot cathode, is not determined by the time when the last electron was previously emitted from that point, and the emission velocity of any particular electron is completely independent of the velocities of the other electrons. Thus the spacing between adjacent electrons as they leave the cathode are not equal, the velocities are different, and the charge density at every point in a given plane across the beam varies irregularly and independently. The beam as emitted therefore carries two independent modulations capable of producing two independent space charge waves.

When the cathode is operated at a sufficiently high temperature to produce a space-charge cloud as described above, the variations in current and charge density are reduced considerably by the phenomenon called space charge smoothing.

Fig. 3 shows the D.-C. velocity u as a function of Z. It is substantially zero at the plane of the virtual cathode, and increases uniformly throughout the accelerating region to a value u_1 at the electrode **11**. It remains constant at this value through the drift tube **13**, then jumps abruptly

to a higher value u_2 as the beam crosses the gap **17**. Throughout the remainder of the beam, the D.-C. velocity remains at u_2.

Since the noise on the beam emerging from the anode **11** behaves as if it had been caused by fluctuations at the virtual cathode in the form of substantially pure velocity modulation, the space charge waves which are produced are very nearly phase position coherent throughout the remainder of the beam. Accordingly, the A.-C. current density q becomes substantially zero at some point **35** along the beam and again at the point **35'**, a distance

$$\frac{\lambda p_1}{2}$$

further along the axis, as shown in Fig. 5, where the solid line **33** represents the magnitude of the A.-C. current density as a function of distance along the beam. The distance of the point **35** from the plane of the virtual cathode is shown as θ_1 in Fig. 5.

The positions of the points **35** and **35'**, as well as those of zero A.-C. velocity such as point **37'**, are constant, and substantially independent of the amplitudes, frequencies and wavelengths of the components of the shot noise which originates the space charge waves. The length of the tubular conductor **13** is made such that the beginning of gap **17** nearest the cathode is located where the A.-C. current density q is substantially zero and the A.-C. velocity is at a maximum. The gap **17** may be placed at the distance θ_1 from the virtual cathode, or at this distance plus any integral number of half wavelengths of the space charge waves.

In the illustrated tube, the side of the gap defined by the end of tube **13** is at the point **35'**,

$$\theta_1+\frac{\lambda p_1}{2}$$

from the virtual cathode. While this distance may be computed approximately in designing a particular tube, it is best determined experimentally, since the quantitative nature of the space charge waves in the accelerating region are not definitely ascertainable from theoretical considerations at present. Adjustment of the accelerating potential on the electrode **11** will cause some variation in λp_1, so that the points **35** or **35'** of zero current density variation can be moved to coincide with the gap **17**.

At the gap **17**, each electron in the stream has its total kinetic energy increased by an amount $V'e$, where V' is the difference in potential between the electrodes **13** and **15**, and e is the charge of an electron. The kinetic energy of an electron approaching the gap at the D.-C. velocity u_1 is $\frac{1}{2} mu_1^2$, where m is the electron mass. Leaving the gap at D.-C. velocity u_2, the electron has a kinetic energy $\frac{1}{2} mu_1^2+V'e=\frac{1}{2} mu_2^2$. Now consider an electron with a different approach velocity, u_1+v_1:

$$\tfrac{1}{2}m(u_1+v_1)^2+V'e=\tfrac{1}{2}m(u_2+v_2)^2$$

Expanding the above,

$$\tfrac{1}{2}mu_1^2+mu_1v_1+\tfrac{1}{2}mv_1^2+V'e=\tfrac{1}{2}mu_2^2+mu_2v_2+\tfrac{1}{2}mv_2^2$$

Subtracting the equation for the electron with an approach velocity u_1 from the equation for the electron with velocity u_1+v_1, and factoring m:

$$u_1v_1+\tfrac{1}{2}v_1^2=u_2v_2+\tfrac{1}{2}v_2^2$$

If we assume $v_1 \ll u_1$ and $v_2 \ll u_2$, v_1^2 and v_2^2 can be neglected, and

$$u_1v_1=u_2v_2$$

Thus

$$v_2=v_1\frac{u_1}{u_2}$$

and the A.-C. velocity v is reduced as the beam crosses the gap, by a factor equal to the ratio of the D.-C. velocities u_1 and u_2. This is equal to the square root of the ratio of the respective beam voltages, and in the present example is

$$\sqrt{\frac{32}{2600}}=0.11$$

The A.-C. velocity v_2 is about one-ninth the original A.-C. velocity v_1. In the embodiment illustrated in Fig. 1, the A.-C. current density is zero on both sides of the gap, the gap being so short that substantially no regrouping of the electrons can occur during the time required to cross it.

The velocity modulation represented by v_2 sets up a new set of space charge waves beyond the gap **17**, wherein the maximum A.-C. velocity is a small fraction (in this case, one ninth) of that in the original waves, and the A.-C. current density is correspondingly less. This represents a substantial reduction in the components of noise current and velocity which were originally produced by the velocity modulation at the virtual cathode.

Returning to Fig. 1, the length of the tubular conductor **15** is principally a mechanical consideration, since substantially all of the electric field associated with it is at the gap **17**. However, there is an optimum position for the starting point of the helix **3**. Noise signals impressed on the first part of the helix will be amplified more than if they were put on farther from the input end. The best arrangement is one in which the total noise, as induced by both velocity and current and amplified on the helix, is a minimum at the output end of the helix. This requires that the helix start a small calculable amount before a current density zero, by an amount that depends upon the gain characteristic of the helix and upon the space charge wavelength λp_2. The location of the helix may be determined analytically, taking into account that the effective plasma wavelength differs somewhat from the ideal plasma wavelength, or it may be found by experiment with a movable helix.

Fig. 6 shows the details of the electron gun and the input end of a travelling wave tube which has been constructed according to the present invention and operated at a frequency of about 3000 megacycles per second. The helix in this tube is of .010 inch diameter tungsten wire, copper coated and wound 26 turns per inch, with an inside diameter of .100 inch. The tubular member **15** is one inch long, with an inside diameter of .120 inch, and is connected to the helix **3** by an extension **4** of the helix wire. The extension **4** is .380 inch long, and it is used as an antenna to pick up the signal to be amplified from an input wave guide **6**.

The end of the tubular member **15** remote from the helix is provided with a radial flange **16**, one half inch in diameter. The drift tube **13'** in this case is .75 inch in diameter, much larger than the member **15**. The reason for this construction was to permit longitudinal adjustment of the position of the helix **3** and members **15** and **16** with respect to the electron gun. The diameter of the drift tube **13'** is not critical. Its length is 2.36 inches.

The accelerator electrode **11** is .074 inch long with an inner diameter of .266 inch and an aperture of .080 inch diameter. The radial wall of the accelerator **11** is spaced .138 inch from the plane of the cathode **7**. The focussing electrode **9** is .072 inch long and .163 inch inside diameter. Its radial wall is in the plane of the cathode and has a .070 inch diameter aperture concentric with the cathode. The cathode, which is oxide coated, is .050 inch in diameter.

The tube of Fig. 6 does not have a gap like the gap **17** in Fig. 1. However, the electrostatic field configuration between the drift tube **13'**, which is operated at a low potential and the aperture to flange **16** which is at a high potential, is such as to provide a much higher potential gradient in the vicinity of the aperture than at any other place in the drift tube, so that the electron stream is accelerated in the vicinity of the flanged end of

the member **15**, within a distance which is very short as compared to a space charge wavelength λp_1.

The high voltage space charge wavelength λp_2, is so long that it is impractical to start the helix at slightly less than one half space charge wavelength beyond the velocity jump, i. e. near the noise current minimum corresponding to the point **35''** in Fig. 5. In the device of Fig. 6, a compromise was effected by making the helix start as close to the velocity jump (corresponding to the point **35'** in Fig. 5) as possible, considering that some axial space must be allowed for the coupling antenna **4** and a short cylinder **15**. Then a correction was made for the non-optimum helix position by making the velocity jump at a point a short axial distance away from the location of a noise velocity maximum. This adjustment can be made conveniently by a small variation in the potential of the accelerator **11**.

The foregoing dimensions, while they are those of a tube which has been built, are given by way of example only. The noise figure of the described tube, operating at 3000 megacycles per second, with D.-C. voltages of 32 and 2600 respectively on the accelerator and the helix, was measured as 9 db.

In the structures of Figs. 1 and 6, the electron beam is started at a relatively low D.-C. velocity, allowed to drift to a point where the A.-C. noise velocity is a maximum, and then abruptly accelerated to the relatively high velocity at which it is utilized. It will be apparent that this noise reducing operation on the beam could be repeated one or more times, either by successive jumps to progressively higher velocities, or by providing alternate increases and decreases in D.-C. velocity at the proper points along the beam. The latter method appears at present to be preferable, since the number of stages of noise reduction is not limited by the maximum practically usable voltage. Increase in the noise where the D.-C. velocity is reduced is avoided by making the jump from high to low velocity at a point where the A.-C. velocity is zero.

In the arrangement shown in Fig. 7, the low voltage drift tube **13''**, which corresponds to the drift tube **13** in Fig. 1 or **13'** in Fig. 6, is separated from the electron gun **1** by a further drift tube **14**. The tubes **13''** and **14** may be made large as compared to the beam diameter, as shown, in which case they are provided with radial flanges to define a short gap **18**. Alternatively, these tubes may be made smaller and the flanges omitted. A gap **17'**, corresponding to the gap **17** in Fig. 1, may be provided between the drift tube **13''** and the member **15**.

The first drift tube **14** is held at a moderately high potential, and made of such length as to place the gap **18** at a noise velocity minimum, like the point **37** in Fig. 5. The second drift tube **13''** is held at a relatively low potential, like the tube **13** in Fig. 1, and is of such length as to place the gap **17'** substantially at a noise velocity maximum. The tubular member **15**, helix **3**, and the collector (not shown) are maintained at a relatively high positive potential.

The operation of the tube of Fig. 7, is similar to that of Figs. 1 and 6, with the addition that the beam is decelerated abruptly before entering the drift tube **13''**, instead of merely being started at a low velocity. This has several advantages, one being that the gun anode or accelerator electrode **11** may be operated at a reasonably high voltage, making it easier to form and maintain the shape of the electron beam. Also, the helix voltage need not be as high, for a given noise reduction, as in the tubes with a single velocity jump. Furthermore, the voltage of the drift tube **13''** can be changed without changing any of the other D.-C. voltages, to adjust the positions of the space charge waves with respect to the gaps **17'** and **18**.

A tube like that of Fig. 7 has been operated with a gain of 18 db at 3000 megacycles per second, and 11 db noise figure. The applied voltages were as follows:

	Volts
Accelerator **11** and drift tube **14**	155
Drift tube **13''**	65
Helix **3** and cylinder **15**	550

The beam current was 150 microamperes.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In an electron discharge device, means for producing and utilizing an electron beam, said beam being characterized by undesired variations in electron velocity and current density, and means for reducing said variations comprising means for abruptly increasing the velocity of said electrons at a location along said beam where the magnitude of said undesired velocity variation is substantially at a maximum value.

2. An electron discharge device comprising means for producing and utilizing an electron beam, said beam being characterized by undesired variations in electron velocity and current density, and means for reducing said variations comprising means for abruptly decelerating said electrons at a location along said beam where the magnitude of said current density variations is substantially at a maximum value, and means for abruptly accelerating said electrons at a subsequent location along said beam where the magnitude of said velocity variations is substantially at a maximum value.

3. Apparatus for reducing shot noise in an electron discharge device of the type which utilizes a stream of electrons for the conversion of direct current energy into oscillatory energy, said stream being characterized by undesired random variations in electron velocity and current density, the magnitudes of said variations being correlated and cyclically variable according to position along said beam in the direction of electron flow, said apparatus comprising means for initiating the beam at a first average velocity, and means for abruptly changing the average velocity of the electrons to a substantially different value, at a position on said stream where one of said magnitudes is at its maximum value, the change in average velocity of said electrons effected by said last-named means being in a predetermined direction for decreasing the magnitude of said undesired variations in electron velocity and current density.

4. Apparatus for increasing the uniformity of velocity and current density in an electron beam, comprising means for initiating the flow of electrons at a relatively low average velocity and with sufficient charge density to produce space charge limiting of the beam, said beam being characterized by undesired random variations in the velocities of the electrons which set up correlated stationary waves of magnitude of variation of velocity and magnitude of variation of current density along the beam, and means for abruptly accelerating the electrons to a relatively high average velocity, at a location along said beam where said stationary wave of velocity variation magnitude is substantially at a maximum value.

5. Apparatus for increasing the uniformity of velocity and current density in an electron beam, comprising means for initiating the flow of electrons at a relatively high average velocity, said beam being characterized by undesired random variations in the velocities of the electrons which set up correlated stationary waves of magnitude of variation of velocity and magnitude of variation of current density along the beam, means for abruptly decelerating the electrons to a relatively low average velocity, at a location along said beam where said wave of velocity variation magnitude is substantially

at a minimum value, and means for abruptly accelerating the electrons to a relatively high average velocity, at a subsequent location along said beam where said wave of velocity variation magnitude is substantially at a maximum value.

6. Apparatus for producing a low-noise electron stream, including a cathode, an accelerator electrode adjacent said cathode and adapted to be maintained at a positive potential with respect to said cathode to accelerate electrons emitted from said cathode to a first relatively low velocity, a second accelerator electrode spaced from said first electrode and surrounding a section of the electron stream where the magnitude of the variation in velocities of said electrons due to shot noise is substantially at a maximum, said second electrode being adapted to be maintained at a substantially higher positive potential than said first electrode, and a conductive tube surrounding said stream between said electrodes and adapted to be maintained at said first potential and to provide a substantially field-free drift space between said electrodes.

7. Apparatus for producing a low-noise electron stream, including a cathode, an accelerator electrode adjacent said cathode and adapted to be maintained at a positive potential with respect to said cathode to accelerate electrons emitted from said cathode to a first relatively high velocity, a second electrode spaced from said first electrode and surrounding a section of the electron stream where the magnitude of the variation in velocities of said electrons due to shot noise is substantially at a minimum, said second electrode being adapted to be maintained at a substantially lower positive potential than said first electrode, and a conductive tube surrounding said stream between said electrodes and adapted to be maintained at said first potential and to provide a substantially field-free drift space between said electrodes, a third electrode spaced from said second electrode and surrounding a section of the electron stream where said variations in electron velocities is substantially at a maximum, said third electrode being adapted to be maintained at a substantially higher positive potential than said second electrode, and a second conductive tube surrounding said stream between said second and third electrodes and connected to said third electrode.

8. A low-noise electron gun, including a cathode, an accelerating electrode adjacent said cathode and adapted to accelerate electrons emitted by said cathode to form an electron stream having a D.-C. velocity u_1, said stream carrying substantially coherent space current waves of A.-C. velocity and A.-C. charge density due to shot noise, said waves varying in magnitude along said stream and exhibiting maxima and minima which are at substantially fixed distances along said stream from said accelerating electrode; a further electrode located at a position where the magnitude of one of said space charge waves on said stream is substantially at a maximum, said further electrode being adapted to change the D.-C. velocity of said electrons to a second value u_2 which is substantially different from u_1, and a drift tube surrounding said stream between said electrodes, said drift tube being connected to said accelerating electrode to provide a substantially field-free drift space between said electrodes.

9. A low-noise electron gun, including a cathode, an accelerating electrode adjacent said cathode and adapted to accelerate electrons emitted by said cathode to form an electron stream having a relatively high D.-C. velocity, said stream carrying substantially coherent space charge waves of A.-C. velocity and A.-C. current density due to shot noise, said waves varying in magnitude along said stream and exhibiting maxima and minima which are at substantially fixed distances along said stream from said accelerating electrode; a further electrode located at a position where the magnitude of said A.-C. current density is substantially at a maximum, said further electrode being adapted to decelerate said electrons to a second D.-C. velocity which is relatively low compared to said first D.-C. velocity, and a drift tube surrounding the space between said accelerating electrode and said further electrode, said drift tube being connected to said accelerating electrode.

10. A low-noise electron gun, including a cathode, an accelerating electrode adjacent said cathode and adapted to accelerate electrons emitted by said cathode to form an electron stream having a D.-C. velocity u_1, said stream carrying substantially coherent space charge waves of A.-C. velocity and A.-C. current density due to shot noise, said waves varying in magnitude along said stream and exhibiting maxima and minima which are at substantially fixed distances along said stream from said accelerating electrode; a second accelerating electrode located at a position where the magnitude of said A.-C. velocity on said stream is substantially at a maximum, said second electrode being adapted to accelerate said electrons to a second D.-C. velocity u_2 which is at least several times as great as u_1, and a drift tube surrounding said stream between said electrodes, said drift tube being connected to said first accelerating electrode to provide a substantially field-free drift space between said electrodes.

11. A low-noise electron gun, including a cathode, an accelerating electrode adjacent said cathode and adapted to accelerate electrons emitted by said cathode to form an electron stream having a relatively high D.-C. velocity, said stream carrying substantially coherent space charge waves of A.-C. velocity and A.-C. current density due to shot noise, said waves varying cyclically in magnitude along said stream and having maxima and minima which are at substantially fixed distances along said stream from said accelerting electrode; a decelerating electrode located at a position where the magnitude of said A.-C. current density on said stream is substantially at a maximum, said decelerating electrode being adapted to decelerate said electrons to a second D.-C. velocity which is relatively low compared to said first D.-C. velocity, a drift tube surrounding the space between said accelerating and decelerating electrodes and connected to said accelerating eletrode, a second accelerating electrode located at a position where the magnitude of said A.-C. velocity on said stream is substantially at a maximum, said last mentioned electrode being adapted to accelerate said electrons to a third D.-C. velocity which is several times as great as said second D.-C. velocity, and a second drift tube surrounding the space between said decelerating electrode and said second accelerating electrode and connected to said decelerating electrode.

12. A travelling wave amplifier device including a helix, means including a cathode for forming and projecting a stream of electrons through and substantially along the axis of said helix, said stream carrying substantially coherent space current waves of A.-C. velocity and A.-C. charge density due to shot noise, said waves having correlated maxima and minima in their magnitudes at locations along said beam which are at substantially fixed respective distances from said cathode, and at least two tubular conductive members in end-to-end relationship between said cathode and said helix and coaxial therewith, said members being axially spaced to provide a beam accelerating gap which is small compared to the lengths of said members for increasing the average velocity of said stream of electrons, said gap being located substantially at a position where the magnitude of said A.-C. velocity is at a maximum.

13. A travelling wave amplifier device including a helix, means including a cathode for forming and projecting a stream of electrons through and substantially along the axis of said helix, said stream carrying substantially coherent space current waves of A.-C. velocity and A.-C. charge density due to shot noise, said waves having correlated maxima and minima in their magnitudes at locations along said beam which are at substantially fixed respective distances from said cathode, and at least two tubular conductive members in end-to-end

relationship between said cathode and said helix and coaxial therewith, said members being axially spaced to provide a gap which is small compared to the lengths of said members, said gap being located at a position near, but slightly closer to said cathode, than a position where the magnitude of said A.-C. velocity is at a maximum, and the end of said helix nearer said cathode being near, but slightly further from said cathode, than said position where said A.-C. velocity is at a maximum.

14. A travelling wave amplifier device including a conductive helix, means for applying high frequency signals to be amplified to one end of said helix, means for leading amplified high frequency signals away from the other end of said helix to a utilization device, a collector electrode adjacent said latter end of said helix, a plurality of tubular conductive members in end-to-end relationship at the first mentioned end of said helix and in axial alignment with said helix, said tubular members being electrically insulated from said helix and axially spaced to provide at least one gap which is short compared to the lengths of said members, means including a cathode for producing and directing a stream of electrons through said tubular members and said helix and substantially along the common axis thereof to said collector electrode, said tubular conductive members being adapted to be maintained at widely different potentials to provide an abrupt change in the D.-C. velocity of said electrons as they pass said gap.

15. An electron discharge device, comprising electron gun means including a cathode and accelerator means for producing and directing an electron beam at an average velocity along an axis, electromagnetic energy means spaced along said axis beyond said electron gun means for velocity modulating the electrons of said beam, drift tube means along said axis between said accelerator means and said electromagnetic energy means, said electron beam between said accelerator means and said electromagnetic energy means carrying stationary coherent space charge waves of A.-C. current density and A.-C. velocity due to shot noise, said waves having correlated maximum and minimum points of magnitude at substantially fixed locations along said beam from said cathode, and means for abruptly accelerating the average velocity of said electron beam at a location along said drift tube means where the stationary space current wave of A.-C. charge density has a minimum magnitude to thereby reduce the magnitude of said space charge waves beyond said location of abrupt velocity acceleration.

16. An electron discharge device as set forth in claim 15, wherein said electromagnetic energy means comprises travelling electromagnetic wave conductor means including input and output electromagnetic energy coupling ends.

17. In combination, means including a cathode and an accelerating anode spaced therefrom for producing and directing an electron beam along a predetermined path beyond said anode, said electron beam containing space charge waves of correlated alternating velocity and alternating current density, and means along said path on the other side of said anode from said cathode and spaced a predetermined distance from said anode for increasing the average velocity of the electrons of said beam throughout an accelerating region beginning substantially at a location of a space charge wave alternating velocity maximum for increasing the wavelength of and de-amplifying said space charge waves.

18. In combination, means including a cathode and an accelerating anode spaced therefrom for producing and directing an electron beam along a predetermined path, said electron beam containing space charge waves of correlated alternating velocity and alternating current density, first beam electrode means spaced along said path from said cathode beyond said anode, second beam electrode means spaced along said path from said cathode beyond said first beam electrode means, said beam electrode means and said cathode being in insulated relationship with each other, said electrode means having apertures in closely adjacent and substantially conformal relationship with said electron beam with the aperture of said first electrode means being located substantially at a region of an alternating current velocity maximum and an alternating current density minimum of said space charge waves, and means coupled to said first and second electrode means for providing a beam accelerating field from the aperture of said first electrode means to the aperture of said second electrode means.

19. In combination, means including a cathode for producing and directing a beam of electrons, said beam being characterized by space charge waves of alternating velocity and alternating current density having a predetermined plasma wavelength λp, said waves including alternating velocity maxima along said beam at substantially fixed positions from said cathode spaced at intervals of $\lambda p/2$ from each other and including alternating density minima occurring along said beam at said positions of alternating velocity maxima, said waves further including alternating velocity minima along said beam at substantially fixed positions intermediate said positions of alternatng velocity maxima and alternating current density maxima at said positions of alternating velocity minima, and means for modifying said beam along a beam region which includes a space charge wave alternating velocity maximum position for increasing the plasma wavelength of said space charge waves and decreasing their amplitudes, said beam region being short relative to said plasma wavelength.

20. Apparatus as set forth in claim 3, wherein said velocity changing means comprises a pair of electron permeable electrode means located along said stream for passage of said stream therethrough, said electrode means defining a beam acceleration region at a position along said stream whereat said electron velocity variation is at a maximum value, the spacing between said electrodes being such that the magnitudes of said current density variation from the beginning to the end of said acceleration region are substantially the same.

21. Apparatus as set forth in claim 4, wherein said accelerating means comprises a pair of closely spaced electron permeable electrodes along said beam for defining an accelerating region in which the magnitude of said current density variation is substantially unchanged.

22. A low-noise electron gun as set forth in claim 8, wherein said further electrode is located at an A.-C. velocity space charge wave maximum, and means connected between said accelerating electrode and said further electrode for supplying an accelerating voltage between said electrodes for increasing the average velocity of said electron stream.

23. A low noise electron gun as set forth in claim 9, further including additional electrode means further along said stream from said cathode beyond said further electrode for acceleration of said electron stream, said additional electrode means being located along said electron stream for providing acceleration thereof in a region of a space charge wave A.-C. velocity maximum.

24. The combination as set forth in claim 17, wherein said velocity increasing means comprises a pair of electron permeable electrodes coaxially spaced from each other along said beam with portions thereof being in close relationship with said beam and facing each other for providing a gap defining said accelerating region, said gap being appreciably shorter than the wavelength of said space charge waves with the magnitude of the space charge wave of alternating current density along said accelerating region being substantially the same.

25. The combination as set forth in claim 18, wherein said first and second beam electrode means are closely spaced axially of said beam and the alternating current density is substantially the same at both of said electrodes.

26. A low noise travelling wave tube device, comprising means including a cathode and electron permeable anode means spaced therefrom for producing and directing an electron stream along a predetermined path through and beyond said anode means, means connected to said anode means for receiving a D.-C. potential for accelerating said stream to a relatively low D.-C. velocity, said stream being characterized by undesired noise modulation which sets up correlated space charge waves of alternating velocity and alternating current density whose magnitudes vary cyclically along said stream, the wave of alternating velocity having maxima of magnitude variations at predetermined locations along said stream which are spaced apart by one half of a space charge wavelength with the wave of alternating current density having minima of magnitude variations substantially at said predetermined locations, a travelling wave propagating structure positioned along the path of said stream for passage of said electron stream therealong, said propagating structure being adapted for the propagation of microwave energy for interaction with said stream, first apertured electrode means positioned along the path of said stream between said cathode and said wave propagating structure for passage of said stream therethrough, second apertured electrode means positioned along the path of said stream between said first electrode means and said wave propagating structure for passage of said stream therethrough, means connected to said first and second electrode means for receiving a D.-C. potential for accelerating said stream

to a relatively high D.-C. velocity compared with said low D.-C. velocity, the location of said first and second electrode means being fixed along said stream for defining a beam accelerating region between a pair of succeeding minima of magnitude variations of said space charge wave of alternating velocity for reducing the magnitude of said space charge waves of alternating velocity and alternating current density prior to passage along said slow wave propagating structure.

27. A low noise travelling wave tube device as set forth in claim 26, wherein one end of said accelerating region is located at a position of maximum magnitude variation of said space charge wave of alternating velocity.

References Cited in the file of this patent

UNITED STATES PATENTS

2,247,338	Ramo	June 24, 1941
2,276,320	Linder	Mar. 17, 1942
2,400,753	Haeff	May 21, 1946
2,422,695	McRae	June 24, 1947
2,537,862	Samuel	Jan. 9, 1951
2,584,597	Landauer	Feb. 5, 1952
2,636,948	Pierce	Apr. 28, 1953
2,654,047	Clavier	Sept. 29, 1953

FOREIGN PATENTS

934,220	France	Jan. 7, 1948